CHAPTER TWO

ENHANCEMENT OF THE NATIONAL GRID

2.1 Introduction

The load-flow problem models the nonlinear relationships among bus power injections, power demands, and bus voltages and angles, given the network constants and the circuit parameters. It is the heart of most system-planning studies and also the starting point for transient and dynamic stability studies. This chapter provides a formulation of the load flow problem and its associated solution strategies [4].

2.2 Load flow model of national grid

The National grid of Sudan is modelled using 500, 220 and 110 KV buses (66 bus-bars). The lines ohmic per unit length data and transformer data are obtained and then converted and expressed in per unit representation. Bus data which represent power generation P_{Gi} and load P_{li}, Q_{li} of the transmission network are obtained.

2.2.1 The National grid of Sudan

Up to the year 2002, the combined grid-connected generating capacity in Sudan was 728 MW. This was far lower than the required rate and the government sought to increase it to avoid blackouts. The design capacity of generation in the national network amounted to 1234.6 MW up to the end of 2008:

- 342.8 MW which were from water generation
- 180 MW from steam generation
- 45.2 MW from diesel generation
- 65 MW from gas generation
- 450 MW from mixed generation

- In addition to thermal plants outside the national electricity network in most of Sudanese cities with a 151.6 MW capacity.

in 2006, Construction of Marwi Dam project was intended to roughly double Sudan’s power generation in addition to increasing the national network security. Marwi Dam with its peak output of 1260 MW will almost double this capacity if it runs successfully.

2.2.2 Data Survey

Data of the network of the national grid are obtained from the National grid control center and it covered all of the following items:

- Transmission lines types and parameters as series resistances, series reactance's and charging capacitances per unit length and lines total length in kilometers.
- Number of circuits of transmission lines and its current capacity limited by circuit breakers and relays settings.
- Number of transformers and its data.
- Generation unit’s maximum output powers and its VAR limits.
- Last modifications on the system configuration.
- Load on the network at heavy load condition.
- Relays setting for maximum permissible current.

The parameters are expressed in per unit values; power base is chosen as100 MVA and each of the voltage levels 500, 220 and110 are taken as voltage.

Table (2.1): NG bus codes and numbers

Bus-bar Number	***Bus-bar Name***	***Bus-bar Code***
1	MARWI POWER PLANT13.8KV	MWP13.8
2	GARI 11KV	GAR11
3	ROSSERIES 11KV	ROS11
4	KHARTOUM NORTH 11KV	KHN11
5	SENNAR POWER PLANT11KV	SNP11
6	MARWI POWER PLANT500KV	MWP500
7	MRKHIAT500KV	MRK500
8	KABASHI 500KV	KAB500
9	ATBARA 500KV	ATB500
10	GARI 220KV	GAR220
11	ROSSERIES 220KV	ROS220
12	MARWI POWER PLANT220KV	MWP220
13	KABASHI 220KV	KAB220
14	SENNAR JUNCTION 220KV	SNJ220
15	MARINJAN 220KV	MAR220
16	GIAD 220KV	GAD220
17	KILO X 220KV	KLX220
18	JABEL AWLIASTATION220KV	JAS220
19	IED BABIKER 220KV	IBA220
20	FREE ZONE 220KV	FRZ220
21	SHANDI 220KV	SHN220
22	ATBARA 220KV	ATB220
23	MASHKOUR 220KV	MSH220
24	MAHDIA 220KV	MHD220
25	RABAK 220KV	RBK220
26	MRKHIAT220KV	MRK220
27	PORTSUDAN 220KV	PORT220
28	MARWI TOWN 220KV	MWT220
29	DEBA 220KV	DEB220
30	DONGOLA 220KV	DON220
31	KHARTOUM NORTH 110KV	KHN110
32	SENNAR POWER PLANT110KV	SNP110
33	KUKU 110KV	KUK110
34	KILO X 110KV	KLX110
35	FAROUG 110KV	FAR110

Bus-bar Number	Bus-bar Name	Bus-bar Code
36	LOCAL MARKET 110KV	LOM110
37	IED BABIKER 110KV	IBA110
38	IZERGAB 110KV	IZG110
39	MAHDIA 110KV	MHD110
40	OMDURMAN 110KV	OMD110
41	MUGRAN 110KV	MUG110
42	SHAGRA 110KV	SHG110
43	JABEL AWLIASTATION110KV	JAS110
44	GIAD 110KV	GAD110
45	BAGAIR 110KV	BAG110
46	HASSAHIESA 110KV	HAS110
47	HAG ABDALLAH 110KV	HAG110
48	MARINJAN 110KV	MAR110
49	SENNAR JUNCTION 110KV	SNJ110
50	MNAGIL 110KV	MNG110
51	RANK 220KV	RNK220
52	TANDALTI 220KV	TND220
53	OMRAWABA 220KV	OMR220
54	OBAID 220KV	OBD220
55	KHARTOUM EAST 110KV	KHE110
56	RABAK 110KV	RBK110
57	MINA SHRIEF 110KV	MIS110
58	ALFAO 110KV	FAO110
59	GDARIF 110 KV	GDA110
60	BANAT 110KV	BNT110
61	GAMOIEA 220KV	GAM220
62	GAMOIEA 110KV	GAM110
63	GENIED 110 KV	GEN110
64	GDARIF 220 KV	GDA220
65	HAWATA 220 KV	HAW220
66	SINGA 220 KV	SNG220

Table (2.2): NG line data (***Per Unit Data)***

No.	***From Bus***	***To Bus***	***R(P.U)***	***X(P.U)***	***1/2B***	***> 1 or < 1 tr. tap at bus nl ,= 1 for lines***
1	1	6	0	0.012094	0	1.05
2	2	10	0	0.02325	0	1.09
3	3	11	0	0.03439	0	1.03
4	4	31	0	0.0205	0	1.09
5	5	32	0	0.056	0	0.95
6	6	12	0	0.1696	0	0.95
7	6	7	0.0019208	0.0189336	0.052444991	1
8	6	9	0.002352	0.023184	0.078913125	1
9	7	26	0	0.0848	0	1.05
10	7	8	0.0004256	0.0041952	0.39	1
11	8	13	0	0.0848	0	1
12	9	22	0	0.0848	0	1.09
13	10	19	0.004152893	0.018719008	0.119088394	1
14	10	20	0.000346074	0.001559917	0.009924033	1
15	12	28	0.005338843	0.028309917	0.023304	1
16	13	20	0.001799587	0.00811157	0.051604971	1
17	14	49	0	0.06975	0	1.09
18	14	15	0.006595041	0.034971074	0.115207581	1
19	14	66	0.00392562	0.020816116	0.068541176	1
20	15	48	0	0.03389	0	1.15
21	15	16	0.011070248	0.058701446	0.193384154	1
22	16	44	0	0.1395	0	1.09
23	16	17	0.003376033	0.01790186	0.058975309	1
24	16	18	0.002491736	0.011231405	0.071489278	1
25	17	34	0	0.01866	0	1.1
26	17	19	0.000969008	0.004367769	0.027801386	1
27	18	43	0	0.066	0	0.95
28	18	23	0.010243802	0.046173554	0.293751371	1
29	18	26	0.005260331	0.046173554	0.150845	1
30	19	37	0	0.05784	0	1.09
31	19	13	0.002076446	0.009359504	0.059574398	1
32	20	21	0.007959711	0.035878099	0.228252754	1
33	22	27	0.070661157	0.374690083	0.308435292	1

No.	From Bus	To Bus	R(P.U)	X(P.U)	1/2B	> 1 or < 1 tr. tap at bus nl ,= 1 for lines
34	23	25	0.007475207	0.033694215	0.214359108	1
35	24	39	0	0.063	0	1.09
36	24	26	0.001384298	0.006239669	0.039696131	1
37	25	51	0.022605579	0.101893802	0.162059456	1
38	25	52	0.015365702	0.069260331	0.110156764	1
39	25	56	0	0.06975	0	1.09
40	26	61	0.002630165	0.011855372	0.075422649	1
41	28	29	0.021983471	0.116570248	0.095957646	1
42	29	30	0.021983471	0.116570248	0.095957646	1
43	31	33	0.001617769	0.007047521	0.001624244	1
44	31	37	0.003322314	0.013338843	0.00595442	1
45	32	47	0.172561983	0.208760331	0.009802452	1
46	32	49	0.028760331	0.034793388	0.001633742	1
47	32	57	0.198446281	0.24007438	0.01127282	1
48	33	34	0.00524876	0.022865289	0.005269768	1
49	33	55	0.001771901	0.00711405	0.000793923	1
50	34	35	0.003876033	0.015561983	0.006946823	1
51	36	42	0.000830579	0.003334711	0.001488605	1
52	37	38	0.008859504	0.035570248	0.015878452	1
53	38	39	0.002214876	0.008892562	0.003969613	1
54	39	40	0.002574793	0.010337603	0.004614675	1
55	40	41	0.002685537	0.010782231	0.004813156	1
56	41	42	0.003045455	0.012227273	0.005458218	1
57	42	43	0.009966942	0.040016529	0.017863259	1
58	44	45	0.008628099	0.010438016	0.000490123	1
59	44	46	0.221454545	0.267909091	0.012579813	1
60	46	48	0.158181818	0.191363636	0.008985581	1
61	46	63	0.004152893	0.016673554	0.007443025	1
62	47	48	0.100661157	0.12177686	0.005718097	1
63	48	50	0.056665289	0.155964463	0.011970865	1
64	48	58	0.204198347	0.247033058	0.011599568	1
65	49	56	0.276099174	0.334016529	0.015683923	1
66	51	11	0.023920661	0.107821488	0.171487287	1
67	52	53	0.01083905	0.048856612	0.077705177	1
68	53	54	0.017442149	0.078619835	0.125042813	1
69	59	58	0.440033058	0.532338843	0.024996253	1

No.	***From Bus***	***To Bus***	***R(P.U)***	***X(P.U)***	***1/2B***	***> 1 or < 1 tr. tap at bus nl ,= 1 for lines***
70	60	62	0.004568182	0.018340909	0.008187327	1
71	61	62	0	0.06975	0	1.09
72	64	59	0	0.06975	0	1.09
73	64	65	0.007613636	0.034318182	0.218328722	1
74	66	11	0.013975207	0.074105372	0.244006587	1
75	66	65	0.006229339	0.028078512	0.17863259	1

Table (2.3): NG chosen base values

Voltage Levels (KV)	MVA base	KV base	Z_{base} (ohm)	I_{base} (A)
500	100	500	2500	115.4700538
220	100	220	484	262.4319405
110	100	110	121	524.8638811

Table (2.4): NG power station data

Station No.	Power Station	Generator Type	Maximum Rated Apparent Power(MVA)	Maximum Active Power(MW)
1	Khartoum North Power Plant	Thermal	552.5	447.4
2	Gari Power Plant	Thermal	635.6	160
3	Rosseires Power Plant	Hydro	308	277.2
4	Senar Power Plant	Hydro	18.8	14.1
5	Mrawi Power Plant	Hydro	1400	1260

2.3 Analysis of Load flow result

The load flow analysis of National Grid of Sudan (66 buses) are carry-out based on Newton-Raphson method appendix [A]. The load flow is done without any compensation at any bus. The result shows that 45 buses found to be under normal voltage level ($V_{bus} < 0.95$p.u) and 2 buses found to be upper than the normal voltage level ($V_{bus} > 1.05$p.u) and the rest within the specific limit. Also ten transmission lines and two transformers are overloaded as shown in appendix [B].

2.4 National grid reinforcement techniques

The suggested techniques to solve the observed problems result from load flow analysis are:

2.4.1 Power transmission capacity upgrade of overhead lines:

The difficulty to find corridors to construct new overhead lines is increasing in industrialized countries and in many cases it is simply impossible. It is not easy to obtain the rights of way for new transmission lines. The construction of new overhead electric lines is increasing difficulty, thus there is a need to look at alternatives that increases the power transfer capacity of the existing right of ways. This circumstance is forcing the use of the existing lines, which represents a cheaper solution than making an underground transmission.

2.4.2 Transmission capacity upgrading by using HVDC

The fast development of power electronics based on new and powerful semiconductor devices has led to innovative technologies, such as HVDC, which can be applied to transmission and distribution systems. The technical and economic benefits of this technology represent an alternative to the application in AC systems. Some aspects, such as deregulation in the power industry, opening the market for delivery of cheaper energy to customers and increasing the capacity of transmission and distribution of the existing lines are creating additional requirements for the operation of power systems. HVDC offer major advantages in meeting these requirements.

The HVDC transmission systems are point-to-point configurations where a large amount of energy is transmitted between two regions. The traditional HVDC system is built with line commutated current source converters, based on thyristor valves. The operation of this converter requires a voltage source like synchronous generators or synchronous condensers in the AC network at both ends. The current commutated converters cannot supply power to an AC system which has no local generation. The control of this system requires fast communication channels between the two stations.

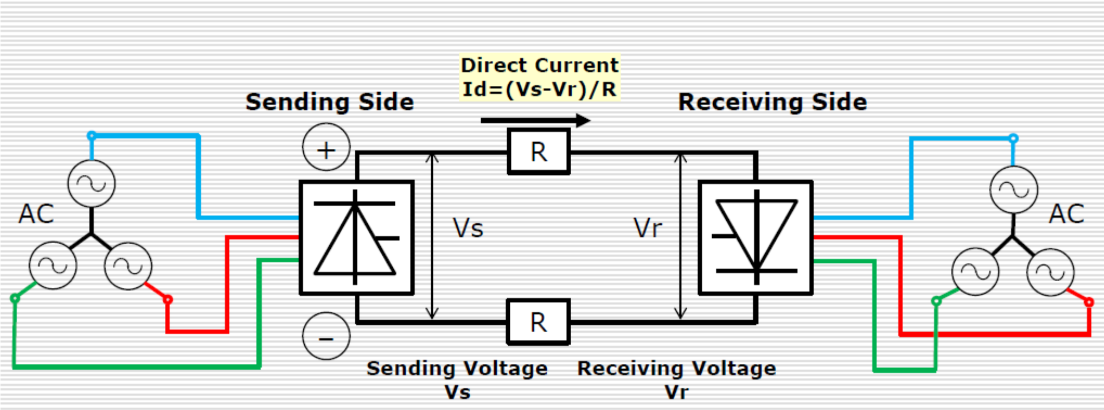
2.4.2.1 DC versus AC

The vast majority of electric power transmissions use three-phase alternating current. The reasons behind a choice of HVDC instead of AC to transmit power in a specific case are often numerous and complex. Each individual transmission project will display its own set of reasons justifying the choice.

A. General characteristics

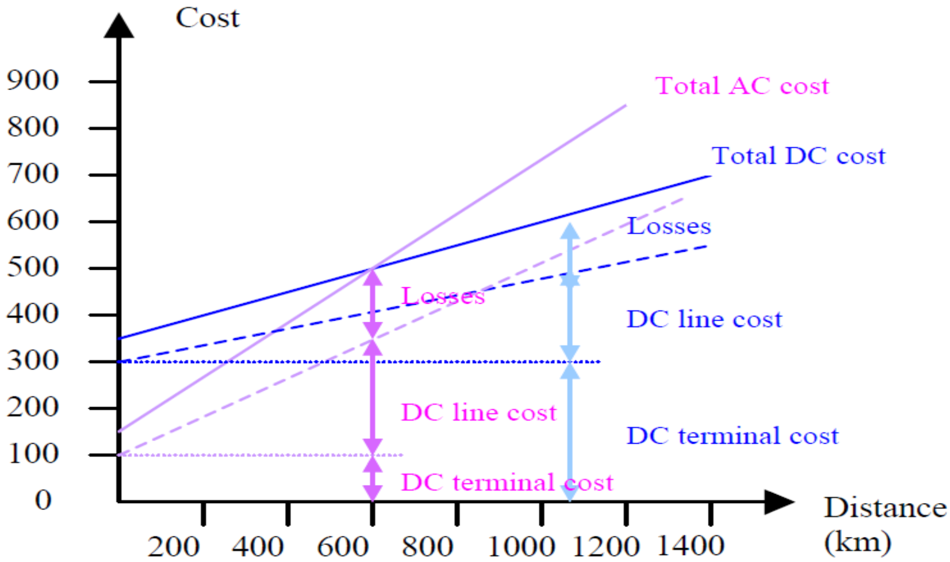
The most common arguments favouring HVDC are:

1) Investment cost. A HVDC transmission line costs less than an AC line for the same transmission capacity. However, the terminal stations are more expensive in the HVDC case due to the fact that they must perform the conversion from AC to DC and vice versa. On the other hand, the costs of transmission medium (overhead lines and cables), land acquisition/right-of-way costs are lower in the HVDC case. Moreover, the operation and maintenance costs are lower in the HVDC case. Initial loss levels are higher in the HVDC system, but they do not vary with distance. In contrast, loss levels increase with distance in a high voltage AC system.



Figure(2.1) HVDC

Above a certain distance, the so called "break-even distance", the HVDC alternative will always give the lowest cost. The break-even-distance is much smaller for submarine cables (typically about 50 km) than for an overhead line transmission. The distance depends on several factors, as transmission medium, different local aspects (permits, cost of local labour etc.) and an analysis must be made for each individual case (Fig. 2.2).



Figure(2.2) HVAC-HVDC cost

2) Long distance water crossing. In a long AC cable transmission, the reactive power flow due to the large cable capacitance will limit the maximum transmission distance. With HVDC there is no such limitation, why, for long cable links, HVDC is the only viable technical alternative.

3) Lower losses. An optimized HVDC transmission line has lower losses than AC lines for the same power capacity. The losses in the converter stations have of course to be added, but since they are only about 0.6 % of the transmitted power in each station, the total HVDC transmission losses come out lower than the AC losses in practically all cases. HVDC cables also have lower losses than AC cables.

4) Asynchronous connection. It is sometimes difficult or impossible to connect two AC networks due to stability reasons. In such cases HVDC is the only way to make an exchange of power between the two networks possible. There are also HVDC links between networks with different nominal frequencies (50 and 60 Hz) in Japan and South America.

5) Controllability. One of the fundamental advantages with HVDC is that it is very easy to control the active power in the link.

6) Limit short circuit currents. A HVDC transmission does not contribute to the short circuit current of the interconnected AC system.

7) Environment. Improved energy transmission possibilities contribute to a more efficient utilization of existing power plants. The land coverage and the associated right-of-way cost for a HVDC overhead transmission line is not as high as for an AC line. This reduces the visual impact. It is also possible to increase the power transmission capacity for existing rights of way. There are, however, some environmental issues which must be considered for the converter stations, such as: audible noise, visual impact, electromagnetic compatibility and use of ground or sea return path in monopolar operation.

In general, it can be said that a HVDC system is highly compatible with any environment and can be integrated into it without the need to compromise on any environmentally important issues of today.

B. Power carrying capability of AC and DC lines

It is difficult to compare transmission capacity of AC lines and DC lines. For AC the actual transmission capacity is a function of reactive power requirements and security of operation (stability). For DC it depends mainly on the thermal constraints of the line.

If for a given insulation length, the ratio of continuous-working withstand voltage is as indicated in equation (2.1).

$$K = \frac{\text{DC withstand voltage}}{\text{AC withstand voltage (r.m.s)}} \quad (2.1)$$

Various experiments on outdoor DC overhead-line insulators have demonstrated that due to unfavourable effects there is some precipitation of pollution on one end of the insulators and a safe factor under such conditions is k=1. However if an overhead line is passing through a reasonably clean area, k may be as high as √2, corresponding to the peak value of r.m.s alternating voltage. For cables however k equals at last 2.

A line has to be insulated for overvoltage expected during faults, switching operations, etc. AC transmission lines are normally insulated against overvoltage of more than 4 times the normal r.m.s voltage; this insulation requirement can be met by insulation corresponding to an AC voltage of 2.5 to 3 times the normal rated voltage.

$$k_1 = \frac{AC.insulation\ level}{rated\ AC.voltage(E_p)} = 2.5 \quad (2.2)$$

On the other hand with suitable convertor control the corresponding HVDC transmission ratio is shown in equation (2.3).

$$k_2 = \frac{DC.insulation\ level}{rated\ DC.voltage(V_p)} = 1.7 \quad (2.3)$$

Thus for a DC pole to earth voltage V_d and AC phase to earth voltage E_p the relations (2.4) exist.

$$Insulation\ ratio = \frac{insulation\ length\ required\ for\ each\ AC\ phase}{insulation\ length\ required\ for\ each\ DC\ pole} \quad (2.4)$$

And substituting (2.1), (2.2) and (2.3) equations, we obtain equation (2.5) for the insulation ratio.

$$Insulation\ ratio = \left(k\ \frac{k_1}{k_2}\right)\frac{E_p}{V_d} \quad (2.5)$$

DC transmission capacity of an existing three-phase double circuit AC line: the AC line can be converted to three DC circuits, each having two conductors at ± V_d to earth respectively. Power transmitted by AC:

$$P_a = 6E_pI_L \quad (2.6)$$

Power transmitted by DC:

$$P_d = 6V_dI_d \quad (2.7)$$

On the basis of equal current and insulation

$$I_L = I_d \quad (2.8)$$

$$V_d = \left(k\ \frac{k_1}{k_2}\right)E_p \quad (2.9)$$

The following relation shows the power ratio.

$$\frac{P_d}{P_a} = \frac{V_d}{E_p}\left(k\ \frac{k_1}{k_2}\right) \quad (2.10)$$

For the same values of k, k_1 and k_2 as above, the power transmitted by overhead lines can be increased to 147%, with the percentage line losses reduced to 68% and corresponding figures for cables are 294 % and 34% respectively.

Besides, if the AC line is converted, a more substantial power upgrading is possible. There are several conversions of AC lines to DC lines proposals, these conversions are carried out as a simple reconstruction.

The most feasible of them is Double Circuit AC Conversion to Bipolar DC; it implies tower modifications that maintain all the conductors at a height above ground of 1 to 2 meters below the original position of the lowest conductor during the whole construction phase. Two new cross arms are inserted at the level of the old intermediate cross arm.

No change is made to the conductors, the total rated current remains the same, which means that the transmitted power increases proportionally to the adopted new DC line-to-ground voltage. The conversion of lines where an increase of phase to ground voltage can be higher than 3, is possible when all the conductors of one AC circuit are concentrated in one DC pole.

The line to line (LL) AC voltage is doubled for use with DC, thus the transmitted power will increase by 3.5 times [5].

2.4.3 Using FACTS

Flexible AC Transmission Systems, called FACTS, got in the recent years a well-known term for higher controllability in power systems by means of power electronic devices. Several FACTS-devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice. Even more concepts of configurations of FACTS-devices are discussed in research and literature.

In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. FACTS-devices provide a better adaptation to varying operational conditions and improve the usage of existing installations.

The basic applications of FACTS-devices are:

- power flow control,

- increase of transmission capability,
- voltage control,
- reactive power compensation,
- stability improvement,
- power quality improvement,
- power conditioning,
- flicker mitigation,
- Interconnection of renewable and distributed generation and storages.

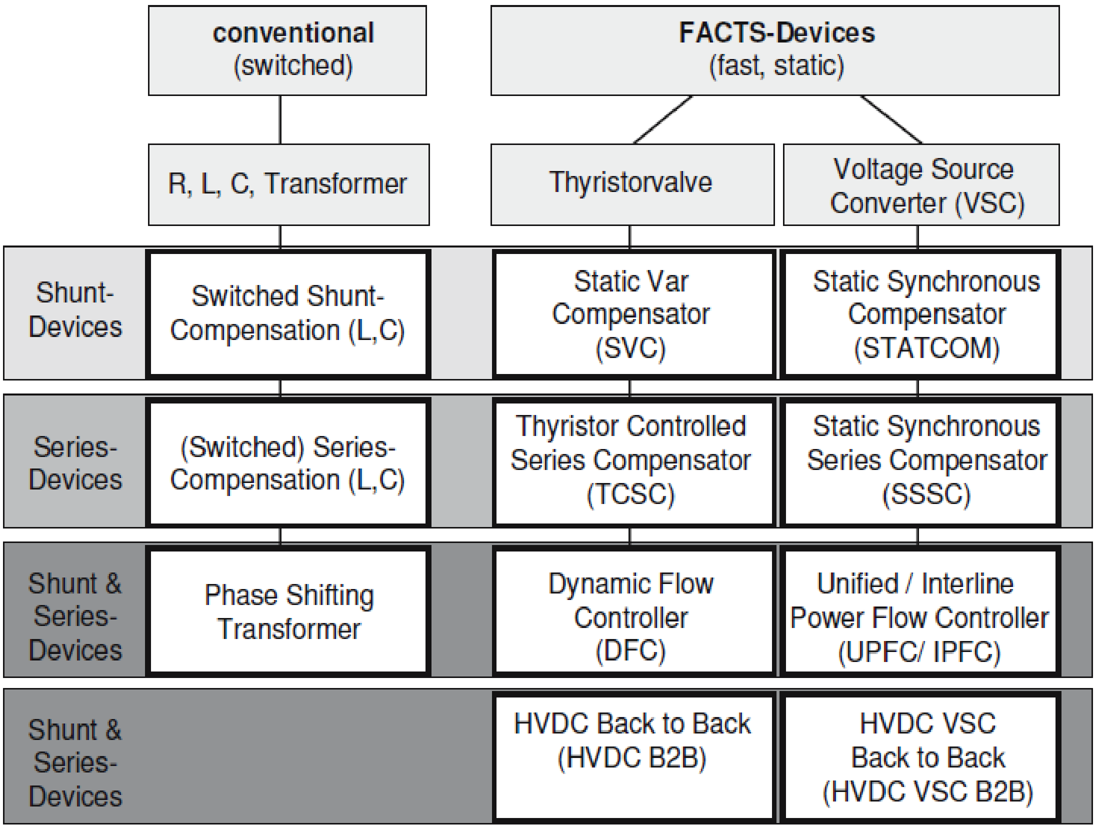


Figure (2.3) Overview of major FACTS-Devices

In Figure (2.3) the right column of FACTS-devices contains more advanced technology of voltage source converters based today mainly on Insulated Gate Bipolar Transistors (IGBT) or Insulated Gate Commutated Thyristors (IGCT). Voltage Source Converters provide a free controllable voltage in magnitude and phase due to a pulse width modulation of the IGBTs or IGCTs. High modulation frequencies allow to get low harmonics in the output signal and even to compensate disturbances coming from the network. The disadvantage is that with an increasing switching frequency, the losses are increasing as well. Therefore special designs of the converters are required to compensate this.

In each column the elements can be structured according to their connection to the power system. The shunt devices are primarily for reactive power compensation and therefore voltage control. The SVC provides in comparison to the mechanically switched compensation a smoother and more precise control. It improves the stability of the network and it can be adapted instantaneously to new situations. The STATCOM goes one step further and is capable of improving the power quality against even dips and flickers.

The series devices are compensating reactive power. With their influence on the effective impedance on the line they have an influence on stability and power flow. These devices are installed on platforms in series to the line. Most manufacturers count Series Compensation, which is usually used in a fixed configuration, as a FACTS-device. The reason is that most parts and the system setup require the same knowledge as for the other FACTS-devices. In some cases the Series Compensator is protected with a Thyristor-bridge. The application of the TCSC is primarily for damping of inter-area oscillations and therefore stability improvement, but it has as well a certain influence on the power flow.

The SSSC is a device which has so far not been built on transmission level because Series Compensation and TCSC are fulfilling all the today's requirements more cost efficient. But series applications of Voltage Source Converters have been implemented for power quality applications on distribution level for instance to secure factory infeeds against dips and flicker. These devices are called Dynamic Voltage Restorer (DVR) or Static Voltage Restorer (SVR). More and more growing importance is getting the FACTS-devices in shunt and series configuration. These devices are used for power flow controllability.

The higher volatility of power flows due to the energy market activities requires a more flexible usage of the transmission capacity. Power flow control devices shift power flows from overloaded parts of the power system to areas with free transmission capability. Phase Shifting Transformers (PST) is the most common device in this sector.

Their limitation is the low control speed together with a high wearing and maintenance for frequent operation. As an alternative with full and fast controllability the Unified Power Flow Controller (UPFC) is known since several years mainly in the literature and but as well in some test installations. The UPFC provides power flow control together with independent voltage control. The main disadvantage of this device is the high cost level due to the complex system setup. The relevance of this device is given especially for studies and research to figure out the requirements and benefits for a new FACTS-installation. All simpler devices can be derived from the UPFC if their capability is sufficient for a given situation. Derived from the UPFC there are even more complex devices called Interline Power Flow Controller (IPFC) and Generalized Unified Power Flow Controller (GUPFC) which provide power flow controllability in more than one line starting from the same substation.

Between the UPFC and the PST there was a gap for a device with dynamic power flow capability but with a simpler setup than the UPFC. The Dynamic Power Flow Controller (DFC) was introduced recently to fill this gap. The combination of a small PST with Thyristor switched capacitors and inductances provide the dynamic controllability over parts of the control range. The practical requirements are fulfilled good enough to shift power flows in market situations and as well during contingencies.

The last line of HVDC is added to this overview, because such installations are fulfilling all criteria to be a FACTS-device, which is mainly the full dynamic controllability.

HVDC Back-to-Back systems allow power flow controllability while additionally decoupling the frequency of both sides. While the HVDC Back-to- Back with Thyristors only controls the active power, the version with Voltage Source Converters allows additionally a full independent controllability of reactive power on both sides. Such a device ideally improves voltage control and stability together with the dynamic power flow control. For sure HVDC with Thyristor or Voltage Source Converters together with lines or cables provide the same functionality and can be seen as very long FACTS-devices.

FACTS-devices are usually perceived as new technology, but hundreds of installations worldwide, especially of SVC since early 1970s with a total installed power of 90.000 MVAR, show the acceptance of this kind of technology. Table 1.1 shows the estimated number of worldwide installed FACTS devices and the estimated total installed power. Even the newer developments like STATCOM or TCSC show a quick growth rate in their specific application areas.

Table (2.5) Estimated number of worldwide installed FACTS-devices and their estimated total installed power

Type	Number	Total Installed Power in MVA
SVC	600	90
STATCOM	15	1.2
Series Compensation	700	350
TCSC	10	2
HVDC B2B	41	14
HVDC VSC B2B	1+7(with cable)	900
UPFC	2-3	250

Power flow through an AC line is a function of phase angle, line end voltages and line impedance and there is little or no control over any of these variables. The consequences of this lack of fast, reliable control are stability problems, power flowing through other than the intended lines, the inability to fully utilize the transmission resources, undesirable VAR flows, higher losses, high or low voltage, cascade tripping and long restoration times. With FACTS devices one can control the phase angle, the voltage magnitude at chosen buses and/or line impedances. Power flow is electronically controlled and it flows as ordered by control centre.

2.5 Compensation Devices

Due to nature of power electronics equipment, FACTS devices are applicable for one or more of the following qualities:

-Rapid dynamic response.

-Ability for frequent variations in output.

-Smoothly adjustable output.

FACTS are a family of devices which can be inserted into power grids in series, in shunt, and in some cases, both in shunt and series.

A. Shunt Device

(1) Static Var Compensator (SVC)

(2) Static Synchronous Compensator (STATCOM)

B. Series Device

(1) Thyristor Controlled Series Compensator (TCSC)

(2) Static Synchronous Series Compensator (SSSC)

Important applications in power transmission and distribution involve devices such as SVC (Static Var Compensators), Fixed Series Capacitors (SC) as well as Thyristor-Controlled Series Capacitors (TCSC) and STATCOM.

2.5.1 The Static Var Compensator (SVC)

The Static Var Compensator can solve many problems of reactive compensation in power system. The installation of Static Var Compensator can greatly improve the quality of electrical energy in power grid. Also, this system enables continuous control and regulation from inductive to capacitive, and the response time is faster. And its ability of voltage-controlled and phase-controlled also is better. The Static VAR Compensator plays an important role in reducing network losses, stabilizing the grid voltage, improving power quality, reducing the damping characteristic of low frequency oscillation and governing harmonic in power system. In short, it can be used as important device which will be widely used in power grid in the future, which is an advanced, economic, energy-efficient technology.

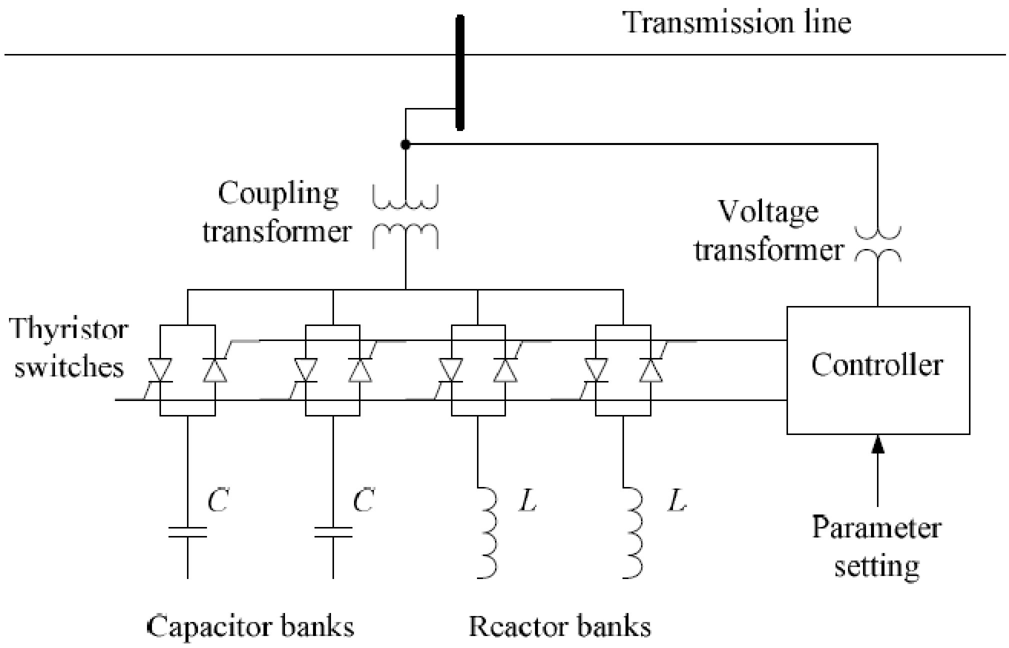


Figure (2.4) Structure of the SVC

2.5.2 The STATCOM

The STATCOM is a VSC system whose prime function is to exchange reactive power with the host AC system. In an electric power transmission system, the STATCOM can be used to increase the line power transmission capacity, to enhance the voltage/angle stability or to damp the system oscillatory modes. In a distribution system, the STATCOM is mainly used for voltage regulation; however, it can also supply real power to the loads in the case of a blackout if it is augmented with an energy storage device, for example, a battery storage system. Moreover, the STATCOM may also be employed to balance a distribution network by compensating for load imbalances.

Flexible ac transmission systems (FACTS) devices such as static synchronous compensator (STATCOM) and static VAR compensator (SVC) are frequently used to address voltage stability and power quality issues in transmission and distribution systems. Static synchronous compensators based on PWM voltage source converters normally have better dynamic performance during ac network disturbances, smaller footprint and produce fewer harmonics than those using multiple thyristor-based converters with complex transformers, and static VAR compensators. But they suffer from high conversion losses and are also expensive.

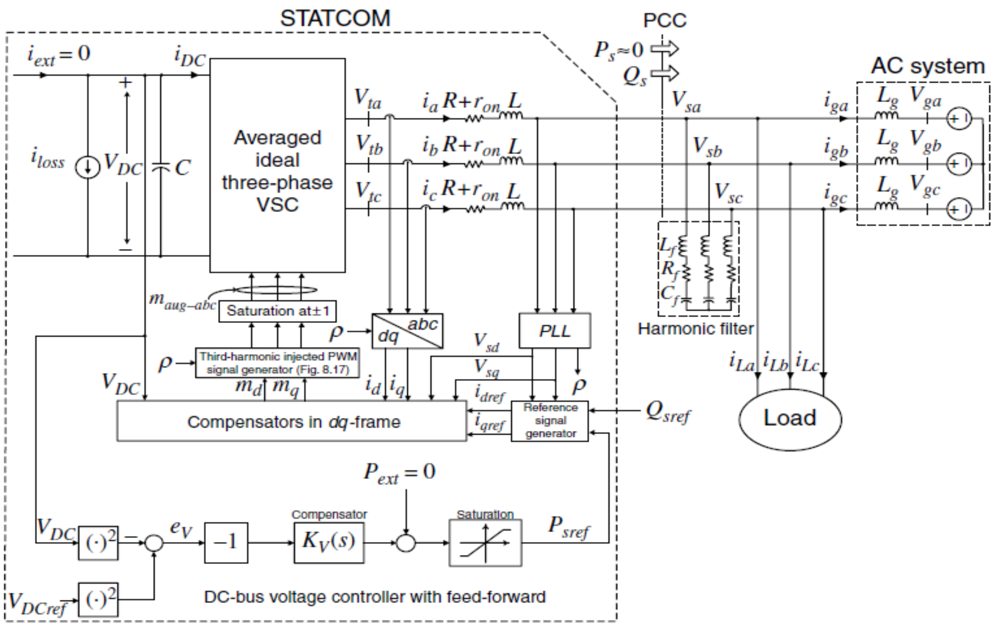


Figure (2.5) Schematic diagram of the STATCOM