REQUIREMENT OF HVDC SYSTEM IN POWER INDUSTRY

BY

SHASHI SHEKHAR

SAP ID: 500064921

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UPES

CENTRE FOR CONTINUING EDUCATION

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Thank You,

Signature – Shashi Shekhar
Name of the Student – Shashi Shekhar
Residential Address – V3S Inderalok, Nyay Khand-1, Indirapuram, GZB
Telephone/Mobile - 9650278997
E-mail: - shashishekhar05@gmail.com

Date – 20th July 2020

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Declaration by the Guide

This is to certify that the **Mr. Shashi Shekhar**, a student of (Program), SAP ID 500064921 of UPES has successfully completed this dissertation report on "**REQUIREMENT OF HVDC SYSTEM IN POWER INDUSTRY**" under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analyzed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfillment for the award of degree of MBA.

Signature – Vikrant Kumar
Name & Designation – Plant Head
Address - Ghaziabad
Mobile - 9871630820
E-mail - Vikrant.Kumar201020@gmail.com

Date: - 20th July 2020

Place- Ghaziabad

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INTRODUCTION

The growth and extension of AC systems and consequently the introduction of higher voltage levels have been driven by a fast growth of power demand over decades. Power systems are extended by applying interconnections to the neighboring systems to achieve technical and economical advantages. Regional systems have been built up towards national grids and later to interconnect systems with the neighboring countries. However, the performance of power systems decreases with size and complexity of the networks. This is related to problemswithload flow, power oscillations and voltage quality. If power should be transmitted through the interconnected system over long distance, transmission systems, need to be reinforced. Such problems are even deepened by the deregulation of electrical power markets, where contractual power flows with daily varying patterns follow the original designcriteriaofexisting networkconfiguration. West–Europeansystem is an example where 400kV voltage level is relatively low for cross border and inter-area power exchange. With identified bottlenecks and for an increase of power transfer, advanced solutions need to be applied.

Additional problems are expected with renewable energies such as large wind farms that have to be integrated into the system especially when the connecting AC links are weak and when there is nosufficient reverse capacity in neighboring systems are available. In future, the loading of existing power system will further increase, leading to additional bottlenecks and reliability problems. System enhancements are essential to balance the load flow and in total to get more power out of the existing grid. Major Blackouts in America and Europe happened in recent years, show how relatively minor malfunctions can have repercussions over wide areas. As one link overloads, it was tripped, increasing the strain on neighboring links, which in turn disconnect, resulting in cascading blackouts over vast area and causing huge productivitylossesfortheeconomy. Firewallsarenecessarytopermitthe interchange of power and to prevent the spread of disturbancesacross the system.

High Voltage Direct Currents (HVDC) and Flexible Alternating Current Transmission system (FACTS) offer an attractive means of bypassing interregional transmission congestion with minimum of investment in new transmission. This is especially true where multiple AC lines with intermediate switch yard and reactive power compensation are required to achieve the desired stable transfer limit, where as AC transmission will remain the primary solution for relieving congestion between and immediate neighbors. HVDC is ideal for „leap- froging" multiple network constraints. Asynchronous HVDC links acts as an effective .firewall" against propagation of outages from one network to other. Many asynchronous interconnections exist in North America between Eastern and Western interconnected systems, between Electric Reliability Council of Texas (ERCOT) and its neighbors, between Quebec and its neighbors. The 2003 North East blackout expanded and propagated around the lower great Lakes, through Ontario, New York and it stopped at Quebec. The weak AC interconnections between New York and New England tripped, where as HVDC links from Quebec continued to deliver power to New England. This issue indicates the significant role of HVDC transmission at cross boarder interconnections. Thus, HVDC permits economical power exchange between distant high and low cost production areas and provides access to remote diverse power supply resources. Controllability of HVDC allows transfers to be made without increasing burden on the underlying AC transmission system

In early days, the converter technology used for HVDC transmission was based on mercury arc valves. The major problem associated with mercury - arc technology was arc-back fault .During arc– back the valve conducts in reverse direction and thus destroys the rectifyingpropertyoftheconvertervalveandconsequentlylead totrigger other problems. In late **1960"s** thyristor technology was developed and overcame the problems of mercury arc technology. Either converters based on mercury arc valves or thyristor valves utilize line commutated current source converters. The basic module of Line commutated converter is the three-phase full wave bridge circuit. This topology is known as Graetz Bridge. Although they are several configurations this topology suppresses the arc backs with grid control and provides other advantages like less peak inverse voltagebetter utilizationoftransformer and valves for given power rating and lowers the voltage across the valve when conducting. The Graetz bridge has been chosen universally and used for LCC–HVDC convertertechnology.

The Graetz Bridge transmits DC power in two directions by applying different firing angles on the valves. In rectifying mode with firing angle less than 90°, the direct current flows from the positive terminal of the DC circuit and thus power flows from AC side to DC side. In inverting mode, the firing angle is greater than 90°, the direct current flows from negative terminal of the DC circuit, the direct voltage changes polarity. The power is then flowing from DC side to AC side. An HVDC link is essentially constructed with two Graetz Bridge circuits, which are interconnected on the DC sides. The interconnection could be an overhead line, a cable or a back-to-backconnection.

The application of LCC HVDC technology has been installed in many of the commercial existing projects over the years and the HVDC links are expected to grow in near future. However, this LCC technology suffers from several inherent weaknesses. The strength of an AC systems connected to the DC link is described in terms of short circuit ratio (SCR). The strength of the system reflects the sensitivity of the system voltage to various disturbances in the system. In a strong system the disturbances does not cause any significant change in system voltage. However, with weak AC systems the transient conditions temporarily reduce AC terminal voltage or increase system impedance resulting greater AC/DC interactions. These problems arebeing addressedandnot likely to pose major difficulties in the adoption of HVDC technology.

One of the problem with LCC converter stations is consumption of reactive power, approximately 50- 60% of the active power. Large AC filters/capacitors are connected to compensate the reactive power consumption. For a common LCC–HVDC links, the filters/capacitors not only increase the cost, but also occupy large amount of spaces of the converter stations. Besides, large filters/capacitors also contribute to the Temporary Over Voltage (TOV) and low order harmonic resonance problems when connects to weak AC systems.

Low order harmonic resonance is another issue of concern when HVDC–LCC converters are connected to weak AC systems. This resonance appears due to the presence of filters and shunt capacitors with AC network impedance. When the weak AC system is connected to an HVDC converter terminal, the system impedances interact through the converter to create resonances on both AC and DC sides of the converter. This can create high oscillatory power system, which would be close to the point of instability. This resonance condition imposes limitations on the design of the HVDC controllers.

Another well-known problem of LCC-HVDC system is the occurrence of commutation failures at the inverter station typically caused by disturbances in the AC system. The commutation failures will temporarily interrupt the supply of power and the consumption of reactive power by the inverters and will discharge the DC cable to a negative voltage. Because of charging time of the cable, it takes a longer time than normal for the inverters to regain commutation. Hence, a commutation failure represents a somewhat more serious event than normally the case for DC transmission by overhead line.

The serious limitation for LCC-HVDC applications is the successful commutation of the alternating current from one valve to the next relies on the stiffness of the alternating voltage i.e., the strength of the AC system. If the AC system has low short circuit capacity relative to the power rating of the HVDC link, the AC/DC interaction problems will be more. Besides, the SCR of the AC system also imposes an upper limitation on the HVDC power transmission, which is often described by Maximum Power Curve (MPC). Recovery after faults is fast with strong systems and takes longer with weak AC systems. However, weakinverter ac system is more in need of fast recovery to preserve stability.

Experiments and theoretical calculations have shown that voltage/power stability is a critical issue for an HVDC transmission links based on conventional LCCs, if the receiving end of the transmission link is connected to an AC system having low short circuit capacity. The lower the short circuit capacity of the connected AC system as compared with the power rating of the HVDC converter, the more problems related to voltage/power stability can be expected. The physical mechanism causing this instability is the inability of the power system to provide the reactive power needed by the converters to maintain an acceptable system voltage level.

The present study focus on the Capacitor Commutated Converter (CCC) HVDC technology, which is an improved type of LCC- HVDC technology, overcomes part of the problems associated with LCC- HVDC technology.

1.1 HISTORICAL GROWTH OF HVDC TECHNOLOGY

The development of HVDC transmission system dates back to the 1930's when mercury arc rectifiers were invented. In 1941, the first HVDC transmission system contract for a commercial HVDC systemwas placed to supply the city of Berlin through an underground cable of 115km in length. In 1945, this system was ready for operation. However due to the end of world war II, the system was dismantled and never became operational. It was only in 1954 that the first HVDC transmission system was commissioned in Gotland, since then from 1960's HVDC transmission system has become a mature and reliable technology. The benefits of an AC interconnection diminish with the size ofthenetworksduetotechnicalproblems likelytooccur in largesystems such as load flow problems, inter area oscillations, which require additional measures such as FACTS to mitigate these problems. On other hand, the transmission problems of long distance made HVDC technology as one of the feasible planning alternative to increasepowerdeliverycapabilityandremovetheidentifiedbottlenecks.

HVDC technology used in transmission system transfers bulk amount of power over long distance more efficiently, with fewer lines through overhead transmission or underground cable lines as there is no need to charge the capacitance of a transmission line with the alternating voltage. The power flow can be controlled rapidly and accurately, as to both the power level and the direction. This possibility is often used to improve the performance and efficiency of the connected AC networks. The number of HVDC projects committed or under consideration has globally increased in the recent years reflecting renewed interest in this mature technology.

Developments in converter designs and filters broadened the range of applications and contributed to the recent growth of HVDC for long submarine cable, asynchronous interconnections, offshore economic replacement of reliability-must run generation, and voltagestabilization. The mile stones in HVDC are presented in Appendix-A.

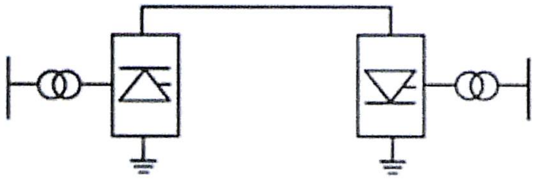
1.2 TYPES OF HVDC CONFIGURATION:

There are different configurations of DC links used for transmitting power based on power capacity.

1.2.1 Monopole Ground Return

The basic configuration use one conductor usually of negative polarity, for transmitting power from one converter station to another station. The return path is provided by ground or water shown in Fig.1.2.1.The cost considerations often lead to the use of such systems particularly for cable transmission. This type of configuration may also be the first stage in the development of a bipolar system.

Fig.1.2.1: Monopole Ground Return



1.2.2 Monopole Metallic Return.

The power is transmitted from one converter station to another converter station through one conductor and metallic conductor is used as return. The earth resistivity is too high or possible interference with underground/underwater metallic structures is objectionable. The conductor forming the metallic return shown in Fig.1.2.2 is at low voltage.

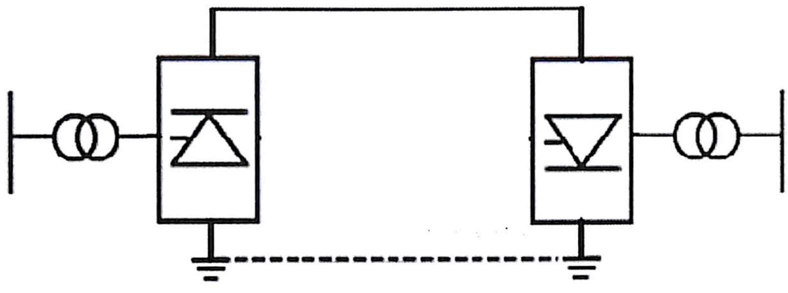


Figure.1.2.2: Monopole Metallic Return

1.2.3 Monopole Midpoint Grounded.

Monopole midpoint grounded shown in Fig.1.2.3 has two conductors same as monopole metallic ground, but instead of return conductor a power transmission conductor grounded at one end is used. It reduces the transmission loss since cables can have full voltage, the total transmission voltage is doubled, and consequently the current needed is half for same power and transmission capacity has been increased. Mono polar offers advantage in situations where continuous ground current is acceptable. The ground current can have side effects on gas or pipelines that lie a few miles of the system electrodes. Pipelines act as conductors for ground current that can cause corrosion of the metal. Therefore, configurations using ground return may not always be acceptable.

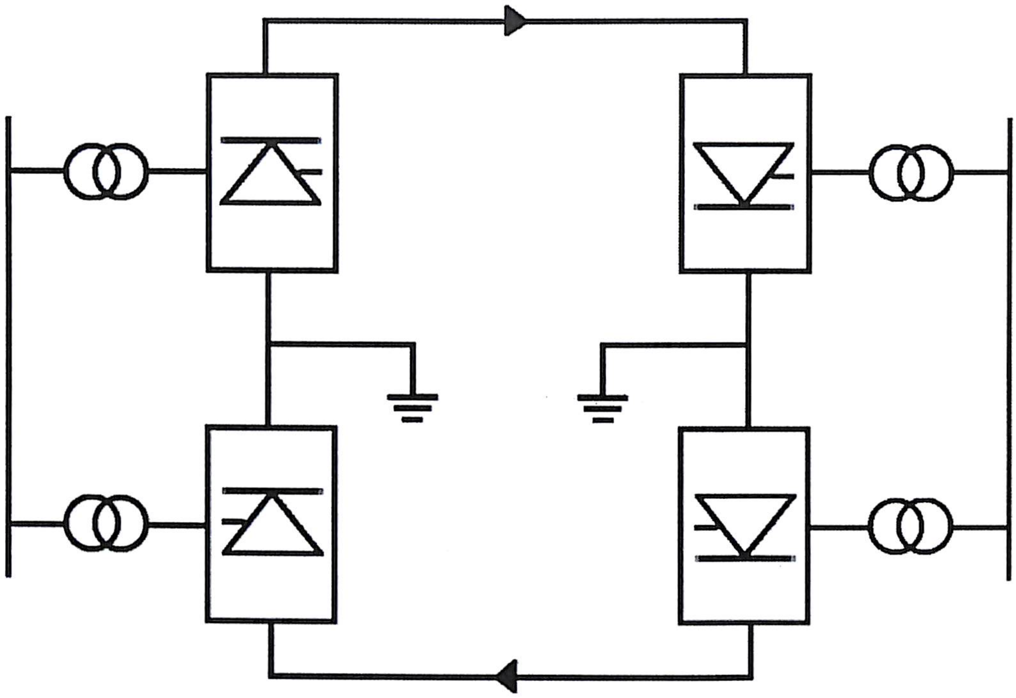


Fig 1.2.3: Monopole Mid-Point Grounded

1.2.4 Bi-Polar Configuration

Bipolar configuration shown in Fig 1.2.4 has two conductors, upper pole is operating with positive current and positive voltage and lower pole is operating in negative voltage and negative current. Both poles transmit a power in same direction. It is grounded at both stations. Both poles are operating at equal currents during steady state, therefore zero current through the ground. It can be operated as a single pole during fault at another pole. Reversal of power flow direction is achieved by changing the polarities of the two poles through controls.

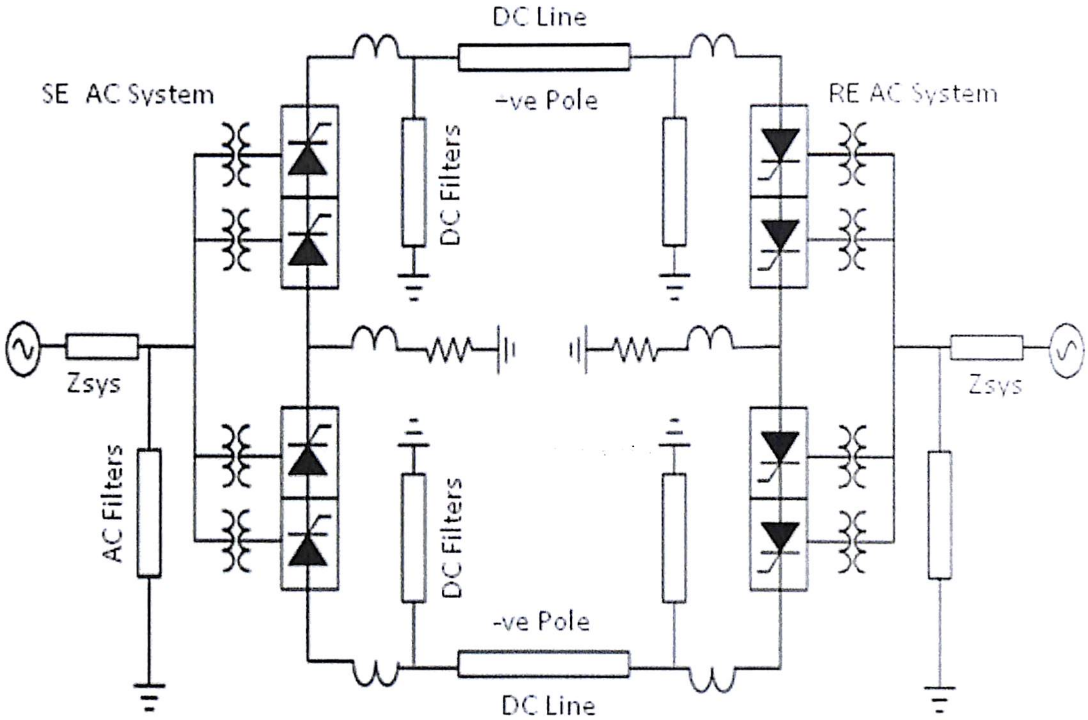


Fig 1.2.4: Bi-Polar HVDC System

125 Back- To-Back Configuration

Both rectifier and inverter stations are located at same place shown in Fig.1.2.5.The normal configuration is to use mono polar blocks, but several converter blocks can be installed in parallel, each with separated DC circuit. The purpose of this kind of configuration is to connect two asynchronous systems. It reduces the total system cost, due to absence of lines/cables. The current rating of the system can be increased with reduced voltage thus, reducing the size of the transformer.

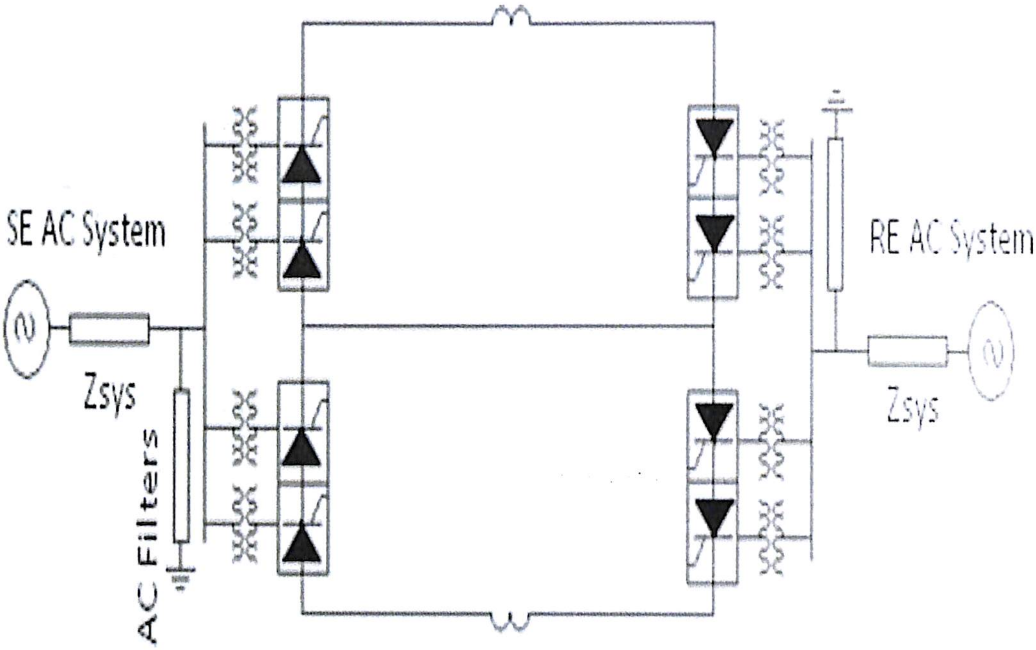


Fig 1.2.5: Back-To-Back HVDC Configuration

1.2.6 Multi Terminal DC System

Multi terminal DC (MTDC) system is formed when the DC system is to be connected to more than two nodes on the ac network. The first Multi terminal DC system designed for continuous operation is the Sardinia Corsica-Italy scheme. This is an expansion of the Sardinia–Italy two terminal DC system built in 1967, a third terminal tap was added at Corsica in 1991. The two terminal DC systems between Des Cantons in Quebec and Comer ford in New Hampshire built in 1986 is being extended to three terminal and then to possible five terminal scheme. The two possible types of MTDC systemsareshown in Fig.1.2.6a&b.

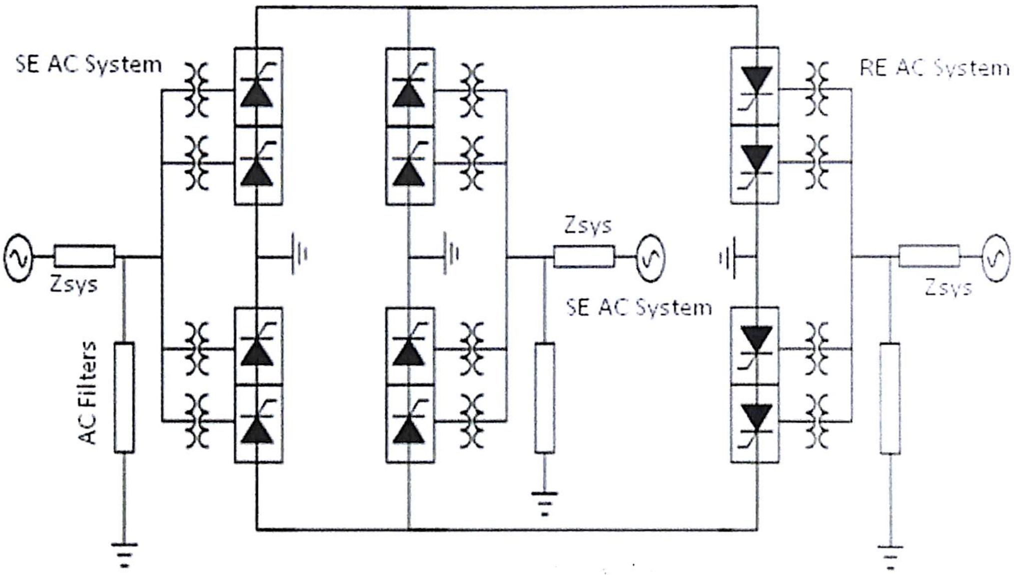


Fig.1.2.6a: Parallel Multi-Terminal DC Scheme

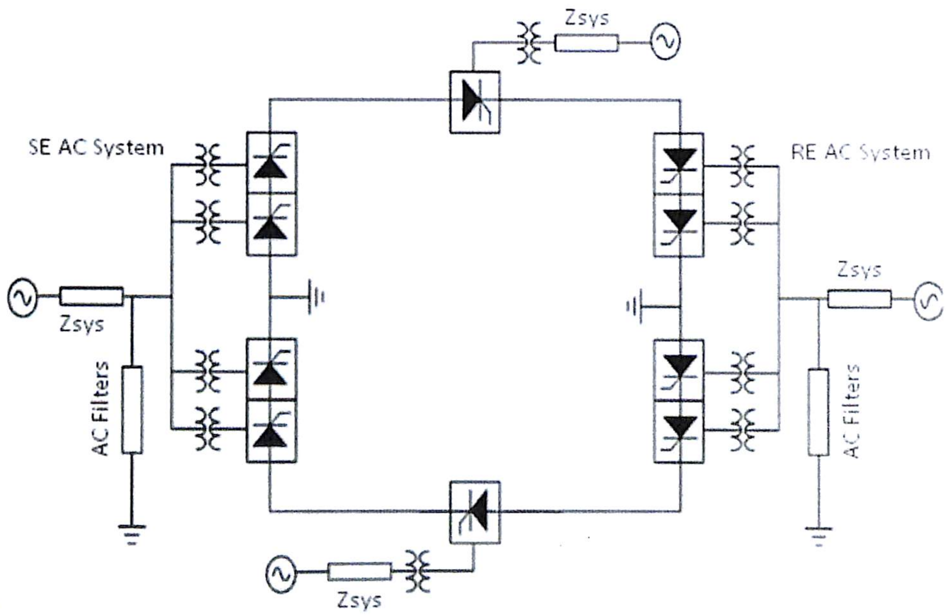


Fig.1.2.6b: Series Multi Terminal DC Scheme

1.3 APPLICATIONS OF HVDC TECHNOLOGY

The mainapplicationsof HVDC technology[18] arepresented andshown in Fig.1.3

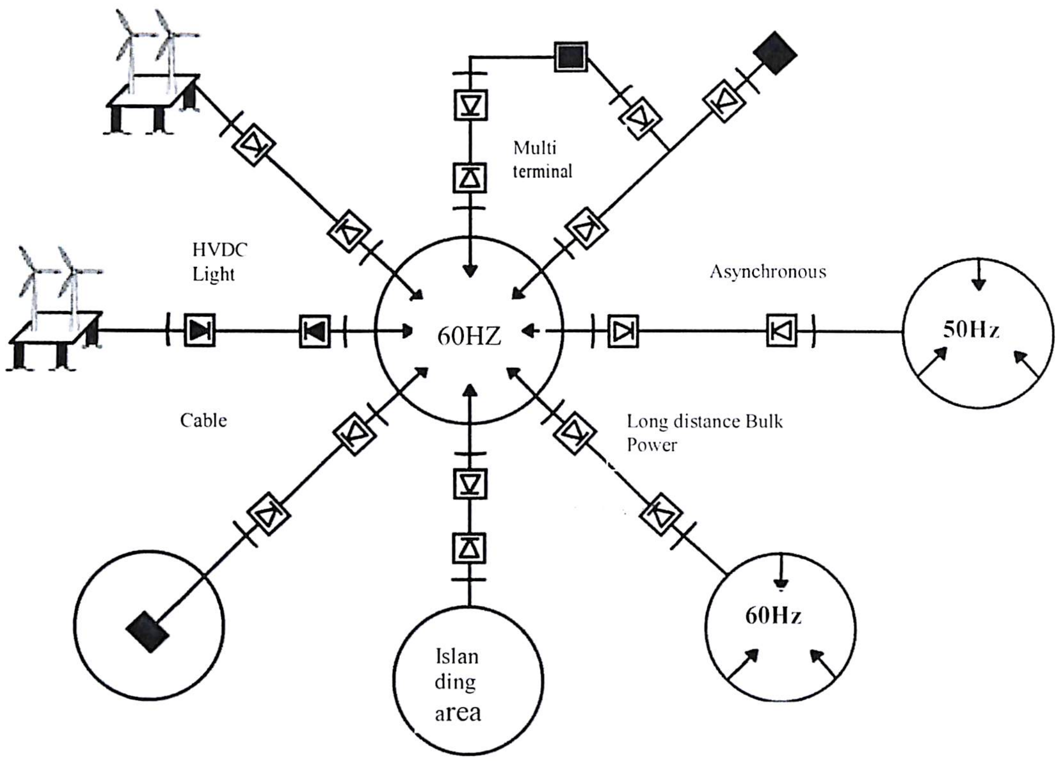


Fig.1.3: Different Applications of HVDC System

1.3.1 Long Distance Bulk Power Transmission

HVDC transmission systems often provide a more economical alternative to AC transmission for long-distance, bulk-power delivery from remote resources such as hydroelectric developments, mine-mouth power plants or large-scale wind farms. In comparison to HVAC transmission, HVDC transmission consumes less conductor consumption, does not require intermediate substations and voltage compensation devices. The controllability of HVDC links offers firm transmission capacity without limitation due to network congestion or loop flow on parallel paths. Controllability allows the HVDC to „leap-frog" multiple „choke-points" or bypass sequential path limits in the ac network.

Whenever long distance transmission is discussed, the concept of "break-even distance" frequently arises as shown in Fig 1.3.1.1.

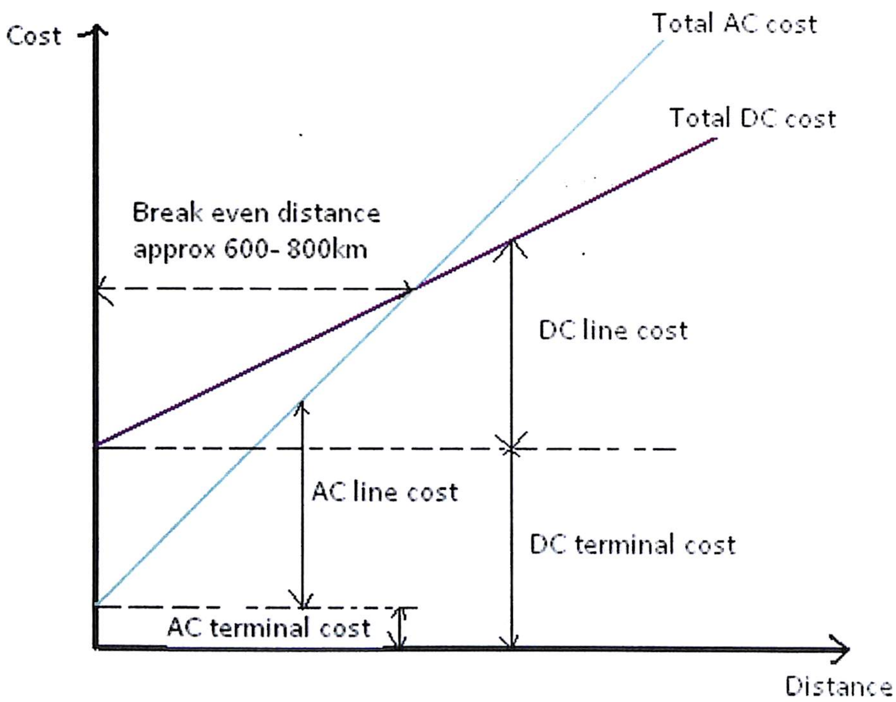


Fig. 1.3.1.1: Variation of Cost Vs Distance

This is where the savings in line costs offsets the higher converter station costs. A bipolar HVDC line uses only two insulated sets of conductors rather than three. This results in narrower Right-Of-Way (ROW), smaller transmission towers and lower line losses than with AC lines of comparable capacity. A rough approximation of the savings in line construction is 30%.

For example, thegeneratoroutlet transmissionalternative forthe± 250 kV, 500 MW Square Butte Project was two 345 kV series- compensated ac transmission lines. The 12,600 MW, Itaipu project has half its power delivered on three 800 kV series-compensated AC lines (three circuits) and the other half delivered on two ± 600 kV bipolar HVDC lines (four circuits). Similarly, the ± 500 kV, 1600 MW Intermountain Power Project (IPP) AC alternative comprised two 500 kV AC lines. The IPP Project takes advantage of the double circuit nature of the bipolar line and includes a 100% short-term and 50% continuous mono polar overload. The first 6000 MW stage of the transmission for the Three Gorges Project [19] in China would have required 5 x 500 kV AC lines shown in Fig.1.3.1.2 as opposed to 2 x ± 500 kV, 3000 MW bipolar HVDC lines.

The 2 x 3150 MW Itapúa HVDC transmission system in Brazil has been operating **at ±600 kV since the mid 1980"s. Transmission voltages of ±600 kV to ±800 kV are** classified as Ultra High Voltage Direct Current (UHVDC). Higher power transfers can be achieved over longer distances with lower losses by increasing the DC voltage level into the UHVDC range.

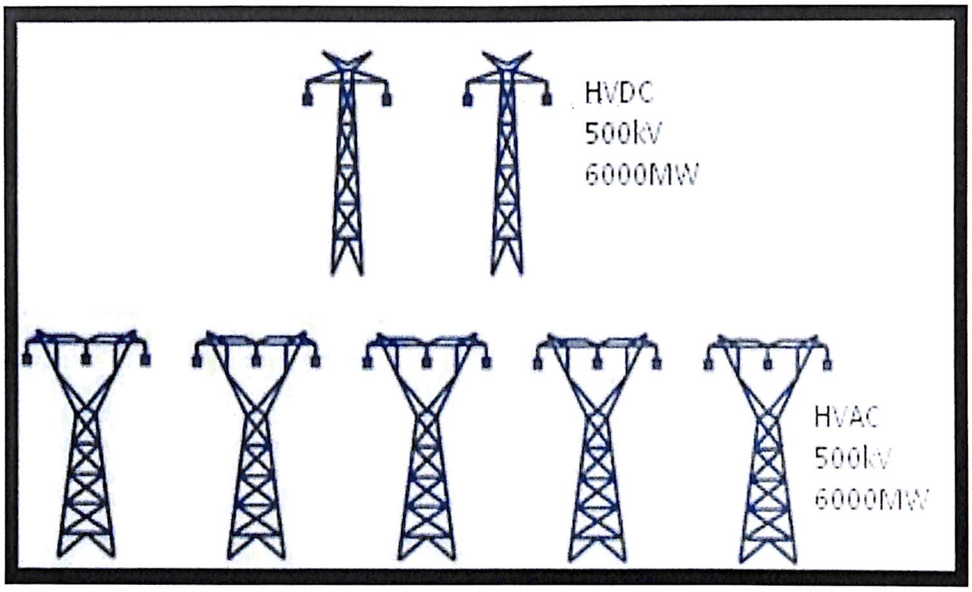


Fig 1.3.1.2: HVDC and HVAC Alternatives for Transmission

A considerable body of work is ongoing in this area for potential applications in China, India and North America. The controllability and, the mechanical and electrical characteristics of UHVDC lines make them in many respects more favorable for long distance bulk power transmission than Ultra High Voltage Alternating Current (UHVAC) lines.

1.3.2 Cable Transmission

In a long AC cable transmission, the reactive power flow due to the large cable capacitance will limit the maximum possible transmission distance. With HVDC, there is no such limitation, making HVDC the only viable technical alternative for long cable links. For a given cable area, the line losses with HVDC cables can be less than half those of AC cables. This is due to more conductors, reactive component of current, skin effect and induced currents in the cable sheath armor.

With a cable system, unequal loadings or risk of post contingency overloads often results in use of a series connected phase shifting transformer. These potential problems do not exist with a controlled HVDC cable system. Furthermore, underground HVDC land cables offer multiple advantages to overhead lines like no visual impact, invisible, maintenance free, low electrical losses, environmentally friendly, unaffected by weather conditions such as high winds or icing, and ideal for highly populated areas.

One example of this application is Fenno-Skan between Dannebo in Sweden and Rauma in Finland, inaugurated in 1989. The 233km (145 mi) long Fenno Skan crosses in form of a 200 km (124 mi) long submarine cable on the Finnish sea bottom.

Another is Kii Channel most powerful submarine cable in the world. It connects the static inverter plant at Anan on Shikoku with the static inverter plant at Kihoku on the island Honshū.Japan.

The first step of the project went in service in 2000 with a bipolar voltage of 250 kV and rated to transmit 1400MW. The first 50 km of the transmission line from the Anan inverter station are a submarine cable. At Yura there is a switching station where the line runs for the remaining 50 km as an overhead power line.

1.3.3 Asynchronous Interconnections

The HVDC technology can connect two asynchronous power systems with the same or different frequency. The asynchronous interconnection allows interconnections of mutual benefit but provides a buffer between the two systems. Power import/export between two asynchronous AC networks can easily be implemented by HVDC back- to-back converters. In case of cascading failures in one of the systems, the interconnection can serve as a „firewall" between the systems preventing the propagation of disturbances from continuing into the connected system. One example of this application is the HVDC back-to-back links at Vindhyachal and Gajuwaka in India, which are used for the interconnection of the power grids of East and central and East and southern India respectively with maximum transmission power of 500MW and operating voltage of 176 kV.

1.3.4 Stabilization in Power Systems

HVDC links can be used within synchronous AC systems to improve the control of power flow from one part of the system to another and thereby prevent large cascading failures or even blackouts in the grid. The stability can be improved, since the link provides a damping torque. The introduction of this sort of application in the existing AC system requires an extensive knowledge of the electrical system in order to design proper control algorithms for the HVDC link. One example of this type of application in a larger synchronous AC system is the Chandrapur-Padghe link (1500 MW) in India. This link has been built to stabilize the system and to increase the power flow capabilities. However, this area of application is still very much unknown and research is going on.

1.4 CONVERTER TECHNOLOGY IN HVDC SYSTEM

1.4.1 Conventional Converter Technology

Either converters based on mercury valves or thyristor valves are called line-commutated converters (LCCs), or current-source converters (CSCs). The basic module of an LCC is the three-phase full-wave bridge circuit known as the Graetz Bridge circuit. Although there are several alternative configurations possible, the Graetz Bridge has been universally used for LCC-HVDC converters as it provides better utilization of the converter transformer and a lower voltage across the valve when not conducting. The DC terminals of two 6-pulse bridges with AC voltage sources phase displaced by 30 degrees can be connected in series for 12-pulse operation scheme. Most modern HVDC transmission schemes utilize 12-pulse converters to reduce the additional harmonic filtering requirements required for 6-pulse operation, e.g., 5th and 7th on the AC side and 6th on the DC side. This is because although these harmonic currents still flow through the valves and the transformer windings, they are 180°out of phase and cancel out on the primary side.

At present the device, voltage rating is in the range of 10kV and current rating up to 5kA. The total installed capacity exceeds above 75000MW in more than 90 projects worldwide. Theseprojectsarelocated

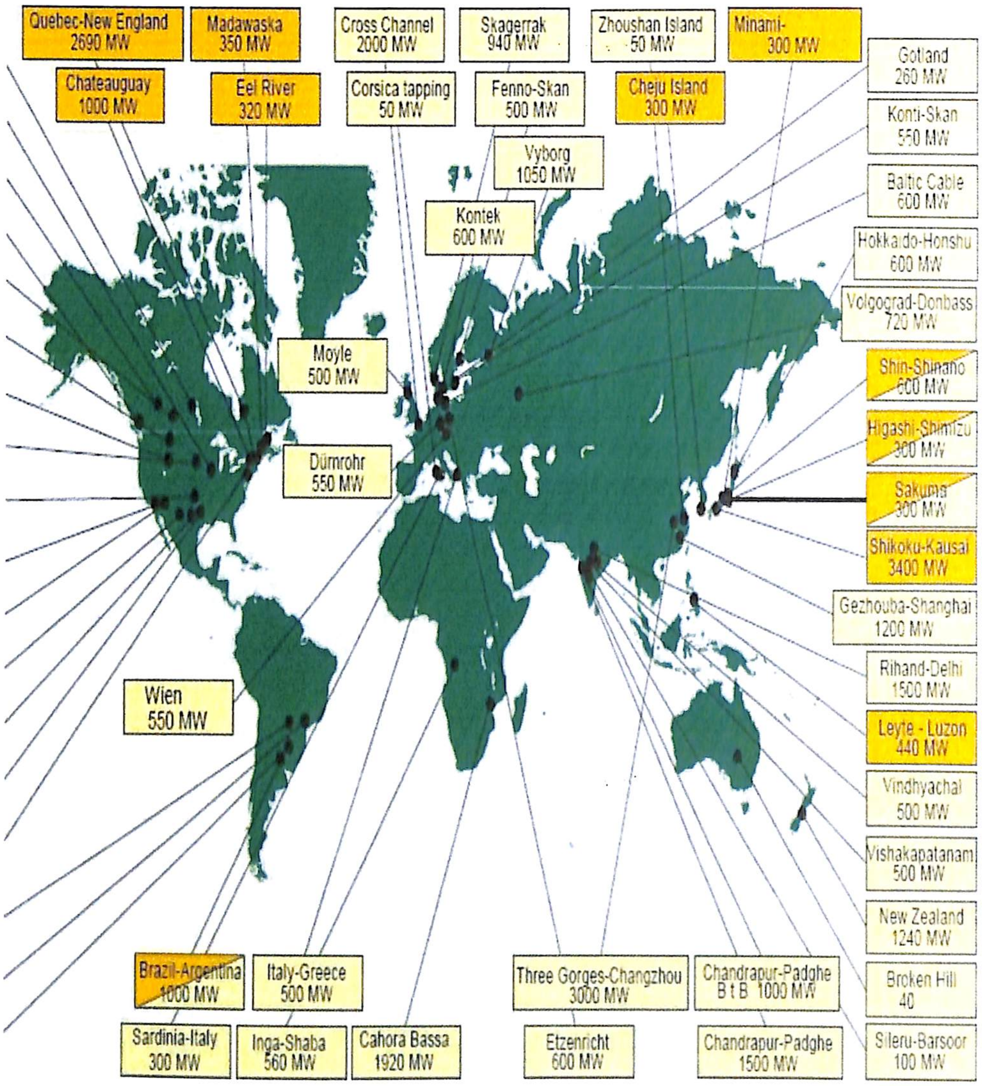


Fig.1.4.1: HVDC Installation in the World

in various countries such as Australia, Brazil, Canada, China, Denmark, Germany, India, Russia, South Africa, Sweden and USA. The details of HVDC projects around the world are given in Fig 1.4.1.

Conventional HVDC systems are recently supplemented with alternative technologies. One of these is the Capacitor Commutated Converter (CCC) technology and the other is Voltage Source Converter (VSC) technology.

1.4.2 Capacitor Commutated Converter (CCC) Technology

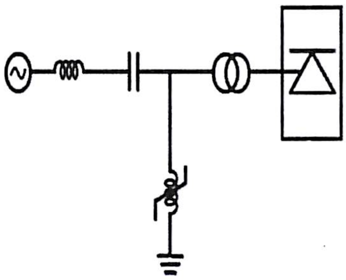
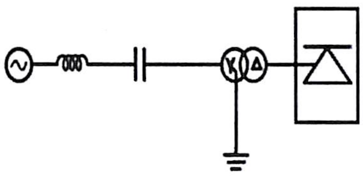
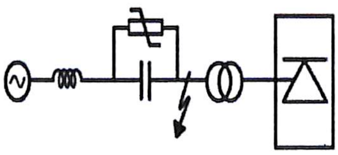
The converter used in CCC concept is characterized by use of commutation capacitor inserted in series between the converter transformer and converter valves. It provides reactive power compensation proportion to load of the converter. Hence, the need of switchable shunt capacitor banks for reactive power compensation is eliminated. The AC filters are necessary only for filtering harmonics and shunt connected reactive power generation is minimized.

The size of the commutation capacitor is so chosen such that full load reactive power consumption of converter is compensated. This reactive power contribution reduces the amount of shunt compensation needed, by providing more reactive power for AC network and thus improves voltage stability in weak ac system applications. This solution found more attractive for back-to-back ties in weak network locations.

The location of capacitor and the problems associated with the connections are presented in Table1.4.2. One possible location of series capacitor is in between converter transformer and converter station and the concept is introduced in the field in 1990. This location found more advantageous as the capacitor stresses are much lower in this position, than locating outside the converter transformer as both operating currents and over currents are controlled by the valve bridge. In addition, there will be no risk of ferro resonance and the rating of converter transformer will be reduced due to reduced reactive power flow. The capacitor overvoltage protection can thus be handled with a varistor of reasonable size. Overvoltage protection of series capacitor is simple since capacitor is not exposed to line faults and the fault current. For internal converter faults it is limited by impedanceoftheconvertertransformers.

With CCC technology shown in Fig 1.4.2d & 1.42e there is no need to switch filter banks or shunt capacitor banks in and out to follow the reactive power consumption when active power is changed where as for conventional converter it is necessaryto subside the var supply in several breaker switched banks. Moreover, the development of automatically tuned AC filters (CONTUNE) has made it possible to match the characteristics of CCC with reactive power requirements. These filters can be built to generate small quantities of reactive power but still provide good filtering.

Table 1.4.2 : Location of Capacitors in CCC Technology

S.No.	Alternate location of capacitor	Problems Associated
1	 Fig: 1.4.2a	Ferro resonance
2	 Fig:1.4.2b	Unsymmetrical charging of capacitors at ac system faults
3	 Fig:1.4.2c	High capacitor varistor stresses as inductance in the converter transformer is not limiting fault current.

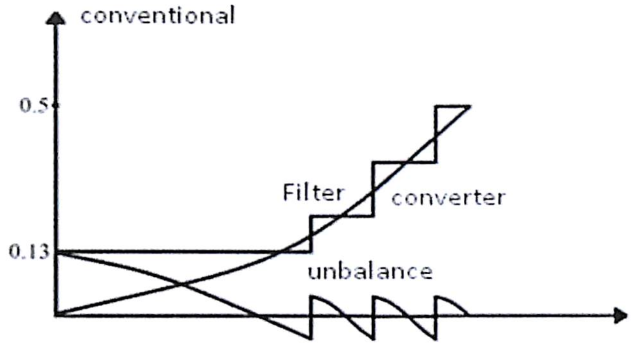


Fig. 1.4.2d: Reactive Power Conditions of LCC Station

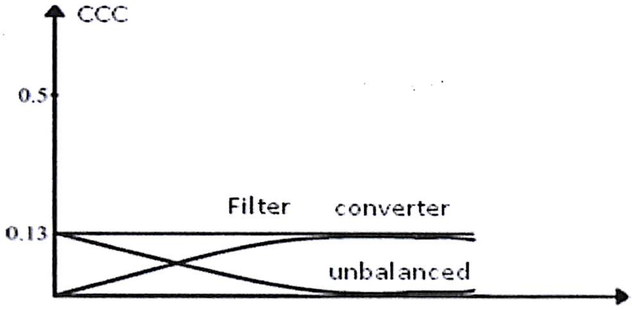


Fig. 1.4.2e: Reactive Power Conditions of CCC Station

The CCC design offers the following advantages when used at relatively weak network locations

- Improved ac network voltage stability
- Reduced need for shunt compensation
- Reduced dynamic over voltage at loadrejection
- Reduced need for switching ofreactive compensation elements with load variation.
- High power transfer capability.
- Reduced commutation failure probability for remote faults
- Robust and resistant to disturbance

Table1.4.2.1:Commercial CCC HVDC Projects Data

Station particulars	Ratings(Garabi)	Ratings(Rapid City DC Tie)
Rated Power	4x550MW	2x100MW
Ratings/converter block rated DC power	550MW	100MW
DC Voltage	±70kV	±12.85kV
DC current	4kA	4kA
CCC capacitor	190Mvar (Argentina) 322Mvar(Brazil)	27Mvar
AC system Voltage and frequency	500kVat50Hz (Argentina) 500kVat 50Hz (Brazil)	230kV (West and East side)
AC filters per converter	85Mvar(Argentina) 11+13contune, 24+36HPF	3x30Mvar+15Mvar (West side) 11+13thand 24+36HPF
	85Mvar(Brazil) 11+13contune, 24+36HPF	3x30Mvar+15Mvar (East side)
Converter Transformer		3phase 3 winding 109MVA

1.4.3 Voltage Source Converter (VSC) Technology

Another latest technology developed to transfer power by means of HVDC is presented by ABB under the name HVDC LIGHT and later by Siemens under the name HVDC PLUS. The first project using Light technology was 10km long test transmission link between Hellsjn and Grang gesberg located in central part of Sweden. It was commissioned in 1997 transmitting 3MW of power. This technology employs Integrated Gate Bipolar Transistors (IGBTs) as switching components that can switch on and off the current in Voltage source converters using PWM technique and simplifying harmonic filtering, Also this type of converters offers advantages while transmitting power from sustainable energy systems. Sometimes it is known as invisible power transmission as it usually use in underground cables. The HVDC Light converter controls reactive power, alongwith AC voltage controlofthe network connected to the converter station. Such rapid AC voltage control can also be used to improve the power quality through controlling flicker and transient disturbances. When connected to a passive network such as a wind farm, it provides control functions for active and reactive power, so that both voltage and frequency can be controlled from the converter station. This allows black starting by controlling the voltage and frequency from zero to nominal.

HVDC Light has been used in two wind farms:

(i) In 1998,Eltra, the independent system operator and the transmission company in western Denmark carried out a trial installation of a 7.2MW HVDC light system at an existing wind farm at Tjareborg comprising four wind turbines with a total installed capacity of 6.5MW.

(ii) In 1999 an HVDC Light system with 70km of underground cables was installed on the Swedish Island of Gotland .The system is rated at 50MW and 65MVA,it is connected in parallel with the existing 70kV/30kV AC grid. The total system has a peak load of about 160MW, and there are a total of 165 wind turbines with totaled installed power of 90MW.

TECHNOLOGICAL DEVELOPMENTS

- High voltage valves with series connectedIGBTs
- Compact, dry, high voltage capacitors
- High capacity control systems
- Solid dielectric cables

ADVANTAGES

- Simultaneous control of both active and reactive power.
- AC voltage can be controlled at both stations
- No need of short circuit power forcommutation
- Can operate against black networks
- Operate without communication between thestations
- Canoperatebycontrollingpowercontinuouslyfromonedirection
- No change of voltage polarity when power direction is changed.

  This makes to build multi-terminal schemes.
- Possible to use robust and extruded cables for land and sea.
- Requirement of space for small converters is reduced.

Semi conductor switches used in this technology have relatively high losses compare to classic of the same rating. Major developments mentioned above increase the **application of VSC"s from 3MW to 400MW power level.** This system found new application in evacuation of power from offshore wind farms, power supply to offshore platforms(producing oil/gas) supply of controllable power to improve security, integration of dispersed or distributed generation.

1.5 CURRENT SCENARIO OF HVDC IN INDIA.

The country"s electricity transmission and distribution progressed through several stages. In 1960's Individual grids were limited in each state, then in 1970"s state grids were interconnected to form regional grids. The concept of national grid was mooted in 1980 but in 1991 it led to formation of a National grid as shown in fig by POWERGRID, through HVDC links.

The Indian national power system has been divided into five regional grids shown in Fig 1.5 namely Northern (NR), Western (WR), Southern (SR), Eastern (ER) and North Eastern region (NER). The distribution of energy resources and consumption centers are extremely unbalanced, as most of hydro potential are in NER and upper part of NR , Coal reserves mainly in ER. To achieve economy of scale in the delivered cost, power transportation from pit-head generating stations it is necessary to establish large no. long distance lines & interconnection of all the five regional grids. The following HVDC system links regional grids as 1)NR-WR,2)SR-ER 3) WR-SR The combined installed generating capacity of these regions was 1,18,000MW. It is estimated that India will need an additional capacity of about 1,00,000MW over next 15 years for ensuring sustained economic growth of about 7-8%. The installed capacity expected to envisage to 2,12,000MW.More HVDC systems are planned in the future especially in the UHVDC range for evacuating power from NER to load centers in NR and ER. The Chandrapur–Phadge, Rihand–Delhi, Talcher–Kolar are some of the following HVDC systems transmit bulk power over long distance and improves the system stability. The HVDC line from Balia to Bhiwaldi is under construction forming a link between NER and NR regions, transmitting bulk power of 2500MW over 780km. Existingand UndercommissioningHVDCprojects in India are listed in Table 1.5

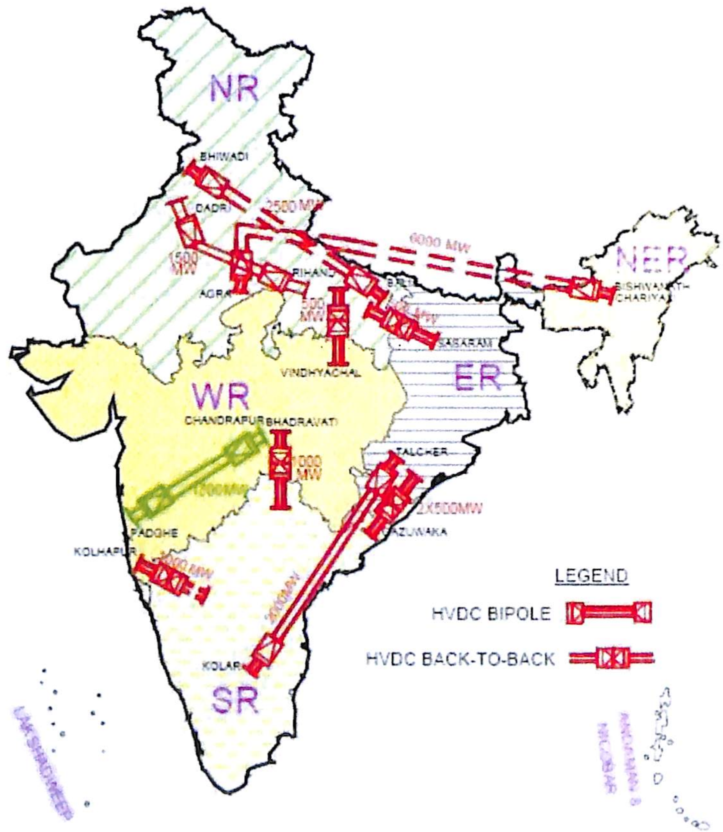


Fig 1.5: Inter - Regional HVDC Links in India

TABLE1.5: List of HVDC Projects in India

Rihand- Delhi	
Commissioning year	1990
Power rating	1500MW
No. of poles	2
AC Voltage	400kV (both ends)
DC Voltage	±500kV
Length of Overhead line	814km
Main reasons for choosing HVDC	Long distance, networkstability
Chandrapur - Padghe	
Commissioning year	1999
Power rating	1500MW
No. of poles	2
AC Voltage	400kV (both ends)
DC Voltage	±500kV
Length of Overhead line	752km
Main reasons for choosing HVDC	Long distance ,stability and environment
Vindhyachal (NR -WR)	
Commissioning year	1989
Power rating	500MW
No. of poles	2
AC Voltage	400kV (both ends)
DC Voltage	70kV
Type of Link	Back-to-Back station
Main reasons for choosing HVDC	Asynchronous station
Talcher - Kolar	
Commissioning year	1999
Power rating	2000MW
No. of poles	1
AC Voltage	400kV (both ends)
DC Voltage	±500kV
Length of Overhead line	1400km
Main reasons for choosing HVDC	Long distance ,stability

Vizag (SR-ER)	
Commissioning year	2005
Power rating	500MW
No. of poles	1
AC Voltage	400kV (both ends)
DC Voltage	176kV
Type of Link	Back-to-Back station
Main reasons for choosing HVDC	Asynchronous network
Sasaram(NR-ER)	
Commissioning year	2002
Power rating	500MW
No. of poles	-
AC Voltage	- (both ends)
DC Voltage	205kV
Type of Link	Back-to-Back station
Main reasons for choosing HVDC	Asynchronous network
Chandrapur Ramgundam	
Commissioning year	1998
Power rating	1000MW
No. of poles	-
AC Voltage	- (both ends)
DC Voltage	2*205kV
Type of Link	Back-to-Back station
Main reasons for choosing HVDC	Asynchronous station
Balia - Bhiwaldi	
Commissioning year	2009-2010(approx)
Power rating	2500MW
No. of poles	2
AC Voltage	400kV (both ends)
DC Voltage	±500kV
Length of Overhead line	780km
Main reasons for choosing HVDC	Long distance ,stability

1.6 FUTURE LOOK

In China and India the demand for energy is growing dramatically. Every year, china installs new power generating capacity equivalent to entire installed capacity of Sweden. Major expansion of available hydro power will be needed to satisfy this demand. The generating electricity must be transmitted between 1500 to 2000km. Till now ±600kV is used for long distance transmission of electric power over distance of around 1000km. With the introduction of ±800kV DC it will be possible to transmit power as far as 3000km with reasonable transmission losses. India and china is currently planning to build one 800kV DC line for every two years over the next ten years with a capacity of 6000MW per line. Main driving force to use 800kV HVDC is the total investment cost and losses are less. The ROW is minimal compared to conventional means, which is often important specificationfortheevaluationofcapitalcost.

Concentrating Solar Power (CSP), schemes are suitably located in deserts, as the land is not used for agriculture, forestry or urban settlement. To transmit large amounts of power over long distances from remote desert locations to population centre"s HVDC transmission is used. Due to risk of salt contamination over the overhead lines, underground cables are preferred. In near future practical cable transmission distances of 2000km are expected. On that basis if CSP schemes take off, then HVDC technology wait to support them.

1.7 LITERATURE SURVEY

There have been many researches on Capacitor Commutated Converter technology. The converter with series capacitors in the transformer windings was considered in the early 50's-60's.Then there was a break because there was no economic way to mitigate the inherent severe transient over voltages caused by series capacitor. The interest resumed in 80's mostly due to development of Metal Oxide varistors. More recently, in 1995 the series capacitor commutated converter has been suggested as an advanced High Voltage Direct Current technology. Presently two commercial projects one commissioned in 1999-2002 at Garabi and another in 2003 at Rapid city,U.S.A both of back-to-back configurations demonstrate the technology.

The literature relevant to the work reported in this thesis can be classified under four headings.

- Performance Evaluation of Capacitor Commutated Converter compared to Line Commutated Converter
- Applications of Capacitor Commutated Converter HVDC technology.
- Different configuration topologies
- Control strategies for Capacitor Commutated Converter

1.7.1 Performance Evaluation of Capacitor Commutated Converter (CCC) Compared to Line Commutated Converter (LCC)-HVDC Technology.

Preliminary investigations focused on the basic theory and operational characteristics of Capacitor commutated converter circuits. Comparative studies with line commutated converter systems show that the performance of CCC is far superior to LCC in improvingcommutation failure, and recovery of the system.

Busemann gave the basic theory and operational characteristics of forced commutation technology,which have been presented and analyzed in. The steady state and transient performance of CCC are compared with LCC to studythe benefits and its drawbacks.

Conventional HVDC converters rely on the AC network voltage for turn-off of the thyristor valves, which is a serious limitation. This poses a serious problem particularly when the converter is applied in extremely long DC cable transmission or feeds a weak ac network. An artificial generated voltage can be used to force commutate the valves. For force commutation, Busemann concluded that series capacitor commutated inverter is the most competitive especially for firing angles at 180° thereby reducing reactive power requirements at the inverter. Reeve, Baron and Hanley have analyzed the circuit in detail, covered the aspects such as steady state operation, range of operation, valve stresses, and faults on the converter, and demonstrated the possibility of inverter into a purely resistive load. The necessary theoretical study for economical base is given in this paper but further study is required for practical applications.

A.M.Gole extended the work of Reeve for more technical assessment using same circuit model for the inverter. State variable approach using numerical and direct solution techniques for simulation is used for studying both transient and steady state behavior of the inverter. The following aspects like effect of ac side faults during operation, AC/DC side harmonics, rate of change of firing angle and operation into weak systems have been discussed. This work acts as a guideline for further study and does not include economic analysis.

Sood and Bowles [38] have carried out simulator studies to test the ability of a forced commutated inverter to supply a lagging load. Digital simulation programs based on Newton Raphson method (Flow charts are given) is proposed by, to obtain current and voltage waveforms of conventionaland Capacitor Commutated Converterconverters as well as commutation angle. The results are verified by experimentally with a prototype 2KVA of six pulse High Voltage Direct Current transmission setup.

S.Gomes et al in his paper describes a model for the Capacitor Commutated Converter, which is valid for low frequency dynamics studies was implemented in computational programs for power flow, power system stability and small signal stability analysis. Results described for small system confirm the superior performance of Capacitor Commutated Converter in applications involving weak ac systems.

1.8 SUMMARY

The HVDC Transmission system is a mature and proven technology for transferring power in bulk over long distances through overhead or cables. HVDC base solution seem to be the best direction that offers the best fit solution at the moment, even with the recent introduction of embedded generation and associated advantages. FACT technologies have been found to improve the power transmission and voltage stability of power networks but it has been found to expensive and imbued with the inherent disadvantages of HVAC transmission system. In addition, HVDC has been found to have fault–current blocking ability, which inhibits cascading effects during blackouts, where as HVAC with FACT system does not have this capability. In this chapter the authors recommends a further research in the area of HVDC systems to find the best solution that will meet the need of power supply. In addition, to rethink the alternate technologies needed to overcome the shortcomings with the existing technology. The literature on operational characteristics, applications, control strategies and performance evaluation comparing with LCC technology of Capacitor Commutated Converter (CCC) technology has been discussed. This capacitor commutated converter technologyseemstobethesuitabletechnologyfor long cable power transmission or in weak AC systems due to developments in modern trends of HVDCtechnology.

In this chapter, a thorough literature survey was performed on the study of capacitor commutated converter configuration for long cable or connected to weak AC system applicationsandperformanceevaluationof CCC compared with LCC.

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