

Viability Analysis of HVDC System Applications in Electric Power Grid

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Abstract - The role of the HVDC in contemporary and future electricity is experiencing a tremendous increase with the worldwide evolution of the electric power sector size, structures and complexity. Its application based on power electronics technology makes it an alternative transmission facility to the HVAC transmission as much as its implementation as tie-line is increasingly gaining significance. This paper examines the viability considerations required for the planning, installation and operation of the HVDC for modern power applications. It enumerates the implication in terms of economy, environmental impact, converter layout and its protection and control. Its potent advantage necessitates the increasing relevance of the HVDC technology for connections of asynchronous systems and oceanic electric power transmission.

Key words: HVDC, Intertie, DC transmission, Thyristor valves, Electric Grids

1.0 Introduction

As electric power flow through transmission lines, transmitting more power with the least of resistance between nodes requires building more AC power lines to forestall the flow of wandering power to overloaded and weaker parts of the grid. While there are new Flexible Alternating Current Technology devices that can squeeze more AC power through an already congested line, their implementation is expensive on a large scale. However, there is a more comparatively elegant alternative in HVDC involving the use of power electronics stationed at both ends: one HVDC line acting as high capacity wormhole that pulls electricity from form near its source and re-injecting it into the AC grid up-to thousands of kilometres away. The first application of the High Voltage Direct Current (HVDC) system was in Europe. There was an installation in 1951 in the then Soviet Union connecting Kashira and Moscow and subsequently an underwater installation by ASEA connecting the Island of Gotland and mainland of Sweden operating at 100kV, 20MW [1]. The existence and application of HVDC allows the interconnection of asynchronous power networks to be made for reliable operation, economic considerations and provide buffer between the connected networks.

1.1 Comparison of Power Transmission by D.C And A.C

In the A.C system the transmission power P , is given by

$$P = \frac{E_1 E_2}{X} \sin \delta \quad (1)$$

Where δ is the electrical angle between the line voltage line reactance, whereas in D.C, the transmission power is given by

$$P = \left(\frac{E_{d1} - E_{d2}}{R} \right) E_{d2} \quad (2)$$

Where E_{d1} and E_{d2} are the d.c voltages at the two ends and R is the line resistance. While the line circuit construction is simpler compared to AC transmission, the reliability index of a bipolar DC line is comparably the same as a 3-phase Two-circuit transmission with six transmission conductors [3].

Power per conductor in case of DC is

$$P_d = V_d I_d \quad (3)$$

While that of a.c is

$$P_a = V_a I_a \cos \phi \quad (4)$$

Where I_a and I_d are currents per conductor and V_d and V_a are the line-neutral voltages and $\cos \phi$ the power factor.

Since $V_d = \sqrt{2} V_a$ and $I_a = I_d$

$$\frac{P_d}{P_a} = \frac{V_d I_d}{\frac{V_a}{\sqrt{2}} I_d \cos \phi} \quad (5)$$

Also, the power capabilities per conductor of DC and AC in terms of 3-phase single circuit line and bipolar line are respectively

$$P_d = 2P_a \text{ and } P_a = 3P_a$$

Where P_d and P_a are power transmitted perthrough a transformer with a wye-connected conductor of DC and AC lines, hence the ratio secondary and the other transformer through a delta-secondary the 30 degrees phase displacement can be achieved.

$$\frac{P_d}{P_a} = \frac{2P_d}{3P_a} \quad (6)$$

$$= \frac{2V_d I_d}{3V_a I_a \cos \phi}$$

$$= \frac{2V_d I_d}{\frac{3}{\sqrt{2}} V_d I_d \cos \phi}$$

$$= \frac{2\sqrt{2}}{3 \cos \phi} \quad (7)$$

$$\frac{P_d}{P_a} = \frac{2.828}{3 \cos \phi} \quad (8)$$

Hence the power transmission capability of a bipolar line is same as that of 3-phase single circuit but simpler and cheaper in terms of Cost and Right-of-Way (ROW), without skin effect and stability issues with less corona loss and radio interference. It also has low short circuit current, possibility of higher operating voltages and requires no form of line compensation such as series and shunt compensation [4]. However, the above advantages are offset by the cost of converters and problem of voltage transformation.

2.0 Review of Related Literatures

The conventional HVDC transmission system uses the line commutated current-source converters requiring a synchronous voltage source for operation. The basic building block for HVDC conversion is the 3- Φ full-wave bridge referred to as a 6-pulse or Graetzbridge. Each of the 6-pulse bridge is comprised of 6 controlled switching elements or thyristor valves and each thyristor valve consisting of a number of series-connected thyristors to achieve the desired dc voltage rating. Most contemporary HVDC transmission schemes utilize the 12-pulse converters to reduce the additional harmonic filtering requirements essential for the 6-pulse operation using the 6th on the dc side and the 5th and the 7th on the ac side. The essence of this arrangement is to ensure that the harmonic currents which flow through the valves and the transformer winding on the primary side remains respectively 180 degree out of phase with each other and cancel out. This 12-pulse operation of modern HVDC is achieved by a series connection of the dc terminals of two 6-pulse bridges with ac voltage sources phase displaced by 30 degrees. The characteristic current of the 12 pulse operation and the voltage harmonics have frequencies of $12n+1$ and the $12n$ respectively. By feeding one bridge

Consider rectification circuit sample shown below being a 3-Phase Rectifier

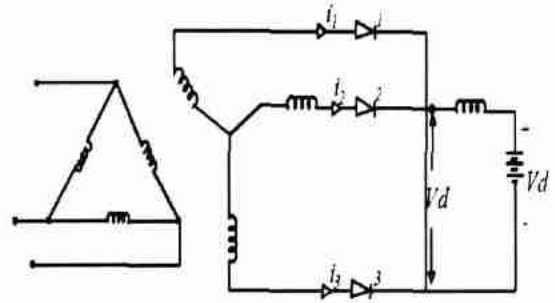


Figure 1: A 3-Phase Rectifier

Since conduction takes place during the positive half cycle, the average value of the DC voltage will be

$$V_0 = \frac{n}{2\pi} \int_{\left(\frac{\pi}{2} - \frac{\pi}{n}\right)}^{\left(\frac{\pi}{2} + \frac{\pi}{n}\right)} V_m \sin \theta d\theta \quad (9)$$

$$V_0 = -\frac{nV_m}{2\pi} [\cos \theta]_{\left(\frac{\pi}{2} - \frac{\pi}{n}\right)}^{\left(\frac{\pi}{2} + \frac{\pi}{n}\right)} \quad (10)$$

Considering ann-phased system, the average output voltage will be

$$V_0' = \frac{n}{2\pi} \int_{\left(\frac{\pi}{2} - \frac{\pi}{n} + \alpha\right)}^{\left(\frac{\pi}{2} + \frac{\pi}{n} + \alpha\right)} V_m \sin \theta d\theta \quad (11)$$

$$= \frac{nV_m}{2\pi} [-\cos \theta]_{\left(\frac{\pi}{2} - \frac{\pi}{n} + \alpha\right)}^{\left(\frac{\pi}{2} + \frac{\pi}{n} + \alpha\right)}$$

$$= \frac{nV_m}{\pi} \sin \frac{\pi}{n} \cos \alpha$$

$$= V_0 \cos \alpha \quad (12)$$

When the delay is α (Firing Angle). For three phases, $n = 3$ and for six phase $n = 6$.

2.1 Operating Modes and Configuration of the HVDC

(a). Monopolar Configuration

The simplest and least expensive HVDC systems are the monopolar schemes. They are essentially made up of two connectors and one insulated cable and are used to moderate power transfers. The capacity of the point of coupling of the back-to-back stations and the adjacent ac

systems limits the possible power transfers. They are used in applications involving low voltage electrode lines and sea electrodes to convey the return current in submarine cable crossings. This scheme is sometimes impractical where monopolar earth or sea return is impossible due to high earth resistivity, heavily area congestion or fresh water cable crossing. The alternative is to use metallic neutral or low voltage cable as return path while the dc circuit employs a simple local ground reference. However, there are more economical alternatives to the metallic return of the monopolar system. For instance, the mid-point of the 12 pulse converter can be connected directly to earth, or through impedance and two half voltage cables or line conductors ensuring that the converter is operated in 12-pulse mode to avoid earth current.

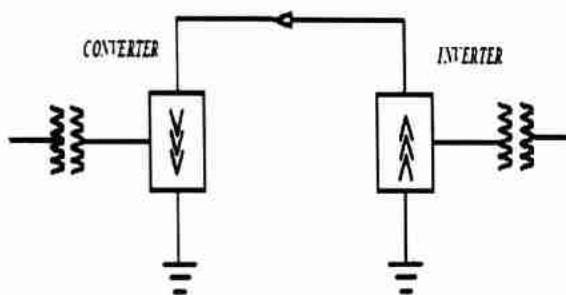


Figure 2(a): Monopolar D.C link

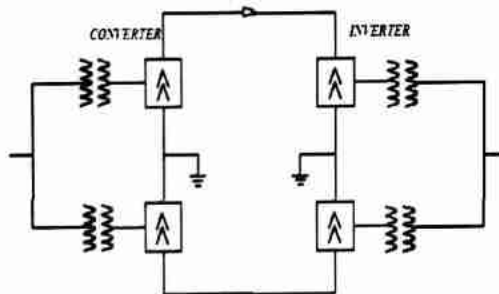


Figure 2b: Bipolar D.C Link

(b). Bipolar Configuration

This is by far the most versatile of modern overhead HVDC transmission configurations. It uses a single 12-pulse converter for each pole at each terminal yielding two independent dc circuits each with half capacity. It has no earth current at normal operation and can be monopolar earth return operated with over load capacity during the outages of the opposite pole. By using the opposite line for metallic return via pole/converter bypass switches at each end, earth

return operation can be minimized during monopolar outages. A metallic return transfer breaker in the ground electrode line at one of the dc terminals is required to commutate the current from the relatively low resistance of the earth conveyed into the dc line conductor. For most dc transmission system, metallic return operation is essential and provided and not only proves effective during converter outages but during line insulation failure where the remaining insulation strength is sufficient to withstand the relatively low resistant voltage drop along the metallic return path. A schematic diagram of this configuration is shown in figure 2b.

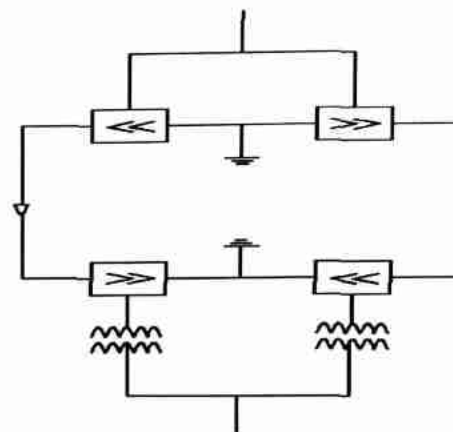


Figure 2c: Homopolar D.C Link

(c). Homopolar Configuration

As shown above, the Homopolar lines have two or more conductors having the same polarity usually negative for reason of corona and radio interference and always operate with ground as the return. In HVDC transmission, the voltage and current levels are so high that a single thyristor cannot meet these requirements. Under such circumstances, it is essential to use more than one thyristor in parallel to obtain increased current requirements and in series to achieve higher voltage. Under this circumstances, the turn-on time for the thyristors differs and to nullify the difference in characteristics these thyristors (finger voltage, holding current, latching current e.t.c. which results in unequal current sharing) insertion of suitable value of inductance in each thyristor circuit is desirable [5].

2.2 Relevance of HVDC Installation Viability Studies

Prior to a successful installation of any HDVC facility, enormous pre and post installation of

studies, modeling and testing are required. Unlike transformers, HVDCs are not bought off shelf as each installation is unique hence feasibility studies are required to achieve accurate system models and installation for long distance transmission, as tie for asynchronous networks or connector between a network and an asynchronous generation from renewable sources like wind farms. The feasibility study for instance helps to determine the preliminary parameters of the planned system and propose viable modification with respect to incorporating known power flow results and other network related studies. Some of these studies conducted at normal and post contingency operating scenario from a variety of base and maintenance conditions includes stability, transient, harmonics, short circuit and steady state analyses. The final results, deductions and recommendation of these studies and testing must be certified before commissioning a HVDC facility and same must be effectively communicated to facility operators and personnel to ensure full and secure system coordination and network improvement.

Transient analysis is useful to establish insulation coordination and to refine the HVDC stability models especially with regards to unbalanced faults. To stabilize system from transient and stability swings the HVDC have the option of ancillary control extensions, hence dynamic loops may be added to modulate the HVDC to provide damping to oscillatory system response. For successful integration of the HVDC to the network power flow analysis is required. This study while examining the overall system steady state issues is relevant to establish parameters for HVDC installation. Such issues include but not limited to normal and contingency system transfer capacity, voltage performance at static and dynamic states, losses, tap ranges for converters transformers, loop flow and contingency with system future expansion needs. Care must then be emphasized in order to provide adequate system models to accurately simulate appropriate response. Harmonic studies are relevant to establish filtering requirements. Short circuit analysis particularly for conventional converters is appropriate especially as high short circuit ratio is an indication of a better conversion short circuit performance. It is instructive to note that beyond being used for electric power transmission, HVDCs are also

used for electric power system protection and control and have the following advantages over high voltage alternating current applications.

1. They allow for control of real power flows at normal and post contingency operating conditions
2. Boosts the transfer capability across transmitting networks through direct and indirect flows regulation
3. They provide system voltage support either By indirect real power control or relative power control
4. They help to achieve power output modulation in response to varying system configurations through the use of special ancillary controls.
5. They lessens the environmental impact of the transmission line as against the ac equivalent with fewer stray voltages, increase power transfer capacity without significantly increasing the short circuit availability.

The comparative advantage of the HVDC transmission line over the AC of same purpose and capacity are numerous. For instance, a rough estimate of saving of not less than 30% during construction has been reported [2]. The obvious proof of this is that for instance a Bipolar HVDC uses two insulated sets of conductors unlike the three conductors used for AC transmission. This culminates in a smaller Right-of-Way (ROW), with less adverse environmental impacts, economic implication and extra compensatory costs and at the same time engaging the use of smaller transmission towers and guaranteeing lower transmission line losses. As a result, the HVDC provides a more economical electric power transmission alternative to the ac transmission for long distances especially for remote routes and applications.

3.0 Considerations for HVDC Application in Electric Power Networks

The viability studies for HVDC installation should be considered from the following perspectives

- i. HVDC Converter station layout
- ii. Economy
- iii. Environmental impact
- iv. Protection and control functionality

(a). HVDC Converter station Layout

According to [1], the HVDC converter station layout composition includes:

Converter transformers, Thyristor valves, AC harmonic filters, Dc harmonic filters, Valve cooling systems, Control and protection systems, Ancillary power schemes and Valve hall building.

With these essential subsystems the station layout depends on a number of stringent factors such as HVDC configuration (Monopolar, Bipolar or back-to-back) asynchronous tie, valve design, ac system interconnection, reactive power compensation requirement, filtering requirements, land availability and local environment. The Thyristor valves are mostly air insulated, water cooled and enclosed in a building called a valve Hall, but for low dc voltages as seen in back-to-back ties. These Thyristors valves may be housed in a prefabricated enclosure and not the Valve Hall. There are certain recommendations to ensure the most compact of design, while reducing the number of insulated high voltage wall bushing. It is recommended that the converter transformers be placed adjacent to the Valve Hall with the Valve winding bushing protruding through the building walls in order to make connection with valves. Valve arresters are also located just adjacent the valves which could double or quadruple valve structure modules within the valve hall. Dry coolers or evaporation cooling towers located outdoors are part of the closed loop valve cooling system used to circulate the cooling medium through the indoor Thyristor valves with heat transferred to them. For personnel safety indoor motor operated grounding switches are employed during maintenance.

(b). Economic viability evaluation of HVDC installation

As in every capital intensive installation economic considerations determine its viability in the presence of competing alternatives. In electric power markets, power pricing and transmission, tariffs are issues of economic importance with regards to capital cost, cost for modifications and improvements, maintenance costs, load and no-load losses and projected availability of the HVDC facility. Economic studies must identify the financial costs and benefits between the parties and should prove economical over vying alternatives. Incorporated in this study is the estimation of energy prices, capacity requirement and cost ancillary services

as well as potential effects on loop flow. The break-even distance is often a stringent factor when considering long transmission lines. This concept in this case portrays how the saving in line costs and lower capitalized cost of losses offsets the higher converter station costs. The break-even distance is influenced by the cost of ROW and the transmission line construction of an upward of 500km. while intermediate shunt compensation can offset for the rapid drop-off in cable capacity with ac transmission over distance due to reactive component of charging current such compensating scheme is impractical for submarine cables of HVDC but losses in HVDC cables are smaller. In fact due to more conductors, reactive component of current, skin-effect and induced currents in the cable sheath and armor for a given cable conductor area, the line losses with HVDC can be less than half of those of the ac cables.

(c). Environmental impact consideration of the HVDC installation

One of the economic considerations in the application of HVDC as a transmission corridor is that its narrow Right-of Way (ROW) implies less adverse environment impact and by extension impacts less on the ecological cycle. The absence of induction and alternating electromagnetic fields from the HVDC transmission through the expanse of its existence is helpful to animal life and lower cable losses implies less heating in the environment. In underground applications, earth heating from conductors is minimized as it is possible that the HVDC transmission share transmission corridor with other utilities without compromising system reliability index due to adverse interference. The switching of the thyristor valves of the electronic converters causes fast current commutations and the voltage changes which results in parasitic current [7]. This parasitic current and its operational harmonics cause disturbances in the kilohertz and megahertz region of radio-frequency spectrum [8].

(d). Protection and Control functionality

The asynchronous nature of HVDC and its controllability provides invaluable advantage in certain transmission applications. Due to this controllability, the utilization of HVDC seems elastic as congestion or loop flow on parallel transmission paths does not result in schedule curtailments for transmission loading relief.

Although the control and protection of the HVDC is known to prevent the spread of system disturbance, its influence causes disturbances with severe ramification. Consequently, understanding the extent of the AC/DC interaction with regards to the protection and control functionality is imperative. [6] emphasized that a HVDC tie may respond to contingencies, including remote ones and as a result converter controls may block or modify the HVDC output possibly due to commutation failure. The publication explains that a trip due to fault of a generator could result in a block HVDC resulting in possible power flow voltage stability and frequency response and operating reserve issues. An understanding of the HVDC controls and their modeling in stability simulations will aid in the designs that protect the converters such as blocking the terminals for close-in faults or commutation protection. While some HVDC interconnections are essentially back-to-back converters without transmission lines, they have a protection capability against events of cascading outages in any part of the interconnection. They act as efficient firewalls that prevent the propagation of cascading outages. This firewall capability was evident during the Northeast blackout of August 2003 [2]. As the outage propagated around the lower Great Lake and through Ontario and New York, it stopped at the Quebec interface of the HVDC connecting the asynchronous networks between Quebec and New England and Maritimes. The weak ac interconnections between New York and New England tripped but the HVDC links from Quebec kept delivering power to New England while protecting this segment of the interconnection.

4.0 Voltage Source Converter Based HVDC Transmission

Over the years, the HVDC had evolved remarkably with numerous aspects of application. The advancement made in these individual aspects encapsulates the overall evolution of the HVDC. For instance, with over 40 years of existence as of 2016, the Pacific HVDC intertie (PDCI) has undergone remarkable changes and upgrades from 1440MW in 1970 to 3100MW as at 2006 enduring two major earthquakes, a fire disaster amid environmental and economic concerns[1]. The Cross Sound Cable (CSC) interconnection

between Eastern Connecticut and Long Island is another example of a HVDC tie that uses the Voltage Source Converter technology [6].

While the conventional HVDC transmissions are commutated current-source converters with thyristor valves, there are certain configurations and technologies which are contemporary alternatives to the HVDC and are commutated differently. They include Capacitor Commutated Converters (CCC), Grid Power Flow Controllers (GPFC) and the Variable Frequency Transformers. The HVDC transmission using Voltage Source Converter (VSC) with Pulse-Width Modulation (PWM) was introduced in the 1990's. These VSC based HVDC transmissions use extruded HVDC cables and achieve forced commutation using the insulated gate bipolar Transistor (IGBT) valves and solid dielectric. This forced commutation allows black start where the converter can be employed as a virtual synchronous generator to synthesize a balanced set of three phase voltages. The uniqueness of VSC based HVDC transmission is emphasized in the reactive power compensation scheme that has overall system performance boost. The independent control of active and reactive power gives enhanced flexibility to system control capability anywhere within the AC network while reactive power can be controlled at each terminal independent of the dc transmission voltage level.

With the VSC based HVDC, the dynamic attributes of the ac voltage at each converter terminal improves the voltage stability and increase the transfer capability of the sending and receiving end AC systems [2]. As a result the VSC based HVDC finds application in the following, namely:

- *Underground Cable Installation*
- *Offshore power transfer and insulator loads*
- *Asynchronous interconnection*
- *Multi-terminal systems*
- *Power supply to insulator load Urban in feed*
- *Outlet transmission for large scale renewable Energy Generation*

(a). Underground Cable Installations

Long distance installation using HVDC transmission is possible and viable from the

perspective of line losses as HVDC cable systems unlike their AC counterparts commute lesser system losses. With the use of lighter extruded cables, which are more flexible and easier to splice than the mass-impregnated, oil paper cables whereas used for conventional HVDC transmissions, the VSC based HVDC extruded cables are much more conducive for land cable applications where transport limitations can heighten cost and ensure that with ROW constraints, distance underground transmissions are economically achieved.

(b) Power supply to Offshore and Insulator loads

The possibility for flexible operation of the VSC converters at variable frequencies can efficiently drive large offshore compressors or pumping load requirements using high voltage motors and being that the VSC based transmission is more compact than the conventional HVDC. Onshore generated transmission of power to offshore loads on mining platforms is viable. This is a credible alternative to the offshore production of same power on these platforms which is comparatively more expensive, less efficient and at the risk of more emission. Whereas for insulator loads, the forced commutation capability, dynamic voltage control feature and black-start capacity of the VSC based HVDC transmissions make this viable for transmission of power to isolated loads on islands through submarine cable eliminating expensive island power generation.

(c). Asynchronous Interconnections

For asynchronous interconnections of networks, the voltage support and inherent system voltage stability feature of the VSC based converters permits higher power transformers without need for system reinforcements especially when networks been at their periphery tend to be weak relative to the desired power transfer. As a result, there is no impossible restriction or limit to economic power schedules with reverse power directions and system stability is enhanced since VSC converters have fast recoveries during nearly ac faults and is not at the risk of commutation failures.

(d). Multi-terminal systems

Unlike the conventional HVDC transmission which requires switching for converter opposite pole connection or polarity reversal using voltage polarity reversal, the VSC based HVDC

achieves power reversal through current direction and the reversed power may be tapped at any intermediate point independent of the main power flow.

(e) Urban In-feed

The population density and use saturation impedes the possibility of new overhead transmission links through large urban settlements from the perspective of land use and ROW. Nevertheless the compact nature of the VSC HVDC can be exploited through the new underground cable transmission by sharing the land within the ROW of transmission lines, so as to import power and provide voltage support ensuring sustainable development and continued reliable economics supply of electricity to indoor compact stations sited in urban areas.

(f) Outlet Transmission for Large scale Renewable Energy Generation

Renewable Energy Generation from solar and wind schemes from remote land or offshore require collector systems, reactive power support and outlet transmissions. Trans-versing through several lands forms, water bodies, scenic and environmentally sensitive areas, the use of VSC HVDC ensures the compact use of transmission corridor over long distances on land or submarine and provide reactive support to wind generation complex.

(g) Ultrahigh Voltage Direct Current (UHVDC) versus UHVAC

The advanced of applications of the HVDC is already employed at ultrahigh voltages. Several long distance HDVC transmission systems with power levels above 1000MW are at a bipolar voltage of $\pm 500\text{kV}$. For instance in Brazil, the operating voltage of such bipolar transmission is $\pm 600\text{kV}$ which has been in operation since mid-1980s. Using transmission voltages between $\pm 600\text{kV}$ to $\pm 800\text{kV}$ which are classified as UHVDC, higher power transfer capacity over very long distances at lower power losses can be achieved. The mechanical and electrical superiority of the UHVDC over UHVAC makes them more viable for long distance bulk power transmission and already reasonable advancement has been made in the application in countries of large population and land mass like the USA, India and China.

5.0 Challenges of HVDC Application

(a) Expensive convertors

Expensive Converter Stations are required at each end of a d.c. transmission link, whereas only transformer stations are required in an a.c. link.

(b) Reactive power requirement

Convertors require much reactive power, both in rectification as well as in inversion. At each converter the reactive power consumed may be as much as 50% of the active power rating of the d.c. link. The reactive power requirement is partly supplied by the filter capacitance, and partly by synchronous or static capacitors that need to be installed for the purpose.

(c) Generation of harmonics

Convertors generate a lot of harmonics both on the d.c. side and on the a.c. side. Filters are used on the a.c. side to reduce the amount of harmonics transferred to the a.c. system. On the d.c. system, smoothing reactors are used. These components add to the cost of the converter.

(d) Difficulty of circuit breaking

Due to the absence of a natural current zero with d.c., circuit breaking is difficult. This is not a major problem in single hvdc link systems, as circuit breaking can be accomplished by a very rapid absorbing of the energy back into the a.c. system. (The blocking action of thyristors is faster than the operation of mechanical circuit breakers).

However the lack of hvdc circuit breakers hampers multi-terminal operation.

(e) Difficulty of voltage transformation

Power is generally used at low voltage, but for reasons of efficiency must be transmitted at high voltage. The absence of the equivalent of d.c. transformers makes it necessary for voltage transformation to be carried out on the a.c. side of the system and prevents a purely d.c. system being used.

(f) Difficulty of high power generation

Due to the problems of commutation with d.c. machines, voltage, speed and size are limited. Thus comparatively lower power can be generated with d.c.

Convertors have very little overload capacity unlike transformers.

6.0 Conclusion

Originally, HVDC lines used converters built from Thyristors which though efficient were limited by their capacities and relied on AC system for Operation. Yet from inception, the HVDC had three hurdles to cross. One of such was the capacity ceiling of a few hundred megawatts. The second was the switching losses of about 1.5 to 2% of transmitted power per converter and the third been its inability to break DC current. Two of these hurdles were eventually crossed in 2010 with the introduction of the Modular multilevel converter gang of several hundred mini-converters or sub-modules which pushed the overall converter capacity from a few hundred to over a thousand MW. Also, each module fires only when needed in the conversion process thereby cutting the switching losses to about 1% per converter. The combined innovations and improvements in electric converters by ABB and Siemens, the penetration of HVDC as a viable alternative has been enhanced high voltage transmission. The enhanced capacity of these technologies ignited by the VSC based HVDC paved the way for successful challenge of the AC for power transmission. For a successful planning, modeling, integration and operation of any HVDC facility, several studies of pre and post installation are necessary. Accurate system power flow analysis and models are required to ensure that studies of normal, post contingency and maintenance are attained. The considerations of functionality, layout, economic and environmental impacts are core in the viability studies of any HVDC proposal. Using accurate models, simulation results must be compared with post installation field test results of before commissioning in order to ensure modifications on the installation. Impacts of HVDC integration on existing network operation must be noted and communicated effectively along with recommendations for sustainable operation.

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