CHALLENGES OF HVDC & ITS PROSPECTS

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Abstract

In order to transmit massive amount of power generated by remotely located power plants, especially offshore wind farms, and to balance the intermittent nature of renewable energy sources, the need of renewable energy sources, the need for a stronger high voltage transmission grid is anticipated. Due to limitation in AC power transmission the most likable choice for such a grid is a high voltage DC (HVDC) grid. However, the concept of the HVDC grid is still under active development as different technical challenges exist. This paper deals with prospects and technical challenges for the future HVDC super grids. A comprehensive overview of different sub-module implementations of multilevel module convertor is given. An overview of short circuit behavior of the modular multilevel converter is also given, as well as a discussion on the choice between cables or overhead lines.

Keyword- HVDC, voltage source converter (VSC), multilevel converter, Harmonics elimination, module multilevel converter, super grid, underground cable.

Introduction

The total scenario involves an electric transmission system that should have a substantially higher capacity than today, and that massive fluctuation in power could be handled without losing stability. A solution based on upgrading of the existing HVAC grid is lacking in densely populated areas because of public opposition, narrow Transmission corridors and limited availability of right of way (ROW).until recently, no obvious converter candidate for such HVDC Super grids was available. Depending on the power semiconductor used in the converter topology, the HVDC transmission can be classified as thyristor based line-commutated converters (LCC) and insulated gate bipolar transistor (IGBT) based voltage source source converter (VSC).

Today, there are more than 92 HVDC projects worldwide transmitting more than 75GW of power employing two distinct technologies as follows:

1. Line-commutated current-source converters (CSCs) using thyristors (Fig. 1, CSC-HVDC). This technology is well established for high power, typically around 1000MW, with the largest project being the Itaipu system in Brazil at 6300MW power level.

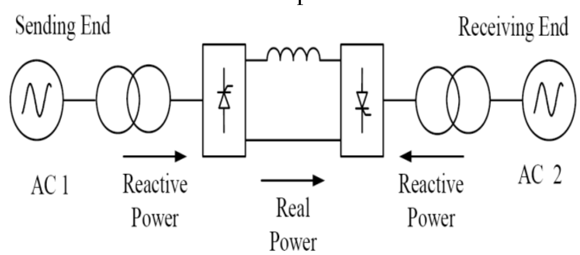


Fig 1: HVDC system based on CSC technology with thyristors

LCCs having high efficiency do not perform well in meshed grid connection as the voltage must be reversed if the direction of power is reversed. Additionally, LCCs suffer from being a burden to the interconnected HVAC grid because of the need for reactive power. Another problem related to the same phenomenon is the risk for commutation failures, normally during inverter operation.

2. Forced-commutated voltage-source converters (VSCs) using gate-Turn-off thyristors (GTOs) or in most industrial cases insulated gate bipolar transistors (IGBTs). It is well established technology for medium power levels thus far, with the largest size project being the latest one named Estlink at 350MW level.

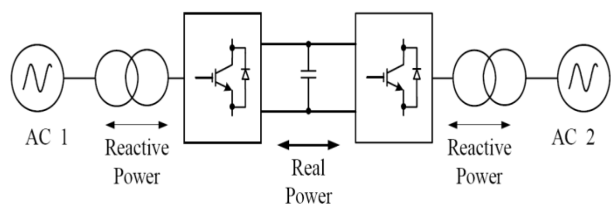


Fig 2: HVDC system based on VSC technology built with IGBTs

VSCs, however, can change power flow through the reversal of current direction rather than voltage polarity. As a result, the VSC technology can use Cross-linked polyethylene(XLPE) cable. They can provide reactive power and do not have commutation problem. They have smaller foot print and allow black start. Since the late nineties, therefore, HVDC transmission based on two or three level VSCs has been promoted and also installed I various parts in the world.

An alternative VSC topology is the multilevel converter for reducing harmonics and modular multilevel converter, which has the potential to have efficiencies higher than 99% and is also promising with respect to reliability and fault handling. The modular multilevel converter is highly scalable with respect to the number of level. The number of submodule can be increased or decreased as the number of level increase or decrease to get the desired output voltage.

The aim of this paper is to describe the prospects and challenge of a HVDC. In First section, the concept of SuperGrid is presented with differenent possible topologies. The second section deals with the possibility of replacing existing HVAC lines by HVDC lines. In the third section, different HVDC converter topologies are described. In fourth section Multilevel Convertor with harmonics elimination. In fifth section Modular Multilevel converter is describe. Short circuit issue for SuperGrids is discussed in the seventh section. In the eighth section, cable system for the Supergrids are discussed. The nineth section conclude this paper.

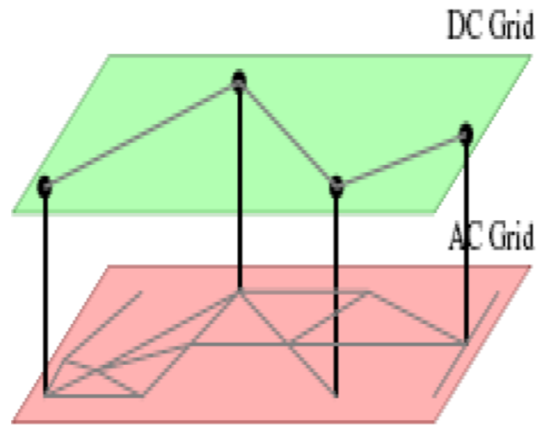
Super Grids

The Super Grid is seen as a solution to allow the massive integration of renewable energy sources into the energy system. As such it acts as a transmission system that securely spreads electric power across national border. HVAC grids available today would not be able to handle the amount of power if the projected amounted of renewable resource need to be connected. An upgrade is needed as it is already operated close to its limits. The up-grading of HVAC grids with overhead transmission lines very difficult because of legal, political, and environmental issues. AC expansion, options, both over head and underground are often limited by voltage or transient stability problems, increased short circuit level and impact of unaccepted network loop flows. The alternative solution to the problem with more power transfer capability in the future is an HVDC grid. Different topologies for possible SuperGrid are shown in fig.3

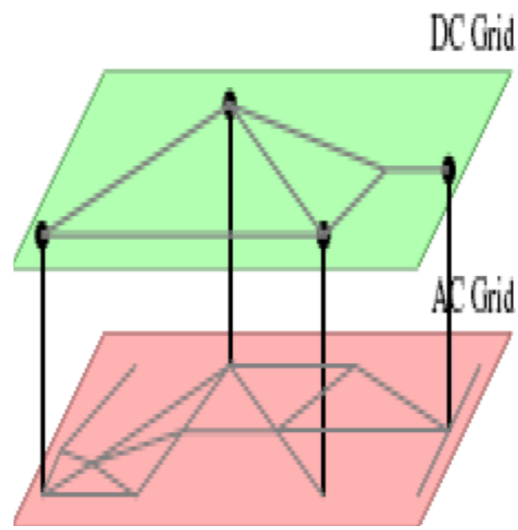
Grid topologies- A first potential topology (Fig.3a) is a simple multi-terminal system, which can be described as a DC bus with several tapping. While being the simplest form of a multi-terminal HVDC system, without DC meshes and no redundancy in the DC system itself as it as it offers no redundancy. Nevertheless, such a topology can be very useful as a component within a hybrid AC- DC grid to reinforce the AC system. The proposed Southwest Link in Sweden is an example of such a setup.

The second topology (Fig.3b) proposes a meshed DC system, with a number of connections between the AC and DC system. The DC system consists of DC nodes connected to each other without converter in between. The DC system is generally meshed, and multiple paths between nodes are possible. This has clearly an influence on reliability, but also in the way in which this system must be protected.

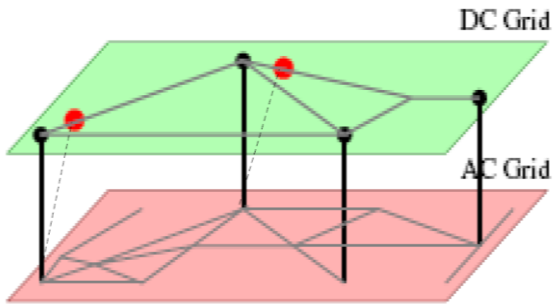
Connected in series with the DC line and AC side is connected the AC grid via transformer T2 on either side via transformer T1 for the multilevel module converter, preferably the side with lower voltage. The additional converters may be either VSCs or LCCs. In the case of VSC they could even be small multilevel module converters. From a cost and robustness point-of-view, however, a double thyristor converter may be preferable. The voltage across capacitor C can be controlled by means of the thyristor converter. By changing the voltage across the capacitor the power flow in the DC lines can be controlled, thus providing additional possibilities for power flow control using a converter that has a rating which is only a small fraction of the multilevel module converter. DC/DC converter can also be used in place of thyristor converters but they are more expensive as they are rated for the full voltage instead of the voltage difference in the thyristor converter case.



(a) Multi-terminal with tapping



(b) DC meshed grid



(c) DC grid with controllable device

Fig. 3: Different possible topology for super grid

Replacement of existing HVAC lines with HVDC lines

The Super grid is not something that will be built in one single stage. Similar to the construction of an AC grid, a possible scenario is to first build point-to-point HVDC connection which later may be connected and integrated into a DC Super grid. Another possibility is that after the accomplishment of the Super grid, some parts of the existing AC grid must be upgrade or replace by dc lines to enhance their power transfer capability and system stability.

In recent years, interesting in converting existing AC lines to DC has grown rapidly. In India, where the construction of new overhead transmission lines is very difficult because of public opposition, geographical distribution and effect of aggregation can be accounted, converting an existing AC line into a DC line is an appearing solution to increase its power transfer capability. In the future, it is expected that during the development of Super grid, conversion of AC lines into DC will get more interest especially where construction of new lines are not possible.

HVDC converter for Super grid

Until recently, no obvious converter candidate for such HVDC Super grid was available was available but the following advantage of the VSC over LCC makes it more favorable.

- The direction of flow of power can be changed by changing the direction of current.
- Independent control of active and reactive power.
- No minimum requirement of short circuit ratio for the connected AC system.
- Forced commutation allows black start.
- Smaller converter station foot-print.
- Light weight and economical extracted polymer DC cable can be used.

For high voltage and high power application these converter with high number of series connected IGBT device also produce valve stressed and electromagnetic interference (EMI) problem. Taking into account the Super grid, these converter show some drawback, which limit their performance and application in Super grids.

Multilevel Converter

In Comparison to two level converters, the switching frequency per switch of the multilevel convertors is substantially lower. Hence, Multilevel converters may have significantly lower losses. The existing multilevel topology are categorized as

1. Diode Clamped or Neutral point clamped (NPC)
2. Flying capacitor or capacitor Clamped(FC)
3. Cascaded H-bridge with separate DC source
4. Modular Multilevel cascaded bridge Converter(M2C) (without separate DC source)

Modeling of Multilevel convertor for Harmonics elimination

Amount of energy stored in convertor. The energy stored is an indicative of the ride through capability along with the size and cost of the capacitor. The equation for the energy stored in the capacitor is given as

$$E= 0.5\, C U^2 n$$

Where, E is the energy stored in the capacitor, C is the capacitance, and U is the DC voltage and n is the number of capacitor in the convertor topology. Higher energy storage leads to better ride through capabilities but with a compromise on the large size of the capacitor and the associated cost for the same voltage and power rating.

For higher number of level the NPC converter requires high number of clamping diode, which makes its structure quite complex. Also voltage balancing is a challenge with a high number of levels. Similarly, for higher number of level the capacitor clamped multilevel convertor topology requires a high number of capacitor. The capacitor becomes bulky, expensive and difficult to pack. For active power transmission, the inverter control becomes complicated and switching frequency and losses becomes high. Their construction becomes complicated and more complex as the number of levels increases.

Modular multilevel converters

The Modular Multilevel Convertor that was proposed by Marquardt and Leisnicar is now getting popularity due to its advantage over the conventional topologies. The basic components of modular multilevel convertors are a sub-module. The number of sub-module can be increased or decreased as the no of level increase or decrease to get the desired output voltage. Three sub-module topologies that have been proposed for modular multilevel convertor are the half bridge sub-module (HBSM), Full bridge sub-module (FBSM) and Clamp double Sub-module (CDSM).

Half bridge sub-module (HBSM)

It is mainly composed of two IGBT switches, two anti-parallel diode and a DC storage capacitor C_0 shown in fig 4(b). The terminal voltage of each Sub-module can either be switched to zero or a voltage V.

Full bridge sub-module (FBSM)

It consists of four IGBTs with anti parallel diode and capacitor as shown in fig. 4(c) The topology allows both positive and negative voltages.

Clamp double sub-module (CDSM)

In normal operation CDSM shown in fig. 4(d) Represent two equivalent HBSMs. The half bridge is connected positive terminal to negative terminal so the insert and bypass switch position are interchanged.

The main advantage of modular multilevel converter

- The internal arms current are continuous.
- The inductor inserted inserted in the arms limit AC-current in case of short circuit at the DC side
- No separate energy sources are required for sub-module capacitors.
- No common DC link capacitor is required.

The losses in two level VSC stations are around 1.6% of the rated transmission capacitor and around 70% of these are dissipating in IGBT valves. With modular multilevel converter the valve losses are expected to be much lower. The choice of sub-module implementation has a significant effect on valve losses. In is shown that conventional HBSM with IGBTs has around 0.5% valve losses of rated power, while CDSM and FBSM implementation approximately give 35% and 70% more losses respectively. Hence with reference to losses, the HBSM implementation for modular multilevel converter would be preferred in future Super Grids.

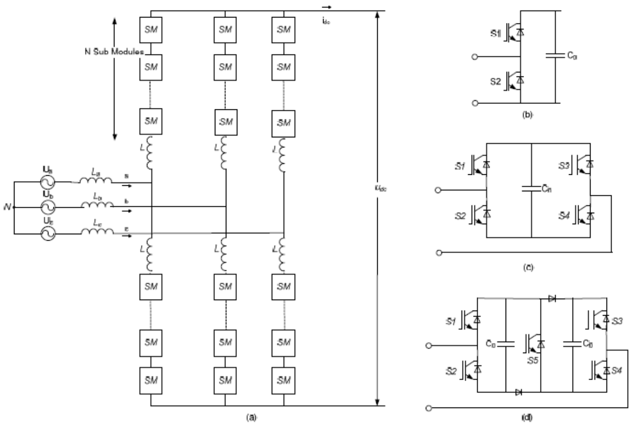


Fig 4: (a) Module multilevel convertor (b)Half bridge sub-module (c) Full bridge sub-module (d) clamp double sud – module.

Short-circuit issues

The protection system may be one of the major problems for the future SuperGrid. When a DC-side short circuit occurs, the VSC loses control as the IGBTs are blocked and the fault current current continue to flow through the anti-parallel diodes across the IGBTs. The stored energy at the DC bus results in extremely high current and current subsequent damage if short circuit at the DC bus cannot be disconnected immediately. The only limit to the fault current is the resistance of the DC line, which should be as low as possible as this influence the losses and the rating of the line. The availability of Super grid depends on the capability to withstand DC faults. Fast interrupt of fault current is essential for grid reliability. Due to limitation in availabity of DC circuit breakers the existing VSC HVDC protection system disconnects the entire DC SuperGrid each time a fault occurs. In a meshed system it is important to disconnect only the faulted part of the grid, but keep the Remaining system operational.

The HBSM is the most common topology for modular multilevel converter, but for a meshed grid this topology requires DC circuit breakers as the conventional method used to handle DC-side fault by AC breakers requires long clearing times. The DC breaker must be significantly faster than AC breakers used today so that the prospective fault current does not cause any damage to the components involved. The losses of a solid state HVDC breaker are much lowers then the losses of an HVDC convertor station, probably 0.2%. If a DC breaker would be available in future, the HBSM topology used in modular multilevel converter for Super grid as it has lowest and the lowest installation costs.

When using FBSM convertor topology, the short-circuit problem is less serve. FBSM has the ability to cut off arm current of any direction by impressing the appropriate polarity of terminal voltage in the arm.

The CDSM is the most recently proposed topology for modular multilevel converter. It is shown that the CDSM can decrease the fault current to Zero within 1ms after detection, without tripping the AC side switches, which makes the entire converter fully operable for immediate restarting. This topology has 35% more losses than a conventional HBSM but this has to be put against possibly reduced requirement for arm inductance, reducing the footprint of the converter station and hence the cost.

Cables and overhead lines

In the future HVDC Super grid it is not obvious that only cable or only overhead lines should be used. However, in general the possibility of using overhead lines is very limited considering environmental concerns, public opposition and limited ROW. Also with overhead lines, there is a higher risk of flash-over due to lighting. The permitting processes of laying underground cable are a higher risk of flash over due to lighting. The permitting process of laying underground cable is much easier than building overhead lines. The permitting process of laying underground cable is much easier than building overhead lines, Two major type of cable namely Mass Impregnated (MI) and Extruded cable are available for HVDC transmission. MI cables are insulated with special paper and impregnated with a high viscosity compounds. Extruded cable is insulated with extruded polyethylene based compound. Paper insulated cable impregnated with low viscosity oil also exist, but are limited to land cable or short submarine crossings, as they need hydraulic system for oil feeding. The choice of cable technology for offshore HVDC transmission depends on whether the polarity should be changed (as for LCC-HVDC). If the polarity of the voltage should changed MI cables should be used. However, if a considerable part of the cable should be on-shore, MI cable is usually avoided due to the moist-shielding led layer. Apart from this requirement, the choice between extracted cables and MI is free. The latter is more expensive due to more complex design and difficult handling. Fig. 5 shows a comparison of power transfer capacity of LCC-HVDC and VSC-HVDC using overhead lines and cables. For the anticipated VSC-HVDC Super grid, extracted cable are preferred due to their low weight and easy installation for both land and submarine applications.

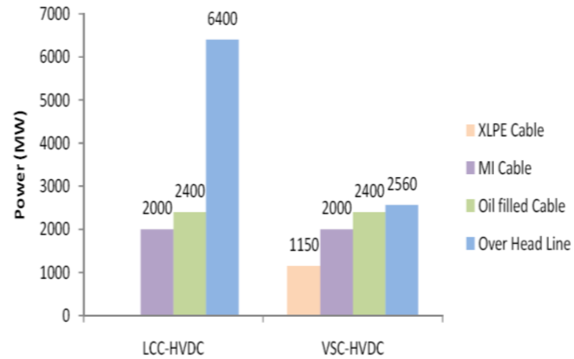


Fig. 5: Transmission capacity (available or announced) for HVDC system

Conclusions

The concept of Super grid allows massive integration of remote source of renewable energy. Building a meshed HVDC grid is very complicated. Technically VSC-HVDC with modular multilevel converter makes it more realistic. It is the most probable technology to be used especially if a cable based grid is considered. With expected higher number of branches and frequent changes in load flow, topology 2 presented in papers is advisable for super grid. Topology 3 can also used as it provides additional power flow possibilities. From a loss point-of-view the HSBM implementation for modular multilevel convertor performs well, but short circuit issues might call for another sub-module implementation, for longer transmission distance DC cable are the only solution for going underground and sea. It is likely that super grid will be used for strengthening the onshore network.

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