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HVDC (High Voltage Direct Current) Transmission System: A Review Paper

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Abstract

In the early days of electrical delivery, transformers used AC (alternating current) to step up and down the transmission of power as required, and it was more readily interrupted than DC (direct current). Using high-voltage AC grids, formerly isolated distribution networks and huge power plants might be linked together to serve industrial and residential customers. The first commercially viable high-voltage direct current (HVDC) connection was not built for many decades after the invention of HVDC technology. Review of present and planned HVDC transmission networks in India is the subject of this research. New advances in HVDC Transmission and other technologies are discussed in the article. The design, operation, building, and maintenance of HVDC transmissions are compared to HVAC in this study. In addition, an economic evaluation of HVDC transmission over an AC framework is included in the study. This study provides an overview of the HVDC transmission frameworks in India that are referenced in this research. The article concludes that HVDC frameworks should be used in the current development of power frameworks.

Key words : Bipolar transmission, HVDC links and transmission.

HVDC History:-

Only 1.5 KW of electricity were transported in the world's first HVDC transmission in Miesbach-Munich power transmission in a year. Between Miesbach and Munich, Germany, it was erected [16,17]. As is well-known, the AC system was immediately used for the production, transmission, distribution, and so on of electricity. [13] In an AC system, the transformer made voltage conversion simple. Low losses and high electric power are the hallmarks of a transformer. Compared to DC generators, the synchronous three-phase generator is an excellent choice. Because of this, transmission via an AC system is more easier than through a DC one. When using asynchronous grids and long-distance transmission, the HVAC system has a wide range of applications.

The following Table 1 shows the evolution of HVDC technology throughout time.[1]

Table 1: HVDV Technology Development

Hewitt's mercury-vapour rectifier, which showed up in 1901.
Experiments with thyratrons in America and mercury circular segment valves in Europe before 1940.
First business HVDC transmission, Gotland 1 in Sweden in 1954. • First robust state semiconductor valves in 1970.
First microcomputer-based control gear for HVDC in 1979.
Highest DC transmission voltage (+/ - 600 kV) in Itaipú, Brazil, 1984.
First dynamic DC channels for excellent separating execution in 1994.
First Capacitor Commutated Converter (CCC) in Argentina-Brazil interconnection, 1998

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Why choose HVDC over HVAC:-

The reason we favour HVDC over HVAC is an intriguing one. Because three-phase alternating current is the most common method of transmitting power. In other words, how does HVDC transmission fit into today's power transmission systems? Despite the fact that the majority of three-phase energy transmission utilises AC, why do we choose HVDC instead? What are the chances of HVDC transmission succeeding in the current network? While AC has been favoured for electrical transmission everywhere, including as in homes and businesses, there have been certain limitations to this technology. For example, the transmission capacity of AC is limited, as are the distances it can cover and the effects of the SKIN. [14] For DC and AC conductors, the skin effect and the corona effect tend to be less important. For the connecting of multiple frequency AC grids, HVDC transmission is particularly useful because of its great efficiency and precise controllability. The fact that DC is capable of transporting a substantial quantity of energy with minimal losses means that we have the option of choosing an HVDC transmission system. Using AC to transmit power is a concern since most renewable energy sources are situated in urban areas, and DC should be used instead. From a technological standpoint, HVDC is required or desired. [2] [16]

HVDCTransmission Network Component:

Converting Station; Converting Units; Converting Valves; Converting T/F; Filters; High-Frequency Filters; Power Source (Reactive); Leveling Reactor; Poles;

Converting Station:

The Rectifier terminal transforms AC to DC at the substation, while the Inverter substation does the reverse at the inverter substation. In order to function as both a rectifier and an inverter, each terminal must be built in such a manner that it can operate in both modes. Two terminals and one HVDC line make up a two-terminal HVDC transmission system. A typical HVDC converter station is shown in Fig. (1) below:

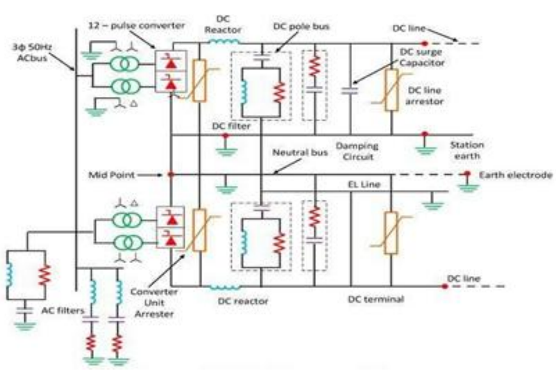

Fig (1).- Schematic Diagram of A Typical HVDC Converter Station [3]

Converting Unit:

Three-phase bridge converters employ a converter unit to convert AC to DC and vice versa, as we've discussed in detail before. There is another name for this circuit: the Graetz Circuit When using HVDC transmission, a 12-pulse bridge converter (shown in figure[2]) is utilised to link two or six bridge converters.

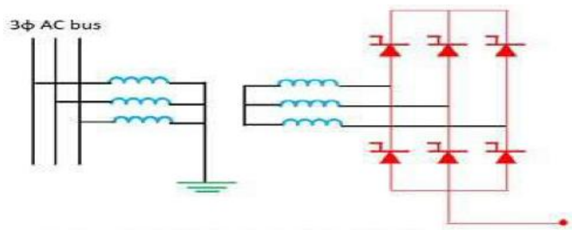

Fig. (2).- 6-Pulse Converter Unit [3]

Converting Valves:

Figure 3 shows the total number of valves in each group of the new HVDC converter's 12-pulse converter units. Series connection valves are made using thyristor-based modules. The necessary voltage across the valve determines the quantity of thyristor valve needed.

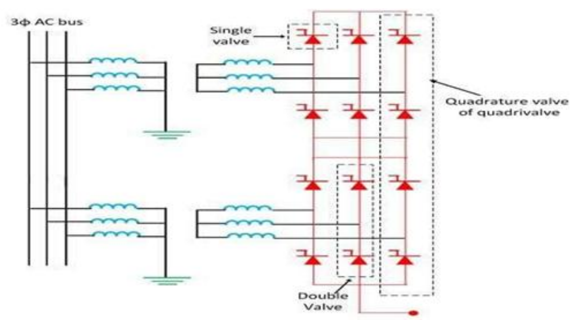

Fig. (3).- 12-Pulse Converter Unit [3]

Converting T/Fs:

Depending on the application, the converter transformer may convert from AC to DC or vice versa. They feature two three-stage winding configurations: AC sidewinding and valve sidewinding, respectively. The converter can eliminate different consonant currents by using Star-Delta and Wye-Delta Connection of T/F to operate with 12 heartbeats each cycle in the AC supply. The whirlpool current's misfortunes, on the other hand, have been boosted by the music current. These other factors have led to the transformer's centre becoming magnetised.

The converter transformer is used to convert from AC to DC and then back again. An AC winding and a Valve sidewinding make up the three stages of winding on these. While the converter used star-delta and delta-star association of T/F to expel different symphonious currents, here the whirlpool current disasters are growing due to sound current. It functioned with 12-heartbeat in every cycle of AC supply. It is because of the following factors that the converter T/F centre gets charged: -: -[17]

a) The sound arrangement for AC.

b) The valve side terminal coordinate voltage also has a few melodies.

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Filters:-

Moreover, the creation of receptive power at the line cumulative converter station relies heavily on filtering harmonics. Separately, the AC and DC sound tracks are injected into the AC and DC lines. The corresponding emphasis points are present in the music as well. The creation of reactive electricity at a range expanding converter plant necessitates filtration. Separate lines for AC and DC are interwoven with the sounds. The following drawbacks are associated with the sounds:

a. Phone lines are clogged as a result.

b. Machine and capacitor power failures are linked in the framework due to the noises.

c. Sound waves emitted in an AC circuit reverberated, resulting in completed voltages.

d. Converter control instability.

AC, DC, and high-recurrence channels are used to restrict the amount of music that may be played. AC Filters, DC Filters, and High-Frequency Filters are all types of networks. Reactive Power Source: There is a need for converter duties Power to react. Shunt capacitors and static var frameworks' synchronous stage modifiers may also be used to provide more power. Control speed is a key consideration in this selection. Smoothing Reactors:- An oil-cooled reactor filled with high-inductance oil is a smoothing reactor. At this point in time, the converter is linked to this reactor. It may be placed on either the line's neutral or line-side. There are two primary reasons for using smoothing reactors:

I. The direct current swells are lessened.

Secondly, they reduce the DC voltage and current harmony.

They also limit the DC line's fault current.

Consequences of the incident When the direct voltage of another arrangement's related voltage breakdown occurs, smoothing reactors reduces the pace of climbing the DC line in the scaffold to prevent inverter disappointments.

Reduces the steepness of voltage and current spikes from the DC line by using smoothing reactors It is possible to reduce the weight of the converter valves and valve surge diverters by doing this. The HVDC Pole:

HVDC substation equipment is included in this section of the transmission system. Transmission lines may also be interconnected with this device. When it is operating normally, it has a straight forward polarity with respect to the earth. As a result, the term "pole" refers to the direct current channel that has the same polarity as the planet. [12] Transmission medium:-

For the most part, the conductors of this overhead wire are bipolar, which means they have different polarities. Submerged transmission often makes use of HVDC lines. It is common knowledge that the healthiest relationships are those that are full of oil. Paper strips impregnated with a high-thickness oil are used to preserve solids, and there is no limit on the length of the strips or the depth of the oil. Low-thickness oil is put into the whole autonomous oil connection, which continues to function even while under stress. According to reports, a connection of this kind might last up to 60 kilometres in length. Recent years have seen an increase in the development of new power cable technologies, and a new subterranean or subsurface HVDC power supply line is now available. It is manufactured of extruded polyethene and utilised in VSC HVDC based systems [14]

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Things to keep in mind while creating, building, managing, maintaining, and budgeting for:-

For large HVDC frameworks with one-year thyristor thyristors, the development time might range from three years to HVDC VSC frameworks dependent on contract date to dispatch. Table 2 shows the experience of numerous HVDC advancements and the unique kind of HVDC through time. [4] [1]

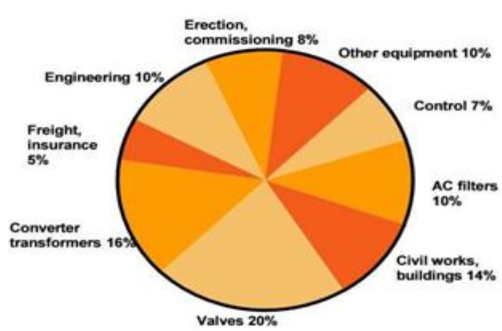
Ordinary commutated HVDC 3 years
CCC based HVDC 2 years
VSC found HVDC 1 year

Table 2 - Different HVDC with Operation Time

Because the word "task" refers to ongoing activities to maintain the accessibility of the framework at a written level. Because of the integrated semiconductor and chip-based control frameworks available today, HVDC connections may be managed remotely. There are currently unstaffed offices. Furthermore, modern HVDC frameworks are built for tasks that do not need human intervention. When there are just a few skilled people and they can operate several HVDC connections from a central location, this component is essential. For the most part, the upkeep of HVDC systems is comparable to that of high voltage AC systems. It is possible to sustain the HV equipment at change stations using methods similar to those used in AC substations. There is a lot of work to be done on AC and DC channels, smooth reactors, divider infiltrations, valve cooling gear, and thyristor valves to be done. Most of the time, the amount of time it takes to get up, start, and get going on a project is sufficient for adequate planning and assistance.

First, a breakdown of costs.

An HVDC framework's price depends on a variety of factors, including the maximum power transferred, environmental conditions, the kind of transmission medium used, and other administrative and well-being needs, for instance. The cost structure may be shown in Figure 4.



Fig(4).- Cost Structure[1]

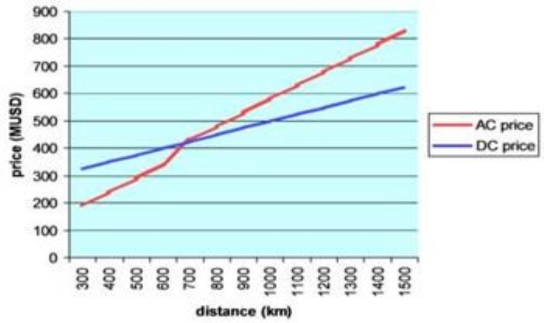


Fig.(5).- price variation for an AC transmission compared with an HVDC transmission[1]

Figure 1 shows the pricing difference between an AC transmission and an HVDC transmission for 2000 MW (5).

A two-circuit AC transmission is predicted to cost 250 USD/km (each), whereas AC substations and arrangement remuneration (over 600 km) are estimated to cost 80 MUSD apiece.. The 250 USD/km cost of the bipolar OH line was acceptable; converter stations are valued at 250 MUSD. [5]

In two separate studies, HVDC and high voltage AC transmission frameworks have been shown to have a strong association with each other, while an HVDC framework given VSC and an AC framework and an age source have also been found to have a strong correlation with each other.

High voltage AC versus thyristor based HVDC:

In comparison to high voltage AC substations, the cost of HVDC converter stations is significant. HVDC also reduces operating and support expenses. The HVDC framework has greater levels of introductory misfortune, but this does not change when the HVDC framework is removed. As shown in Fig. 2, a high voltage AC framework's misfortune levels rise with deletion, despite what one may suppose (6).

HVDC vs AC: Which one is better?

Short range parts of the power transmission range (many kilometres) may benefit from VSC HVDC-based frameworks. As shown in the following picture, the most feasible alternative to a high voltage AC framework is the VSC-based HVDC framework (7). [5]

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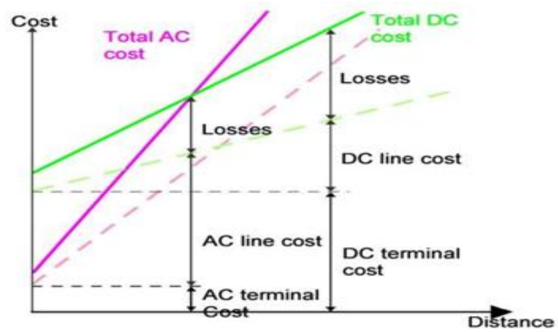
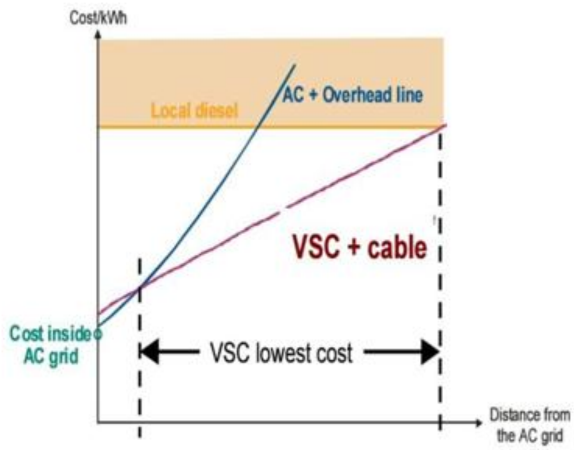


Fig(6): Thyristor based HVDC system [5]



Fig(7): VSC based HVDC system[5]

Overview Of HVDC Application:- Following Fig(8) is showing an outline of HVDC application.

	Long distance transmission over land	Long distance transmission over sea	Interconnections of asynchronous networks	Windmill connection to network	Feed of small isolated loads
Natural commutated HVDC with OH lines	x		x		
Natural commutated HVDC with sea cables		x	x		
Capacitor Commutated Converters (CCC) in Back-to-Back			x		
Capacitor Commutated Converters (CCC) with OH lines	x		x		
Capacitor Commutated Converters (CCC) with sea cables		x	x		
VSC Converters in Back-to-Back			x	x	
VSC Converters with Land or Sea Cables	x	x	x	x	x

Fig. (8).- Overview of HVDC Application [5]

3 types of HVDC frameworks are the most used in the industry. The operational necessities, demand adaptability, problem of consistent quality, and cost all play a role in determining each structure throughout the arranging stage. The following are some of the most well-known HVDC design diagrams. [15]

Monopolar

For the arrival of momentum, it uses land or the water and a single negative extremity driver. The metal back may also be used in rare circumstances. Two converters are placed at the end of

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each post in this configuration. At 15 and 55 kilometres from the terminal stations, anodes are used to anchor shafts to their respective foundations. This link, however, has a few drawbacks since it relies on the earth as a return channel. In the modern world, the monopolar interface is not often utilised. In Fig. 3, the monopolar contact can be shown (9). [5]

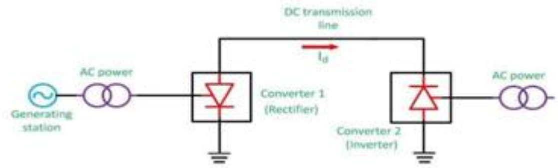

Fig.9.- Monopolar Link [3]

Bipolar link –

There are two conductors in a bipolar connection: one is positive for the earth and the other is negative. Both ends of the link are transformed by the connection. Anodes connect the converter stations to the ground at their midpoints. Only a small fraction of the conductor's power is sent via the field's voltage terminals, which are connected to it. If one of the connections in a bipolar connection fails, the connection proceeds toward Monopolar mode because of the arrival to ground. Framework. The remaining half of the building continues to provide energy. HVDC frameworks often use these kinds of connections. The bipolar connection may be seen in figure (10) [4].

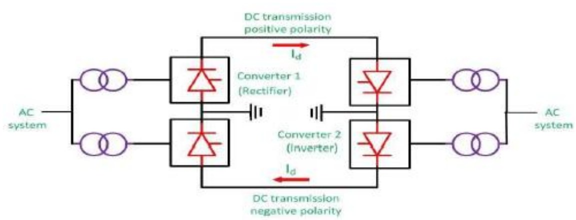

Fig.10- Bipolar Link [3]

Homopolar Link–

Conductors with comparable extremities, usually of the negative kind, are used in conjunction with mass or metallic returns. The cost of protection is reduced since the shafts operate in parallel in homopolar connection. This framework is currently not used. In Figure 11, homopolar security may be shown.

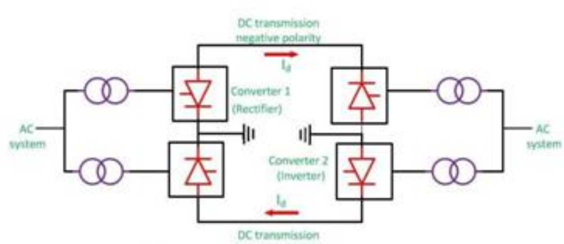

Fig.11- Homopolar Link [3]

Long-distance Transmission:-

High-voltage transmission is made possible by using this transmission method when distance between the two AC stations is greater than the initial outlay. Fig.12 shows the HVDC transmission system with a long spacing. [5]

Fig.12- Long Distance Transmission [3]

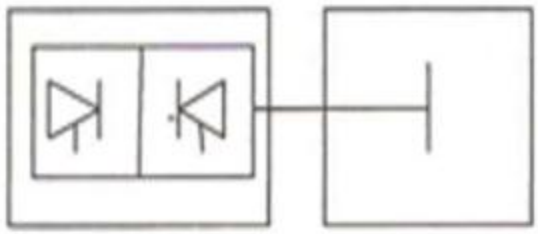

Fig.13-Back To Back Transmission [3]

Back to Back Transmission:-

When the voltage to be transferred is high and the two stations operate at different frequencies, this sort of transmission is linked. Consecutive Fig. 13 shows the HVDC transmission structure.

HVDC TRANSMISSION IN INDIA:_Following Fig.14 is showing HVDC Transmission Existing in India.[6][10]

HVDC Transmission Existing in India
Source: Central Electricity Authority of India

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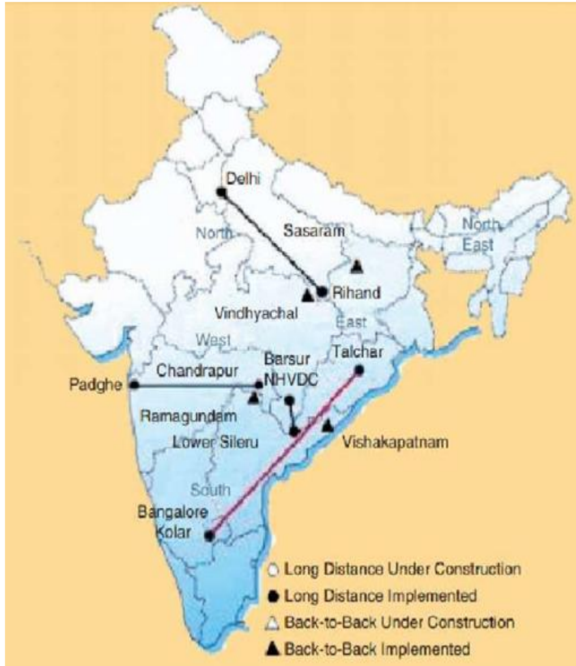

Electrical Authority of India).

a) Bipole line ±500 kV	Circuit kilometers
Chandrapur-Padghe (1999)	1,504
Rihand-Dadri (1990)	1,634
Talcher-Kolar (2002)	2,738
Balia-Bhiwadi (2009)	1,800
Biswanath-Agra (2014)	3,600
b) Bipole transmission capacity	MW
Chandrapur-Padghe (1999)	1,500
Rihand-Dadri (1990)	1,500
Talcher-Kolar (2002)	2,500
Balia-Bhiwadi (2009)	2,500
Biswanath-Agra (2014)	4,000
c) Back-to-back transmission capacity	MW
Vindhachal (1989)	500
Chandrapur (1999)	1,000
Gazuwake (2009)	1,000
Sasaram (2002)	500
Vizag (1990)	500
d) Monopole line Barsur-Lower Sileru (2000)—162 circuit kilometer	200
e) Monopole transmission capacity Barsur-Lower Sileru (2000)	200

Fig14.- HVDC Transmission In India [6]

(1) Dadri HVDC Project: Below Fig. 15 & Table 3 is showing details of this project.

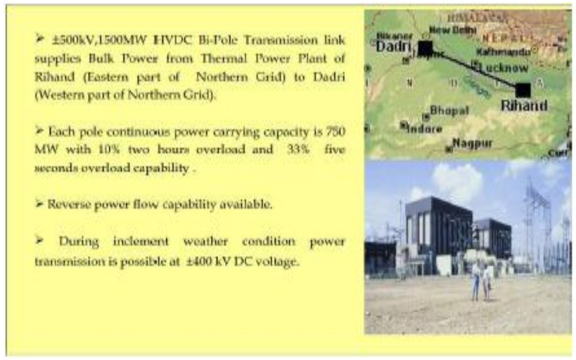

Fig.15.- Dadri-HVDC Bi-Pole Transmission Link [10]

Main Data:

a) Commisioning Date: Dec-1991
b) Rating: 1500 MW
c) Poles: 2
d) Voltage (AC) : 400 kV
e) Voltage (DC) : + 500 kV
f) Converter Transformer Rihand
g) Terminal: 6 x 315 MVA Dadri
h) Terminal : 6 x 305 MVA
i) Length of overhead HVDC line: 816 KM.

Table 3.- Dadri HVDC Project Details[6]

2) Vindhyachal Back to Back Station:

Table 4 is showing details of this project.

Main Data:

a) Project Completing Date: April 1989
b) Power rating : 2 x 250 MW.
c) Blocks : 2
d) Voltage (AC): 400 kV
e) Voltage (DC): ± 70 kV
f) Converter Transformer : 8 x 156 MVA

Table 4 - Vindhyachal Back to Back Station Project Details.[10]

3) Chandrapur Back to Back Station:

Main Data:

a) Starting date: November 1993
b) Completing period: Dec 1997
c) Power rating: 2 x 500 MW.
d) Blocks : 2
e) Voltage (AC) : 400 kV
f) Voltage (DC) : 205 kV
g) Converter Transformer : 12 x 234 MVA

Table 5 - Details of Chandrapur Back to Back Station Project Details.[10]

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4) Talchar – Kolar Transmission: -

The longest commercial HVDC link in India is Talchar-Kolar transmission, the distance around (1369 Km.). Table 6 is showing details of above project.
project:

System Salient Features:

Main Data:

a) Completing date: June 2003
b) Power rating : 2000 MW
c) Poles : 2
d) Voltage (AC): 400 kV
e) Voltage (DC): + 500 kV
f) Converter Transformer at Talcher : 6 x 398 MVA
g) Kolar : 6 x 398 MVA

Table 6.- Talchar-Kolar Transmission Project Details[10]
Project Details [10]

(5) Sasaram Back to Back Station:

It is located between Pusauli (Eastern Region) to Sasaram (Eastern part of Northern Grid) of Indian Grid (Power Transfer mainly from ER to NR). Table 7 is showing details of the above

Main Data:

a) Completing date: Sep 2002
b) Power rating: 1 x 500 MW.
c) Blocks : 1
d) Voltage (AC) : 400 kV
e) Voltage (DC) : 205 kV
f) Converter Transformer : 6 x 234 MVA

Table 7 - Details Of Sasaram Back to Back Station

6) Gazuwaka Back to Back Station:

This transmission line is connected between Jeypore (Eastern Region) to Gazuwaka (Southern Region) Thermal Power Stations of Indian Grid.
Following Table 8 is Showing details of this Project:-

Main Data:

a) Completing date: 1st Block: Feb 1999, 2nd Block: March 2005
b) Power rating: 2 x 500 MW.
c) Blocks : 2
d) Voltage (AC) : 400 kV
e) Voltage (DC) : 205 kV in 1st Block and
   i. 177 KV in 2nd Block,
f) Converter Transformer: 1st Block : 6 x 234 MVA
   1. 2nd Block: 6 x 201.2 MVA

Table 8.- Details of Gazuwaka Back to Back Station [10]

7) Ballia – Bhiwadi Transmission Link:
That transmission line is connected between Ballia (Eastern Part) and Bhiwandi (Northern Part).

Main Data:
Pole 1 Commissioned on 31-03 2010
Power rating: 2500 MW
Poles: 2
Voltage (AC) : 400 kV
Voltage (DC): + 500 kV
Length of Overhead HVDC transmission: 780 Km.
Converter Transformer at Ballia : 8 x 498 MVA
And at Bhiwadi 8 x

Table 9.- Details of Ballia – Bhiwadi Transmission Link Project [10]

Advantages of HVDC over AC transmission:

HVDC frameworks now combine the extensive knowledge of older systems with recently developed improvements and materials. In the end, the outcome is a highly targeted means of delivering electrical vitality that has a minimal environmental impact. Not only does an HVDC system carry electrical power from one location to the next, but it also includes a substantial amount of value that would have been difficult to grasp if it used a standard AC transmission technique.

The following are a few of these aspects:-

a) Because just two wires are required to transmit data, transmission costs are lower.
b) b. Reactive power does not exist. So, transmission losses are decreased..
c) c. Due to high voltage transmission, the same power current is reduced. I2R loss is thus quite low.
d) It is possible to utilise very thin conductors because DC transmission has no skin effect. Whereas in the case of HVAC transmission, thick conductors must be employed to eliminate the skin effect.
e) e. HVDC transmission lines may link two AC frameworks with different frequencies. HVAC transmission frameworks do not allow for this.
f) f. It is less expensive to install. With HVDC, there are just two wires and smaller towers needed.
g) In HVDC, electronic converters are used. HVAC, on the other hand, may be implemented far more quickly. As a result, the DC transmission architecture has significantly improved transient stability.
h) The HVDC framework's electrical control levels may be changed if problems arise (i.e., quick).
i) HVDC is preferred for control transmission across links because it does not need charging current and active power.

j) HVAC, in contrast to the HVDC transmission structure, activates body streams near the conductors.
k) k. In the protection of conduits, HVDC transmission has no difficulties with dielectric misfortune warming.
l) l. HVDC is the quietest and has the lowest radio and television impedance.
m) m. The voltage levels are changed in relation to the ground due to bipolar transmission.
n) n. DC connections are less costly than AC links for transmission.
o) The absence of charging and reverberation in HVDC leads to a high level of productivity.

HVDC's drawbacks as a means of transmission

- HVDC transmission necessitates a high cost of switching and changing sources. This means that low power supplies over short distances are not cost-effective.
- Controlling converters is a mind-boggling undertaking.
- An HVDC transmission architecture will need additional channels at various stages. As a result, there is an immediate high cost of entry. [7] [8]

The Electricity Industry's Use of HVDC Technology:-

HVDC transmission vs AC transmission is often a topic of discussion. In the past, HVDC was considered the best option for situations such as:

1. Long-distance transmission of broad measurements of intensity (>500 MW) was required;
2. Submerging a force in water;
3. In a nonconcurrent method, two AC's are linked together.
4. HVDC frameworks continue to be the most cost-effective and environmentally friendly option for the above-mentioned typical applications. HVDC frameworks, on the other hand, may be preferred over high-voltage AC frameworks in a variety of situations due to three distinct factors: innovation advancement, deregulation of the power sector around the world, and a quantum leap in efforts to moderate the Earth. I'll go into further detail about this:
5. For example, the VSC-based HVDC frameworks, and the new ejected polyethene DC connections, have enabled HVDC to become financially viable at bringing down power levels (up to 200 MW) and across a transmission distance of just 60 kilometres.

6. Different demands for the foundation of power have been hastened as a result of liberalisation. Today, transmission is a contractual service, and any divergence from the agreed-upon specifications or costs may have serious consequences. HVDC is the preferred method for legally binding transmission administrations because it provides greater control over the power interface.
7. Liberalism has sped the marvel of transferring power, which is bi-directional power swaps depending on economic circumstances. 7. The bi-directional power streams can only be enabled by HVDC frameworks, as opposed to AC frameworks (two parallel structures would be required).

8. Because establishing rights-of-way used to be easier under the old norm of "Famous Domain" (i.e. a state-owned, vertically organised utility), it used to be easier to secure the transmission benefit. The transmission benefit arrangement is generally in the region of corporatized, now and then privatised, substances with development of the transmission benefit arrangement. Land acquisition and right-of-way acquisition are currently significant expenditures for the project. In comparing HVDC vs. AC, these costs are added up and it becomes clear that HVDC is far more environmentally friendly since it uses less land/right-of-way to produce the same amount of power.
9. The reduced impression of HVDC transmission frameworks becomes the primary probable technique to manufacture a power connection in an environmentally sensitive place, for example, national pauses and assured asylums.
10. How should control framework organisers, investors in control foundation (both open and private), and agents of such foundation be directed in choosing between HVDC and high voltage AC elective? Allowing the "market" to decide is the proper course of action. When it's all said and done,
11. As an alternative to the practise of publishing specialised details (which are often unyielding and frequently incorporate more seasoned advancements and strategies) while accepting transmission framework proposals, the organisers, speculators and lenders should issue useful decisions for the transmission framework to qualified temporary workers.

12. For example, the power limit, separation, accessibility and unchanging quality requirements; and, finally, the ecological circumstances might be specified.
13. Bidders should be able to provide either an HVDC or AC solution, and the best option should be selected.
14. Many additional transmission projects may choose HVDC as a result of changes in power market circumstances, developments in mechanical technology, and environmental considerations. [9][11].

Conclusion

As far as the future of HVDC is concerned, we can only speculate. This can be done, but more contemporary and open spectra from the HVDC invention must be incorporated to get the most out of it for both the organisations and the general population. A few years from now, the neighbouring states will continue to cooperate with each other. It's also possible that additional new or existing large power plants may be linked to HVDC in the future (as observed today in India, China, Brazil...). Finally, I believe that the whole EU will be "interlaced" with HVDC lines, and then the next step will occur - an affiliation of these various lines into a single complicated framework. This is my greatest hope.

Is it possible that this will take place in the future? Then I have no clue what you're talking about. I am certain that the methods will be developed, despite the excruciating process that goes with almost every EU decision and arrangement, since there are issues that need to be addressed and HVDC control framework is one (and maybe the only) of the solutions.

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