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New Comparison of HVDC and HVAC Transmission System

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ABSTRACT

Alternating current (AC) is the main driving force in the industries and residential areas, but for the long transmission line (more than 400 miles) AC transmission is more expensive than that of direct current (DC). Technically, AC transmission line control is more complicated because of the frequency. DC transmission does not have these limitations, which has led to build long HVDC transmission lines over the last 40 years. HVDC technology made possible to transfer bulk power over long distances. This paper presents a comparative evaluation of HVDC and HVAC transmission systems .

Key Words—HVDC and HVAC transmission, Transmission cost, Environmental impact.

I. INTRODUCTION

Electric power transmission was originally developed with direct current. The availability of transformers and the development and improvement of induction motors at the beginning of the 20th Century, led to greater appeal and use of a.c. transmission. Through research and development in Sweden at Allmana Svenska Electriska Aktiebolaget (ASEA), an improved multi-electrode grid controlled mercury arc valve for high powers and voltages was developed from 1929. Experimental plants were set up in the 1930's in Sweden and the USA to investigate the use of mercury arc valves in conversion processes for transmission and frequency changing. D.c. transmission now became practical when long distances were to be covered or where cables were required. The increase in need for electricity after the Second World War stimulated research, particularly in Sweden and in Russia. In 1950, a 116 km experimental transmission line was commissioned from Moscow to Kasira at 200 kV. The first commercial HVDC line built in 1954 was a 98 km submarine cable with ground return between the island of Gotland and the Swedish mainland. Thyristors were applied to d.c. transmission in the late 1960's and solid state valves became a reality. In 1969, a contract for the Eel River d.c. link in Canada was awarded as the first application of sold state valves for HVDC transmission. Today, the highest functional d.c. voltage for d.c. transmission is +/- 600 kV for the 785 km transmission line of the Itaipu scheme in Brazil. transmission is now an integral part of the delivery of electricity in many countries throughout the world .

II. WHY USE DC TRANSMISSION?

The question is often asked, "Why use d.c. transmission?" One response is that losses are lower, but this is not correct. The level of losses is designed into a transmission system and is regulated by the size of conductor selected. D.c. and a.c. conductors, either as overhead transmission lines or submarine cables can have lower losses but at higher expense since the larger cross-sectional area will generally result in lower losses but cost more. When converters are used for d.c. transmission in preference to a.c. transmission, it is generally by economic choice driven by one of the following reasons:

I. An overhead d.c. transmission line with its towers can be designed to be less costly per unit of length than an equivalent a.c. line designed to transmit the same level of electric power. However the d.c. converter stations at each end are more costly than the terminating stations of an a.c. line and so there is a breakeven distance above which the total cost of d.c. transmission is less than its a.c. transmission alternative. The d.c. transmission line can have a lower visual profile than an equivalent a.c. line and so contributes to a lower environmental impact. There are other environmental advantages to a d.c. transmission line through the electric and magnetic fields being d.c. instead of ac.

II. If transmission is by submarine or underground cable, the breakeven distance is much less than overhead transmission. It is not practical to consider a.c. cable systems exceeding 50 km but d.c. cable transmission systems are in service whose length is in the hundreds of kilometers and even distances of 600 km or greater have been considered feasible.

III. Some a.c. electric power systems are not synchronized to neighboring networks even though their physical distances between them is quite small. This occurs in Japan where half the country is a 60 hz network and the other is a 50 hz system. It is physically impossible to connect the two together by direct a.c. methods in order to exchange electric power between them. However, if a d.c. converter station is locatedin each system with an interconnecting d.c. link between them, it is possible to transfer the required power flow even though the a.c. systems so connected remain.

III. COMPARISON OF A.C AND D.C TRANSMISSION

Alternating current (AC) became very familiar for the industrial and domestic uses, but still for the long transmission lines, AC has some limitations which has led to the use of DC transmission in some projects. The technical detail of HVDC transmission compare to high voltage AC (HVAC) transmission is discussed to verify HVDC transmission for long distances. . Current and voltage limits are the two important factors of the high voltage transmission line. The AC resistance of a conductor is higher than its DC resistance because of skin effect, and eventually loss is higher for AC transmission.

The switching surges are the serious transient over voltages for the high voltage transmission line, in the case of AC transmission the peak values are two or three times normal crest voltage but for DC transmission it is 1.7 times normal voltage. HVDC transmission has less corona and radio interference than that of HVAC transmission line. The total power loss due to corona is less than 5 MW for a ± 450 kV and 895 kilometers HVDC transmission line [3-4]. The long HVAC overhead lines produce and consume the reactive power, which is a serious problem. If the transmission line has a series inductance L and shunt capacitance C per unit of length and operating voltage V and current I, the reactive power produced by the line is :

$Q_c = wCV_2$ (1)

and consumers reactive power

$Q_L = wLI_2$ (2)

per unit length. If $Q_C = Q_L$

– –/ (3)

where is surge impedance of the line. The Z power in

= ( ) = Z

the line is

– (4)

is called natural load. So the power carried by the

and = V =

line depends on the operating voltage and the surge impedance of the line. Table I shows the typical values of a three phase overhead lines.

Tab.1 Voltage rating and power capacity

Voltage (kV)	132	230	345	500	700
Natural load (MW)	43	130	300	830	1600

The power flow in an AC system and the power transfer in a transmi sion line can be expressed

(5)

E_1 and E_2 are the two terminal voltages, δ is the phase

P = sin

difference of these voltages, and X is the series reactance.

Maximum power transfer occurs at δ= 90° and is

p

(6)

P_{max} is the steady-state stability limit. For a long

distance transmission system the line has the most of the reactance and very small part is in the two terminal systems, consisting of machines, transformers, and local lines. The inductive reactance of a single-circuit 60 Hz overhead line with single conductor is about 0.8 Ω/mi (0.5Ω/km); with double conductor is about 3/4 as greater.

The reactance of the line is proportional to the length of the line, and thus power per circuit of an operating voltage is limited by steady-state stability, which is inversely proportional to length of line.

For the reason of stability the load angle is kept at relatively low value under normal operating condition (about 30°) because power flow disturbances affect the load-angle very quickly. In an uncompensated line the phase angle varies with the distance when the line operating at natural load and puts a limit on the distance. For 30° phase angle the distance is 258 mi at 60 Hz. The line distance can be increased using series capacitor, whose reactance compensates a part of series inductive reactance of the line, but the maximum part that can be compensated has not been determined yet. On the other hand D.C transmission has no reactance problem, no stability problem, and hence no distance limitation.

IV. ADVANTAGES AND INHERENT PROBLEMS ASSOCIATED WITH HVDC

I) Advantages of HVDC

(a) More power can be transmitted per conductor per circuit

:

The capabilities of power transmission of an a.c. link and a d.c. link are different.

(b) Use of Ground Return Possible:

In the case of hvdc transmission, ground return (especially submarine crossing) may be used, as in the case of a monopolar d.c. link. Also the single circuit bipolar d.c. link is more reliable, than the corresponding a.c. link, as in the event of a fault on one conductor, the other conductor can continue to operate at reduced power with ground return. For the same length of transmission, the impedance of the ground path is much less for d.c. than for the corresponding a.c. because d.c. spreads over a much larger width and depth. In fact, in the case of d.c. the ground path resistance is almost entirely dependant on the earth electrode resistance at the two ends of the line, rather than on the line length. However it must be borne in mind that ground return has the following disadvantages. The ground currents cause electrolytic corrosion of buried metals, interfere with the operation of signalling and ships'ompasses, and can cause dangerous step and touch potentials.

(c) Smaller Tower Size

The d.c. insulation level for the same power transmission is likely to be lower than the corresponding a.c. level.Also the d.c. line will only need two conductors whereas three conductors (if not six to obtain th samereliability) are required for a.c. Thus both electricaland mechanical considerations dictate a smaller tower.

(d) Higher Capacity available for cables

In contrast to the overhead line, in the cable breakdown occurs by puncture and not by external flashover. Mainly due to the absence of ionic motion, the working stress of the d.c. cable insulation may be 3 to 4 times higher than under a.c. Also, the absence of continuous charging current in a d.c. cable permits higher active power transfer, especially over long lengths. (Charging current of the order of 6 A/km for 132 kV). Critical length at 132 kV ≈ 80 km for a.c cable. Beyond the critical length no power can be transmitted without series compensation in a.c. lines.

Thus derating which is required in a.c. cables, thus does not limit the length of transmission in d.c. A comparison made between d.c. and a.c. for the transmission of about 1550 MVA is as follows. Six number a.c. 275 kV cables, in two groups of 3 cables in horizontal formation, require a total trench width of 5.2 m, whereas for two number d.c. ±500 kV cables with the same capacity require only a trench width of about 0.7 m.

(e) No skin effect

Under a.c. conditions, the current is not uniformly distributed over the cross section of the conductor. The current density is higher in the outer region (skin effect) and result in under utilisation of the conductor crosssection. Skin effect under conditions of smooth d.c. is completely absent and hence there is a uniform current in the conductor, and the conductor metal is better utilised.

(f) Less corona and radio interference

Since corona loss increases with frequency (in fact it is known to be proportional to f+25), for a given conductor diameter and applied voltage, there is much lower corona loss and hence more importantly less radio interference with d.c. Due to this bundle conductors become unnecessary and hence give a substantial saving in line costs. [Tests have also shown that bundle conductors would anyway not offer a significant advantage for d.c as the lower reactance effect so beneficial for a.c is not applicable for d.c.]

(g) No Stability Problem

The d.c. link is an asynchronous link and hence any a.c. supplied through converters or d.c. generation do not have to be synchronised with the link. Hence the length of d.c. link is not governed by stability.

In a.c. links the phase angle between sending end and receiving end should not exceed 30o at full-load for transient stability (maximum theoretical steady state limit is 90°).

$$\theta = w\sqrt{l_c}\ per\ km = \frac{2\pi \times 50}{3\times 10^5}\frac{rad}{km} \times \frac{2 \times 180 \times 50}{3\times 10^5} \approx 0.06\,{}^{\circ}/km \quad (7)$$

The phase angle change at the natural load of a line is thus 0.6o per 10 km. The maximum permissible length without compensation ≈ 30/0.06 = 500 km With compensation, this length can be doubled to 1000 km.

(h) Asynchronous interconnection possible

With a.c. links, interconnections between power systems must be synchronous. Thus different frequency systems cannot be interconnected. Such systems can be easily interconnected through hvdc links. For different frequency interconnections both convertors can be confined to the same station. In addition, different power authorities may need to maintain different tolerances on their supplies, even though nominally of the same frequency. This option is not available with a.c. With d.c. there is no such problem. 188 High Voltage Engineering - J R Lucas, 2001

(i) Lower short circuit fault levels

When an a.c. transmission system is extended, the fault level of the whole system goes up, sometimes necessitating the expensive replacement of circuit breakers with those of higher fault levels. This problem can be overcome with hvdc as it does not contribute current to the a.c. short circuit beyond its rated current. In fact it is possible to operate a d.c. link in "parallel" with an a.c. link to limit the fault level on an expansion. In the event of a fault on the d.c line, after a momentary transient due to the discharge of the line capacitance, the current is limited by automatic grid control. Also the d.c. line does not draw excessive current from the a.c.

(j) Tie line power is easily controlled

In the case of an a.c. tie line, the power cannot be easily controlled between the two systems. With d.c. tie lines, the control is easily accomplished through grid control.

II) Inherent problems associated with hvdc

(a) Expensive convertors

Expensive Convertor 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 convertor the reactive power consumed may be as much at 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 convertor.

(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 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.

(g) Absence of overload capacity

Convertors have very little overload capacity unlike transformers.

V. ECONOMIC COMPARISON

B The hvdc system has a lower line cost per unit length as compared to an equally reliable a.c. system due to the lesser number of conductors and smaller tower size. However, the d.c. system needs two expensive convertor stations which may cost around two to three times the corresponding a.c. transformer stations. Thus hvdc transmission is not generally economical for short distances, unless other factors dictate otherwise. Economic considerations call for a certain minimum transmission distance (break-even distance) before hvdc can be considered competitive purely on cost. Estimates for the break even distance of overhead lines are around 500 km with a wide variation about this value depending on the magnitude of power transfer and the range of costs of lines and equipment. The breakeven distances are reducing with the progress made in the development of converting devices.

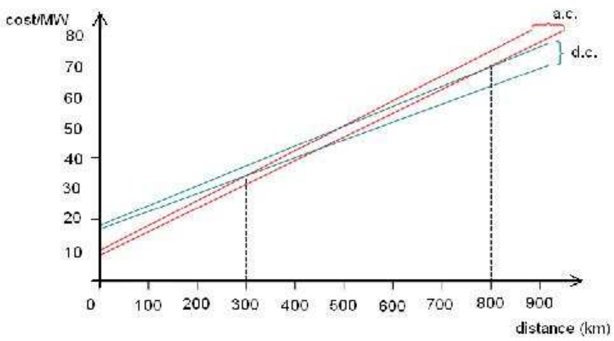

Fig.1. Break-even distance for d.c. transmission

Figure 1 shows the comparative costs of d.c. links and a.c. links with distance, assuming a cost variation of ± 5% for the a.c. link and a variation of ± 10% for the d.c. link. For cables, the break-even distance is much smaller than for overhead lines and is of the order of 25 km for submarine cables and 50 km for underground cables.

VI. ENVIRONMENTAL ASPECT

The purpose of the power transmission line is to carry energy from generation stations to urban or industrial places. To satisfy the growing need of the energy the transmission line capacity has been increased rapidly recent years, and this trend is continuing. The typical high voltage transmission line range is 400-1000 kV and this huge voltage has to cross all kinds of terrain - urban area, village, water, desert, and mountain. The effect of high voltage on the environment and human being is a topical and even controversial issue in recent year. This section discusses HVDC transmission effects on the

The magnetic field around a conductor depends on the current flowing through the conductor and the distance from the conductor. The magnetic flux density is inversely

proportional to the distance from the conductor. For ± 450 kV DC transmission line the flux density is about 25 μT, where the Earth's natural magnetic field is 40 μT [6].

B. Electric Field

Electric field is produced by the potential difference between the overhead conductor and the earth and the spacecharge clouds produced by conductor corona. Directly under the conductor has the highest electric field and is approximately 20 kV/m for a ± 450 kV transmission line [7]. The electric field may change with the weather, seasonal variation and relative humidity. DC has less electric field problem than that of AC because of the lack of steady-state displacement current; thus HVDC require much less right-ofway (ROW) than horizontal AC configuration and less height than the AC delta configuration of HVAC transmission of comparable rating [2]. The potential difference between land electrode and line conductor is termed as step voltage, can cause shock current. The typical human body resistance of 1000 ohms, a limit value of 5 mA current can flow through the human body safely and DC has the less electric current density, which is 70 nA/m2 for ± 450 kV transmission line [7].

C. Corona

Corona effects on the surface of high voltage overhead power transmission lines are the principal source of radiated noise. The ion and corona effects on the DC transmission lines lead to a small contribution of ozone production. The natural concentration of ozone in the clean air is approximately 50 ppb (parts per billion) and in the city area this value may reach 150 ppb. The limiting values for persons risk is around 180-

environment in the context of Nelson River transmission system. The common effects of high voltage transmission systems are magnetic fields, electric fields, RF interference,

corona effects, electromagnetic interference, electrodes

A. Magnetic Field

200 ppb. The HVDC overhead transmission line produces 10 ppb as compared with naturally occurring concentration [6].

D. Radio, Tv, And Telephone Interference

The switching process of the thyristor valves of the electronic converters causes fast current commutations and voltage changes, which produces parasitic current. The parasitic current and operational harmonic cause disturbances in the kilohertz and megahertz region of the radio-frequency spectrum [6]. These high frequencies propagate to the overhead line through the converter transformers. Radio interference radiation can be reduced by electromagnetic shielding of the valve hall. The radio-interference level of an HVDC overhead transmission line

is lower than that of HVAC overhead transmission line.

For the HVDC it is 40 dB (μV/m) for 0.5 MHz, 300 meter

from the conductor, for the 380 kV HVAC overhead transmission line the value is 50 dB (μV/m) [2]. The fair

weather corona-generated line radio interference is about 35 dB at 30 m and 40 dB at 15 m from the outer conductor at ± 450 kV [7]. The power line carrier frequency interference can occur at the frequency band 30-400 kHz. The thyristor operation produces the harmonics, and this harmonic current induces potentials in the lines as results of their electromagnetic fields. These potentials can

interfere with the telecommunication systems electrically and magnetically. This interference can be reduced using appropriate filter circuits**.**

E. Acoustic Noise

The main sources of acoustic noise are the road and rail traffic, and very small portion come from the industrial plant like power plant. The subjective perceptions of acoustic noise nuisance are dependent on the amplitude, frequency and duration of the noise [6]. The accepted limit of the acoustic noise for the industrial plant depends on the local conditions but is generally between 35 and 45 dB (A). The HVDC transmission system contains numbers of subassemblies and components which cause noise. The transformer is the principle source of noise, and its noise mainly depends on the core flux density. The no load operational noises are 10 to 20 dB (A) higher than that of the rated load operation. With converter transformers, on the other hand the sum of all load noises is approximately 10 dB (A) higher than the no load noises, and the frequency content of the emitted noise is evenly spread over 300 to 3000 Hz. The noise can be controlled or reduced using high quality low noise equipments, enclosure of equipment to attenuate noise emission, shielding room or separating the noisy equipment by distance. For a typical HVDC station has a noise intensity of less than 10 dB(A) at a distance of 350 m [6-7]. The HVDC transmission line has less width for the right of-way compare to HVAC transmission line and hence, DC transmission has less visual impact. In general, from all environmental aspect, the audible noise could only be the limiting factor for HVDC line in meeting existing or future regulations.

VII. CONCLUSION

Long distances are technically unreachable by HVAC line without intermediate reactive compensations. The frequency and the intermediate reactive components cause stability problems in AC line. On the other hand HVDC transmission does not have the stability problem because of absence of the frequency, and thus, no distance limitation. The cost per unit length of a HVDC line lower than that of HVAC line of the same power capability and comparable reliability, but the cost of the terminal equipment of a HVDC line is much higher than that of the HVAC line. The breakeven distance of overhead lines between AC and DC line is range from 500 km (310 miles) to 800 km (497 miles). The HVDC has less effect on the human and the natural environment in general, which makes the HVDC friendlier to environment

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