Electric Power Systems Research 81 (2011) 1341–1348

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Conversion of AC distribution lines into DC lines to upgrade transmission capacity

D. Marene Larruskain*, Inmaculada Zamora, Oihane Abarrategui, Zaloa Aginako

Electrical Engineering Department, University of the Basque Country, Faculty of Technical Engineering of Bilbao, La Casilla 3, E-48012 Bilbao, Spain

A R T I C L E   I N F O

Article history:
Received 4 March 2010
Received in revised form 5 January 2011
Accepted 31 January 2011
Available online 9 March 2011

Keywords:
Conversion
Distribution
Direct current
Transmission capacity

A B S T R A C T

Nowadays it is difficult to find corridors for building new overhead lines in industrialized countries. In many cases it is simply impossible. For that reason, new solutions for the upgrading of existing overhead lines are required. The conversion of existing AC lines into DC lines represents an alternative to upgrading the power carrying capability for the existing rights of way (ROW). Thus, this paper presents a comparison between AC and DC technologies for power transmission and distribution. The underlying technology is reviewed and different conversions are analyzed, for simple and double circuit lines. Also, increased power carrying capability and loss reduction are studied. Finally, an example of the conversion of a 66 kV double circuit AC distribution line into a DC line is included.

1. Introduction

Power demand increases continuously each year and installed power must also grow to meet this demand. Moreover, this increasing bulk energy has to be transmitted to final customers. Nowadays, however, some electric lines are virtually saturated because they are reaching critical values of ampacity and sag. When the conductor temperature rise is excessive, sag can increase substantially and clearances to ground can reduce dangerously. Additionally, building a new line is difficult and takes a long time. As a result, it is necessary to look for alternatives for increasing the transmission capacity of existing overhead lines.

There are different methods for upgrading this transmission capacity. Traditional methods consist of increasing the line voltage and the number of conductors. But there are other options, such as increasing the current density, using high temperature low sag conductors (HTLS), employing high surge impedance loading technology (HSIL) or using AC lines to transmit DC power [1–5]. This paper analyzes the conversion of existing overhead AC lines into DC lines to upgrade the transmission capacity. This solution has been chosen because of the many interesting added values that high voltage direct current (HVDC) technology offers while upgrading the transmission capacity of the line.

The fast development of power electronics, based on new and powerful semiconductor devices, has led to innovative technologies, such as HVDC, which can be applied to transmission and distribution systems. HVDC technology has technical and economic benefits which represent an alternative to the application of AC systems. In addition, there are factors such as the liberalization of markets and the abovementioned upgrading of transmission capacity which create additional needs for the operation of power systems. Once again, HVDC technology offers advantages to meet these requirements.

The first commercial HVDC transmission link was built in 1954, between the Swedish mainland and the island of Gotland, with a rating of 20 MW, 200 A and 100 kV. From that moment on, many line commutated converter (LCC) links have been installed. For well over a decade, voltage sourced converter (VSC) technology has also been used.

In this paper, a review of the characteristics, advantages and disadvantages of HVDC technology is presented. This is followed by an analysis of the conversion of overhead AC distribution lines into DC. This analysis consists in general criteria for the conversions, increased power carrying capability and loss reduction. Finally, an example of the conversion of a 66 kV double circuit AC distribution line into a DC line is included.

2. HVDC technology

HVDC transmission systems are usually point-to-point configurations where a large amount of energy is transmitted between two regions. These systems convert electrical current from AC to DC at the transmitting end and from DC to AC at the receiving end. The two main options applied in this technology are presented below.

* Corresponding author. Tel.: +34 946014472; fax: +34 946014300.
E-mail addresses: marene.larruskain@ehu.es (D.M. Larruskain), inmaculada.zamora@ehu.es (I. Zamora), oihane.abarrategui@ehu.es (O. Abarrategui), zaloa.aginako@ehu.es (Z. Aginako).

0378-7796/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2011.01.020

2.1. LCC classical technology

HVDC traditional systems use line commutated converters. The principal device of these converters is the thyristor. The firing angle can be selected during the direct polarization of the device, but it is not possible to control the turn-off which is achieved when it is inversely polarized.

Considering LCC, it is possible to control active power, but reactive power is a function of active power. For this reason, large capacitor banks are needed. Additionally, operation of this converter requires sufficient short circuit power. Because of those characteristics, traditional converters cannot supply power to a system which has no local generation [6–8].

2.2. VSC technology

VSC technology is characterized by the utilization of IGBTs. These devices started to be used in HVDC technology in 1997 (Hellsjön, Sweden). IGBTs can control both the turn-on and turn-off, thus making the independent control of active and reactive power possible [6,9–11]. Moreover, they require a low energy control signal because of the MOSFET type gate insulation [12]. The control signal is usually obtained with a Pulse Width Modulation (PWM) technique, which consists in the generation and filtration of a high frequency signal, producing a signal at the desired frequency.

Some additional advantages, when compared with LCC, include: black-start capability, no need for short-circuit ratio and a smaller converter station size. The most significant disadvantages are increased losses of the converter station and the behavior of the system when DC faults appear. Also, voltage and power levels available nowadays are smaller than those of LCC systems.

Finally, it is important to point out that VSC is an emerging technology that is being developed continuously.

3. DC versus AC

The vast majority of power transmission lines use three phase alternating current. The reasons behind a choice of HVDC, instead of AC, to transmit power in a specific case, are often numerous and complex. As such, each individual transmission project displays its own set of reasons justifying the choice.

A comparison between AC and DC power lines is presented below. In this comparison, general characteristics, the increased power carrying capability that can be obtained when an existing AC line is used to transmit DC power and the fault performance of AC and DC lines are analyzed.

3.1. General characteristics

In this section, the main differences between AC and DC systems are reviewed. Thus, the most common reasons favoring HVDC are the following:

(1) Power losses. An optimized HVDC transmission circuit has lower losses than an AC circuit for the same transmitted power. However, losses in the converter stations and substations must, of course, to be added. Considering these aspects, it can be established that initial loss levels in HVDC systems are higher, whereas in high voltage AC systems these loss levels increase with distance.

(2) Investment cost. An HVDC transmission line costs less than an AC line for the same transmission capacity, and land acquisition costs are also lower. Moreover, the operation and maintenance costs are lower in the HVDC case. However, the terminal stations are more expensive for HVDC, due to the fact that they must perform the conversion from AC to DC and vice versa. Fig. 1 shows a relation between costs and losses in AC and DC transmission lines.

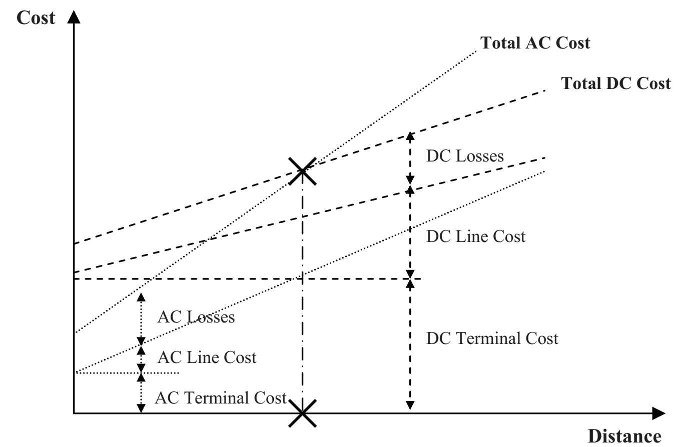

Fig. 1. HVAC vs. HVDC cost.

Furthermore, market tendency in recent years has shown that converter station costs are falling, whilst AC substation costs have been rising, therefore the difference between initial costs has been dropping.

As a result of the above conditions, above a certain transmission distance, the HVDC alternative will always give the lowest cost. This distance is called "break-even distance" and is marked with a cross in Fig. 1. This distance depends on several factors, such as transmission medium and different local aspects (permits, cost of local labor, etc.). Therefore, an analysis must be made for each individual case. Also, it can be said that this "break-even-distance" is much smaller for submarine cables (typically between 40 and 80 km) than for an overhead transmission line.

(3) Long distance water crossing. In a long AC transmission cable, the reactive power flow due to the large cable capacitance will limit the maximum transmission distance. With HVDC there is no such limitation. Thus, for long cable links, HVDC is the only feasible technical alternative.

(4) Asynchronous connection. Sometimes the connection of two AC networks is difficult or impossible due to stability reasons. In such cases, HVDC is the only option to make a possible power exchange between the two networks. There are also HVDC links between networks with different nominal frequencies (for example, Japan and South America).

(5) Controllability. One of the fundamental advantages with HVDC technology is that power controlling in the link is very easy.

(6) Short-circuit currents. An HVDC transmission line does not contribute to the short-circuit current of the interconnected AC system.

(7) Environment. The land coverage and the associated ROW cost for an HVDC overhead transmission line is not as high as for an AC line. For this reason, the visual impact of HVDC systems is lower. On the other hand, it is also possible to increase the power transmission capacity for the existing ROW. There are, however, some environmental issues which must be considered for the converter stations, such as: audible noise, visual impact, electromagnetic compatibility and use of ground or sea return path in monopolar operation [13].Taking into account all the reviewed characteristics, it can be concluded that HVDC technology can improve power transmission possibilities which contribute to a more efficient utilization of existing power plants.