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HVDC electricity transportation technology: feasibility study (Algeria)

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***Abstract*— HVDC technology is gradually becoming a standard in electrical energy transportation. Even more, in some situations it's the best practical solution. The research work presented hereafter is dedicated to the exploration of the basic notions, the induced gains, the basic components, the basic and extended structures, the applications and the real implemented projects of such technology. An overview on the research works concerned by the challenges of this expandable technology and an economic study of the deployment of real electrical transportation lines and their feasibility in Algeria are presented.**

Keywords—HVDC, Electrical power transportation, LCC, VSC, valve

I. INTRODUCTION

Since the use of electricity as a source of domestic energy, distribution and transport are major concerns for energy companies.

HVDC (high voltage direct current) technology can operate and transport electricity over long distances with minimal loss. HVDC electrical cable networks are deploying faster and faster between countries. Economically, this solution can quickly become a very attractive alternative to HVAC transport over long distances (beyond 500 km) and for large powers (beyond 200 MW). Indeed, this electricity transport system has losses of around 3% per 1000 km [1]. In addition, a 1/2 gain in wiring can be obtained as well as a huge reduction in the cost of cable supports. It also happens that this type of electricity technology is most suitable for PV electricity since the latter is directly produced in continuous form [1][2].

Given that Algeria is a highly sunny country; which allows it to claim a very high production of clean PV energy which will far exceed its consumption and will thus become an exporter of this type of highly coveted energy. However, the sites for mass production of this type of energy are far to the south; which makes HVDC electricity transportation technology a suitable candidate for the case of our country and encourages its adoption.

Research in the HVDC field is very active and is mainly focused on electronic parts called boost converters, the exploitation of PV energy in HVDC form for everyday applications and of course the transport.

II. BASIC NOTIONS AND IMPORTANCE

Since HVDC is not a new technology, it took advantage from several decades of research works, laboratory experimentations and real projects deployment. In the following subsections we will the essential basis of this technology.

A. Basic notions on HVDC

The old competition between AC and DC electricity operating forms has primarily turned in favor of the AC. For long decades, AC electricity dominated the market especially for electricity usage in production, transport, distribution and consumption. However, researches and applications on DC electricity continued actively exploiting the developments in materials science, semiconductor technology and control theory and their applications. Significant developments brought HVDC technology comeback on the scene of the electricity transportation. This comeback was aided by 4 general advantages versatile the AC configuration namely [3];

- Lower investment and lower losses for bulk power transmission
- Possibility to realize interconnections between Asynchronous grids
- Possibility of use to improve transmission in parallel AC circuits
- Better controllability since it permits an instant and precise power flow control
- For an equivalent ROW, DC provides 3 times more power than AC.

Moreover, advanced HVDC configurations permit also more advantages namely;

- More adaptability for underground and submarine cables realization
- Costs are close to overhead lines
- Possibility to connect passive loads
- Useful for enhancement of connected AC networks
- Active and reactive power are controlled independently

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- Short delivery times for comparable projects with AC ones.

B. HVDC projects' deployment :

HVDC electrical power transport had been exploited since the middle of the past century. Hereafter is a graphical HVDC projects' deployment in the different part of the world.

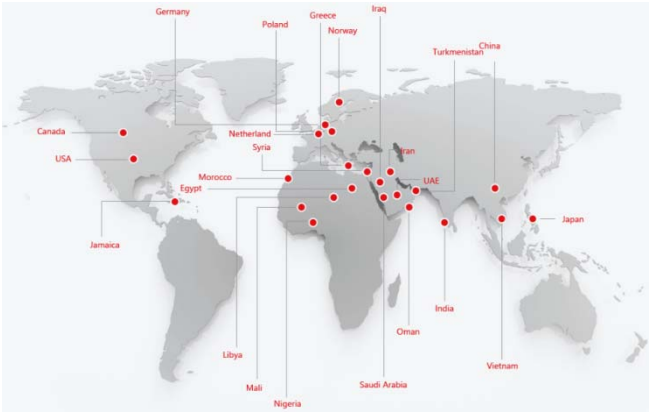

Figure 1: World's projects deployment of HVDC electrical power transmission

Despite the fact that HVAC technology is by far the most widely used in different electrical process such as production stations, electrical line transmission, distribution and industrial and domestic consumption; HVDC technology is in full expansion and is starting to conquer some terrain like electricity production through the widely spread of PV plants and electricity transportation especially on longue distances which has been favored by the trend of the globalization of the electricity transportation [4][5].

For Algeria, HVAC technology is exclusively used. the availability of petroleum fuel resources had pushed the exclusive producer of electricity (SONELGAZ) to create production stations close to the consumer and therefore the transport of electricity is limited to short distances [6].

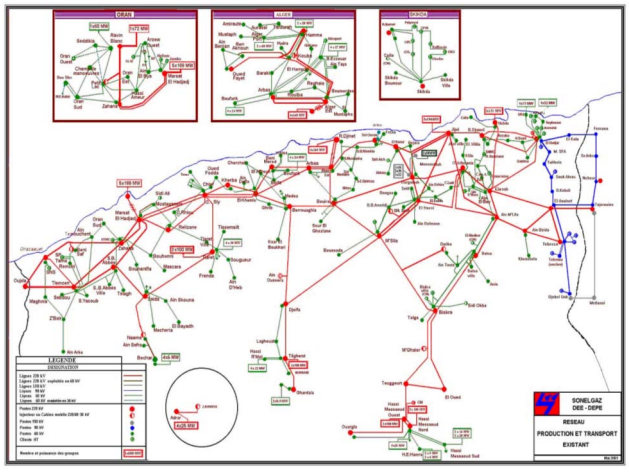

Figure 2: Algerian electricity production and transmission network deployment

The figure 2 gives an overview of the topology of the electricity production stations and transmission lines of the Algerian network deployment. Red and blue circles determine the production stations with different power's production and the red and blue lines determine the transmission lines with different powers and voltages [7][8].

However, new development trends tend to change the course of this industry. The following Algerian specificities could drive such a trend:

- Emergence of so-called renewable and especially photovoltaic electricity production technologies.

- Algeria has enormous photovoltaic potential

- The largest solar deposits are far to the south (the Sahara)

- The large area of the country (more than 2.3 Million Km^2)

- Algerian economic strategy plan could be to become a major exporter of renewable electricity, especially to Europe

Technologists, economists, and even politicians are all aware of energy issues in the coming decades. Renewable energies became not only a trend subject of discussions for different interested actors in Algeria but a real challenge that has to be met. The Algerian electricity and gas company (SONELGAZ), exclusive producer and distributor of electricity in Algeria, had already taken a practical step by creating a subsidiary which deals with the production of renewable electricity. Plans and schedules are ongoing to attain important renewable electrical power production not only for local consumption but also exportation. However, important production stations will be spread far to the south where the most important irradiation rates are recorded. To support this trend, HVDC technology could be deployed according to economical and environmental studies.

III. Environmental and Econlomical Aspects

Many solutions are found to protect the environment and meet this growing energy demand such as offshore wind and solar energy in deserts and at the same time these types of energy are clean and they are also adapted to our environment. But these sources of energy are located in areas far removed from cities and the transmission of enormous electrical energy is carried out over long distances. To solve this problem, the use of HVDC technology is one of the solutions that can help to provide power from these areas. Therefore, new trends to attain a more sustainable world will give the HVDC technology an important role in this way of developments. In addition, the new HVDC technology enhancements like VSC and MTC technologies appear to be economically good alternatives for the future extensions of the transmission networks across the planet.

Power transmission efficiency, economical benefits, technical concerns and environmental issues are the main supports of the HVDC technology.

A. Environmental adventages of HVDC

- Visual impact and space requirements:

The efficiency of HVDC transportation technology permits more efficient exploitation of existing standard power plants and even new renewable energy ones. This fact will lead to minimize power losses and to improve earth's exploitation resources which are important parameters to measure the environmental-friendly of any technology [9].

In HVAC electrical power transportation, the over-head transportation trough cables and tower's is the main mean which is used at 90% of cases since it's technologically and economically the most efficient mean. HVDC technology offers more alternatives. In HVDC transportation technology the three known transportation means; namely over-head, underground and underwater; could be used alternatively according to environmental topographical characteristics. For over-head transportation mean the tower's visual impact is therefore reduced to only converter stations comparatively to the case of HVAC [9] [10].

From the point of view of visual impact and for a comparable power transmission capacity, HVDC overhead transmission lines have less intrusive environmental effect. Example given could be the case of Bipolar HVDC transmission lines which have two conductors and already because of that are simpler in design in comparison with the three-phase structure of a HVAC line of the same capacity and comparable voltage levels. In this case, shorter tower heights are used for HVDC technology which affects environmental and economical parameters [11].

Another exemplar case would be the case when quadric-polar HVDC lines are used for power transmission. Here, flat towers or towers with two cross-arms, according to transmission corridor's conditions, will be used. For a ±500 kV HVDC transmission line, Figure 2 gives schematic views of these tower types. Approximate tower dimensions are indicated. According to the specificities of the constructed transmission line, a choice of tower design would be done. However, for any case, the dimensions of the towers for the HVDC quadric-polar line are smaller than those used for a double-circuit HVAC line with comparable capacity [11]. Moreover, the width of corridors opened for the electrical line transmission are consequently reduced (about 1/3) in case of HVDC technology compared to HVAC one.

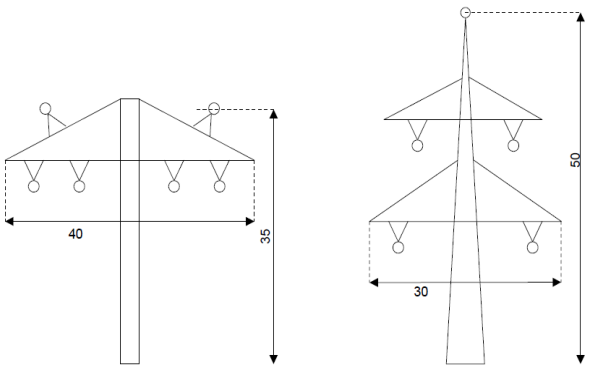

Figure 3 : Schematic of two tower's variants (flat and two cross-arms) used for ±500 kV quadric-polar HVDC transmission line

Moreover, HVDC technology offers superior performances and capabilities when using underground or underwater connections. For underground connections, they will be considered as exclusive for HVDC since for HVAC they will require large tranches to avoid interactivity between the three phase's cables. In the case of HVDC, tranches about only 50cm to 80cm large and 1m to 1.5m of deepness are sufficient to contain bipolar electrical transmission line with a power transmission of about 1200 MW. According to an environmental point of view, narrow tranches are the friendliest means for such transmission lines.

In the case of submarine transmission lines and over a 150 Km, the use of HVDC technology becomes inevitable. Studies demonstrate no consequent effects of established submarine transmission lines on submarine's life. Furthermore, installed cables do not need any maintenance or servicing operations during their lifetime (except in force majeure cases) which permits their integration to their surrounding environment.

- Electric and magnetic fields:

A well known physical effects produced by conducting electricity in cables are electric and magnetic fields. These two effects were well studied and efficiently measured. For an HVDC over-head transmission line, for example, the electric field is due to firstly the potential difference between the electrical conductor and the earth and secondly to the space charge clouds that are due to Corona effect in the conductor [12].

As a natural effect, the Electrostatic fields are spread through the global atmosphere but they became stronger around electrical conductors. As this, human bodies are adapted to this type of physical effects but when they still at acceptable natural ranges. However, out of natural ranges values, they will become an ecological and even biological concern for human beings like possible shock hazards [13]. Combination of the electrostatic field and the space charge field creates the electrical field generated by an HVDC transportation line. Fortunately and in the way, the conductors of the HVDC transmission line in corona generate ions of the same polarity as the conductor itself which are drifted either to the ground or to a conductor of opposite polarity.

Measurements of the electrical field distribution at ground level under HVDC electrical line transmission demonstrate that it depends on the distribution of space charges between the conductors and the ground. The presence of space charge with the same polarity as the conductor increases the electrical field at the ground level but those with opposite polarity decreases it [13]. This fact, encourages the use of bipolar and even quadric-polar HVDC line transmissions instead of mono-polar ones since the presence of conductors of opposite polarities will decreases the global density of the electrical field at the ground level.

In the same way and for environmental and biological concerns for the human body, the magnetic field associated with an HVDC transmission line was studied. Studies demonstrate that magnetic field had no noticeable effects on the human body. In a counterpart, this physical phenomenon has important influences on certain types of human machines. The well known case is the disturbances that were measured for the

magnetic compass systems mounted on vessels when they became close to an undersea HVDC transmission line [9][10].

TABLE 1: EXAMPLES OF NATURAL AND ARTIFICIAL SOURCES OF ELECTRIC AND MAGNETIC FIELDS.

	NATURAL SOURCES	ARTIFICIAL SOURCES
ELECTRIC FIELDS	Static electricity Charges built-up in thunderstorm clouds	Electrified railways Televisions with cathode ray tubes
MAGNETIC FIELDS	The Earth	Mobile telephony Battery-powered appliances MRI machines Electrified railways

- Radio/TV interference:

Here also for radio interference caused by electric power transmission lines, HVDC technology still preferred to HVAC technology. This is due to the fact that for HVDC conductors the result of the corona discharge around them is generated only by conductors of positive polarity hence they are those who generate radio interferences. This encourages the use of bipolar and even quadric-polar HVDC transmission lines which permits an important increase of the transported power without increasing interferences. This could not be applied to HVAC transmission technology since all the transmission conductors are sources of interferences and increasing the number of conductors would imperatively increase these interferences.

Radio frequency perturbations produced by electrical transmission conductors are also subject to weather conditions. Indeed, rainy weather affects the HVDC and HVAC transmission conductors differently since it causes an increase of about 10 dB of radio interference generated by conductors of an HVAC line transmission. However, for conductors of an HVDC line the radio interference decreases considerably under condition of providing a surface voltage gradient of 25kV/cm.

In normal conditions and for an equal capacity transportation of conductors and maximum levels of electrical field intensity on their surfaces, the radio interference level of HVDC lines is typically lower by 6-8 dB than of HVAC lines [11].

However, for HVDC transmission line, converters' switching modes cause disturbances in the kHz and MHz regions of interference. The main solution to this problem was the introduction of an appropriate shielding of valves which minimizes the amount of these disturbances and makes the radio interference of the HVDC line comparable with AC solutions [14].

- Audible noise:

Audible noise is an easily perceptible problem by each human body. Thus it's with great concern that designers of electrical transmission lines deal with the control parameters of such a problem for both overhead lines and substations. However, used means to decrease audible noise of these electrical sources are quite costly. As a standard rule, the audible noise from transmission lines should not exceed, in residential areas, 50 dB during the day, or 40 dB at night.

For HVDC systems, the principal sources of audible noises are the substations and the transmission conductors. The substations contain converter-transformers which are the main sources of audible noises. These devices are generally surrounded by screens which provide an efficient limitation of the noise levels that outgo the substations and pollute the environment. On the other side, the transmission lines produce broadband noises which pollute noises extent to high frequencies. Electrical line transmission noise is most prevalent in fair weather. Audible noise levels produced by conductors of HVDC line usually decrease during foul weather which is completely the opposite state for the AC transmission lines for which it increases considerably.

In the case of underground and submarine HVDC transmission lines, no audible noise is perceptible. The main issue rises for the over-head transmission lines during foggy weather.

Consequently, restrictions are imposed on the construction of buildings at the closest areas of a transmission lines and their substations. Studies and measurement demonstrate that audible noise is directly related to line's voltages levels, technical line's specifications and the climatic state of the regions crossed by the electrical transmission line [15].

B. Economical benefits of HVDC

Despite the notorious environmental effects already exposed, the practical implementation of any technological solution (HVDC in this case) is directly linked to the economic parameters and advantages it presents.

As it's depicted in Figure 3, the establishment of any electric transmission line, in HVDC or HVAC technology, induces costs mainly related to the materials used (cables, towers, electronics), to engineering works (actual installation) and to preparation works (civil works). Other expenses of lesser amounts are also expected including investigation work as well as insurance on the works and on the line.

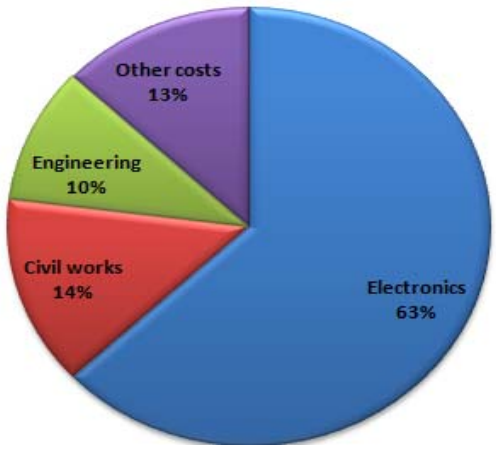

Figure 4: Distribution of Costs in percentage related to different types

We present hereafter economic comparatives between comparable transmission lines in HVDC and HVAC technologies.

- Used materials:

Electronics are the most applied costs in the installation of an electrical transmission line (about 63%). Compared to terminal stations of an HVAC connection, terminal converter stations on the two ends of an HVDC electrical transmission line costs much more. However, HVAC connections on long distances increase mutual inductances and capacitances that are related to the nature of the alternative current. These two phenomenons added to losses on the long distances line impose the construction of intermediate switching stations for voltages levels maintain and reactive power compensation. Figure 5, gives an approximate partition of the line cost between the terminal stations' expenses and the rest of the realization works for both HVDC and HVAC technologies [16].

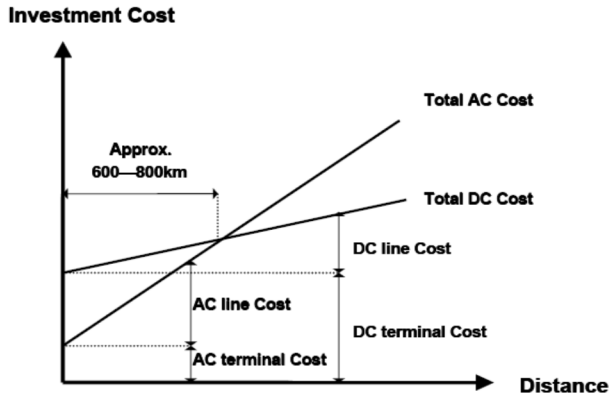

Figure 5: Partition of line cost between terminal stations realization and other works for both HVDC and HVAC technologies

HVDC transmission lines installation requires that technical staff has to be more specialized since on one hand the electronics technologies involved in this type of installation are the newest and on another hand each new HVDC transmission line is characterized by each own specific technologies like for the types of cables, the valves configurations and so on. This involves more expenses compared to an HVAC transmission line which technologies have already attained its maturity long time ago. However, these supplementary costs are compensated by the reduced works that are required for an HVDC line compared to an HVAC one. Here also the "Break-even distance" has to be determined for a given electrical transmission line.

- Engineering civil works:

Civil works are an important part of the electrical transmission line realization. With an amount of about 14% of the global amount of the whole realization cost of the transmission line, civil works represents the second portion of expenses. Civil works encompass the route study and optimization, the installation of towers for over-head connections, the digging of tranches and their fitting out for underground parts of the line and even works on the seabed for underwater connections. The preliminary study determines the type of connection adapted to each type of terrain such as plains, plateaus, mountains, lakes and seas

The Figure 5 also demonstrates that by increasing the line connection distance, the advantage balance goes in favor of the HVDC connection technology [17]. What is exactly the distance from what we opt for HVDC technology depends on several parameters. This distance is called "Break-even distance".

Cables that are used for electricity transmission are also an important parameter that weights in balance. Indeed, HVDC technology uses much more technological developed cables which means much more expensive but fortunately, the quantity of cables for a comparable HVDC transmission line is reduced at least by the third compared to HVAC one. At the beginning of HVDC transmission line projects, mono polar connections were used. However, newly installed projects are using bipolar transmission lines since for same number cables we can double the transmitted power.

Towers that support cables have more reduced structure in HVDC transmission lines which makes them less high with less weight and consequently much cheaper than those used for HVAC technology [11].

- Engineering works:

Engineering works encompass all technical operations related to the installation of terminal converter stations, the passage of the cables and realization of the necessary tests and verification of the validity of the connection. It represents 10% of the total cost of the transmission line which is a lot.

The study of the overall cost of an electrical transmission line determines a comparison between realization costs using HVDC and HVAC technologies. A general rule called "Break-enev distance", illustrated on Figure 5, is often used to prevail one over the other [16].

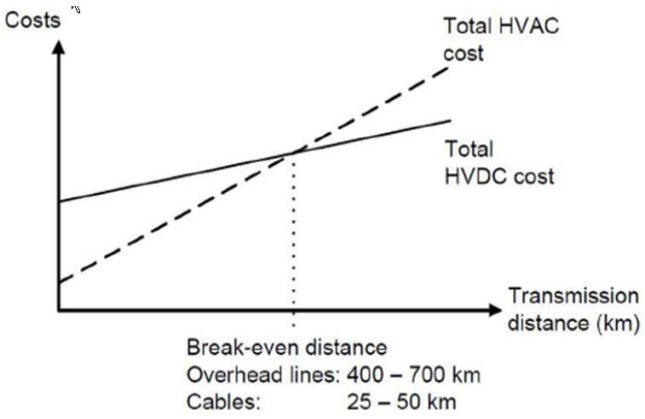

Figure 6: HVDC and HVAC electrical line costs according to the transmission distance

In addition to economical reasons, technical ones are also important to make balance between HVDC and HVAC technologies. Indeed, HVDC technology is well known for providing a practical stability improvement of the network and could make connection between HVAC networks with different operating frequencies.

IV. CONCLUSION

HVDC electrical transmission technology is gradually replacing HVAC one for long distances over-head transmission lines, underground connections and submarine electrical lines. HVDC Power transmission efficiency and better controllability are no longer to be demonstrated. Moreover, HVDC technology seems to be more adapted to new trends of renewable energy production technologies especially photovoltaic plants and offshore wind farms.

Algeria is an over-sunny country that tends to develop new industrial renewable energy plants especially photovoltaic ones not only for local consumption but for electricity exportation also. However, these stations are planned to be spread far to the south which makes HVDC technology the best candidate for the transmission of produced electricity towards the north where are the main industrial poles and the most populated regions for local consumption and also far to the north for an eventual electricity exportation to the European countries. However, deeper economic and environmental studies have to be conducted for eventual specific projects that could be planned.

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