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High Voltage Direct Current, a Novel Technical Applied in Transmission Systems

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ABSTRACT :*reactive power to keep its integrity. This control may lead to a system collapse that is becoming ever more complex. Global electricity transmission infrastructure relies on a mix of HVAC (High Voltage Alternating Current) and HVDC (High Voltage Direct Current) technologies to support an increasingly interconnected transmission grid; HVDC is all about making existing power grids efficient. In a world consumed by cost-cutting yet obliged to improve environmental impact, HVDC is the answer to one of the biggest challenges faced by energy managers: move more power, more efficiently, with the lowest losses possible, this technology uses direct current for the bulk transmission of electrical power, in contrast with the more common alternating current systems. For long-distance transmission, HVDC systems may be less expensive and suffer lower electrical losses. This paper presents a study of a HVDC project which helps technical and economic advantages compared by HVAC system. This study has an objective applied in future electricity in Africa and specifically in Algeria. The proposal of HVDC system is chosen because of the tension transmitted which is 400kV and the transmission distance is over 800km desert full of obstacles.*

KEYWORDS*: HVDC, transmission cost, DC current, transient power, EP in HV*

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I. INTRODUCTION

Demand for reliable supply of electricity is growing, increasing the need for a higher level of system reliability. The electrical power is generated as an alternating current (AC). It is also transmitted and distributed as AC and, apart from certain traction and industrial drives and processes; it is consumed as AC [1]. The electricity networks of today increasingly need control and stability at high levels of loading. Increasing the stability through adding more lines is not always an option due to restrictions in right-of-way or limits to acceptable short circuit current [2].

The development of electric power industry follows closely the increase of the demand on electrical energy. In the last years of power system developments this increase was extremely fast, also in industrialized countries. Fast development and further extension of power systems can therefore be expected mainly in the areas of developing and emerging countries [3].

The transmission of electric energy over long distances by high voltage AC overhead transmission lines is limited by the inductance of the line. Above a certain length, the magnitude of which depends on the geometry of the system and its voltage, the voltage drop across the inductive impedance reaches a value which makes the system ineffective [4]. However, because of a lack on available investments, the development of transmission systems in these countries does not follow the increase in power demand. Hence, there is a gap between transmission capacity and actual power demand, which leads to technical problems in the overloaded transmission systems. Interconnection of separated grids in the developed countries can solve some of these problems, however, when the interconnections are heavily loaded due to an increasing power exchange, the reliability and availability of the transmission will be reduced [3]. The security of power supply in terms of reliability and availability has the utmost priority when planning and extending power grids. The aspect of sustainability is gradually gaining in importance in view of such challenges as global climate protection and economical use of dwindling power resources. In many circumstances, however, it is economically and technically advantageous to introduce direct current (DC) links into the electrical supply system.

In particular situations, it may be the only feasible method of power transmission. Electric power transmission was originally developed with direct current. HVDC transmission system technology has the advantage of being able to almost instantly change its working point within its capability curve and to increase the efficiency of overhead power lines. This can be used to support the grid with the best mixture of active and reactive power during stressed conditions. HVDC has characteristics that render it attractive for transmission applications where it include independent control of active and reactive power, operation against isolated A.C networks with no generation of their own, very limited need of filters and no need of transformers for the conversion process.

The HVDC transmission has become a mature and well accepted technology suitable to transmitting bulk power over extremely long distances. Trendsetting and innovative solutions of HVDC offer an excellent opportunity to support and improve the power supply of sustainable, efficient and reliable future grids. The researches of technologies of HVDC systems offers expertise and long-term experience in helping to ensure stable power supply with a high degree of green energy wherever it is needed. HVDC system is a highly efficient alternative for transmitting large amounts of electricity over long distances and for special purpose applications to reduce or completely avoid the inductive current and to increase the efficiency of an overhead line.

HVDC system transmission has revolutionized the existing power system. The biggest advantage being ease of long distance and bulk power transmission, it has facilitated the transmission of electricity from power rich states to power deficit states which coincidentally happen to be economically poor and economically rich respectively [5]. As a key enabler in the future energy system based on renewable, HVDC is truly shaping the grid of the future.

Advancements in power electronics are making HVDC transmission systems more and more attractive and reliable. Specifically, the development of semiconductors and control equipment is presently very rapid and it is evident that this technology will play an important role in the future expansion of electric transmission and distribution systems. Thus, the HVDC installations has several advantages such as, independent control of active and reactive power, dynamic voltage support at the converter bus for enhancing stability possibility to feed to weak AC systems or even passive loads, reversal of power without changing the polarity of DC voltage and no requirement of fast communication between the two converter stations.

The final transmission solution in this study will have to be supported on technical and economic studies. Network planning studies have been undertaken to determine the most relevant HVDC parameters. Reliability studies have been conducted to assess the most likely performance of the link. Economic studies were developed to determine the minimum cost solution. Such a solution must fulfil environmental, economic and technical constrains.

II. DESCRIPTION OF HVDC SYSTEMS

Simple representation of a HVDC interconnection is shown in Figure 1. AC power is fed to a converter operating as a rectifier. The output of this rectifier is DC power, which is independent of the AC supply frequency and phase. The DC power is transmitted through a conduction medium; be it an overhead line, a cable or a short length of bus-bar and applied to the DC terminals of a second converter. This second converter is operated as a line-commutated inverter and allows the DC power to flow into the receiving AC network.

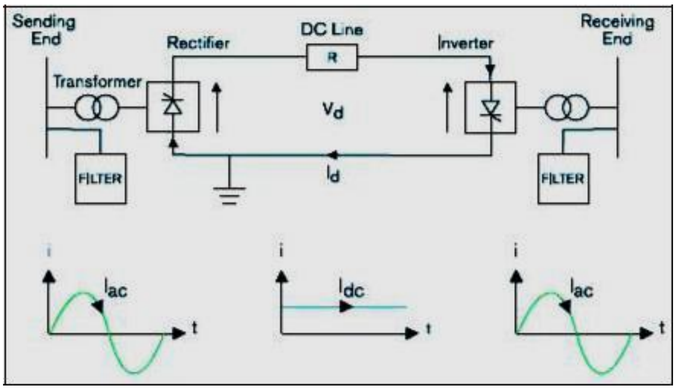

Fig.1. Data-logger unit for monitoring solar PV plants

The AC system connects to a HVDC converter station via a “converter bus”, which is simply the AC busbar to which the converter is connected. The AC connection(s), the HVDC connection(s) along with connections to AC harmonic filters and other possible loads such as auxiliary supply transformer, additional reactive power equipment, etc., can be arranged in several ways normally dictated by: reliability/redundancy requirements, protection and metering requirements, the number of separately switchable converters and local practice in AC substation design. [1]

The converter station includes shunt connected switchable AC harmonic filters to limit the impact of these AC harmonic currents and the absorbed reactive power.

The AC harmonic filters are automatically switched-on and off with conventional AC circuit breakers when they are needed to meet harmonic performance and reactive power performance limits. The AC harmonic filters are typically composed of a high voltage connected capacitor bank in series with a medium voltage circuit comprising air-cored air-insulated reactors, resistors and capacitor banks. These components are selected to provide the required performance from the AC harmonic filter and to ensure that the filter is adequately rated.

The converter transformer is the interface between the AC system and the thyristor valves. Typically the HVDC converter transformer is subjected to a DC voltage insulation stress as well as the AC voltage stress normally experienced by a power transformer. In addition, it is important that the converter transformer be thermally designed to take into consideration both the fundamental frequency load and the AC harmonic currents that will flow from the converter through the converter transformer to the AC harmonic filters. Typically, the converter transformer is arranged as an earthed star-line winding and a floating-star and delta secondary windings. There is normally an on-load tap changer on the line winding.

III. TECHNICAL COMPARISON

The capabilities of power transmission of an AC link and a DC link are different. For the same insulation, the direct voltage Vd is equal to the peak value of the alternating voltage Va.

$$V_d = \sqrt{2}\ V_a \tag{1}$$

For the same conductor size, the same current can transmit with both DC and AC if skin effect is not considered.

$$I_d = I_a \tag{2}$$

Thus the corresponding power transmission using 2 conductors with DC and three conductors with AC according three phases (a, b and c) and each phase can use 1, 2, 3 or 4 conductor cables, called beams. So, the power transmission in DC and AC are as follows.

DC power per conductor:

$$P_d = V_d \cdot I_d \tag{3}$$

AC power per conductor:

$$P_d = V_d \cdot I_d \cdot cos\varphi \tag{4}$$

The greater power transmission with DC over AC is given by the ratio of powers.

$$\frac{P_d}{P_a} = \frac{V_d I_d}{V_a I_a cos\varphi} = \frac{\sqrt{2}}{cos\varphi} \tag{5}$$

In practice, AC transmission is carried out using either single circuit or double circuit 3 phase transmission using 3 or 6 conductors. In such a case the above ratio for power must be multiplied by 2/3 or by 4/3.

In general, we are interested in transmitting a given quantity of power at a given insulation level, at a given efficiency of transmission. Thus for the same power transmitted P, same losses PL and same peak voltage V, we can determine the reduction of conductor cross-section Ad over Aa.

Let Rd and Ra be the corresponding values of conductor resistance for DC and AC respectively, neglecting skin resistance.

The DC current is given by:

$$I_d = \frac{P_d}{V_d} \tag{6}$$

The losses power in DC link is:

$$P_L = I_d^2 R_d = \left(\frac{P_d}{V_d}\right)^2 R_d = \left(\frac{P_d}{V_d}\right)^2 \left(\frac{\rho l}{A_d}\right) \tag{7}$$

So, the AC current is given by:

$$I_a = \frac{P_a}{(V_a/\sqrt{2})cos\varphi} = \frac{P_a\sqrt{2}}{V_a cos\varphi} \tag{8}$$

The losses power in AC link is:

$$P_a = \left(\frac{\sqrt{2}P_a}{V_a cos\varphi}\right)^2 R_a = 2\left(\frac{P_a}{V_a}\right)^2 \left(\frac{\rho l}{A_a cos\varphi^2}\right) \tag{9}$$

Equating power loss for DC and AC

$$\left(\frac{P_a}{V_a}\right)^2 \left(\frac{\rho l}{A_a}\right) = 2\left(\frac{P_a}{V_a}\right)^2 \left(\frac{\rho l}{A_a cos\varphi^2}\right) \tag{10}$$

$$\frac{A_d}{A_a} = \frac{cos\varphi^2}{2} \tag{11}$$

The DC link is an asynchronous link and hence any AC supplied through converters or DC generations do not have to be synchronized with the link. Hence the length of DC link is not governed by stability. In DC links the phase angle between sending end and receiving end should not exceed 30° at full-load for transient stability (maximum theoretical steady state limit is 90°).

$$\theta = \omega\sqrt{I_c}\ per\ km = 0{,}08°/km \tag{12}$$

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

$$Q_C = \omega CV^2 \tag{13}$$

And consumers reactive power

$$Q_L = \omega LI^2 \tag{14}$$

Per unit length, if QC = QL

$$\frac{V}{I} = \left(\frac{L}{C}\right)^{1/2} = Z_l \tag{15}$$

Where Zl is surge impedance of the line. The power in the line is given by following equation and is called natural load.

$$P_l = VI = \frac{V^2}{Z_l} \tag{16}$$

So the power carried by the 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 [6].

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

$$P = \frac{E_1E_2}{X}sin\delta \tag{17}$$

E_1 and E_2 are the two terminal voltages, δ is the phase difference of these voltages, and X is the series reactance. Maximum power transfer occurs at δ = 90º and is

$$P_{max} = \frac{E_1E_2}{X} \tag{18}$$

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 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. [6]

Due to its fast controllability, a DC transmission has full control over transmitted power, an ability to enhance transient and dynamic stability in associated AC networks and can limit fault currents in the DC lines. Furthermore, DC transmission overcomes some of the following problems associated with AC transmission as stability limits, voltage control and line compensation [7].

With the DC option, since there are only two conductors, the power transmission losses are also reduced to about two-thirds of the comparable AC system. The absence of skin effect with DC is also beneficial in reducing power losses marginally, and the dielectric losses in case of power cables is also very much less for DC transmission.

Corona effects tend to be less significant on DC than for AC conductors. The other factors that influence line costs are the costs of compensation and terminal equipment. DC lines do not require reactive power compensation but the terminal equipment costs are increased due to the presence of converters and filters.

IV. Economic comparison

Bulk power could be transferred using HVDC or HVAC transmission system from a remote generating station to the load center [6]. The cost of transmission line comprises of the capital investment required for the actual infrastructure and cost incurred for operational requirements. The cost comparisons between AC and DC transmission should be taken into consideration all main systems elements.

Two different comparisons are needed to highlight the cost comparison between high voltage AC and HVDC systems, one is between thyristor based HVDC systems and a high voltage AC transmission system; and the other between a VSC based HVDC system; an AC system and a local generation source.

Figure 2 shows a typical cost comparison curve between AC and DC transmission considering:

- AC vs DC station terminal costs
- AC vs DC line costs
- AC vs DC capitalized value of losses

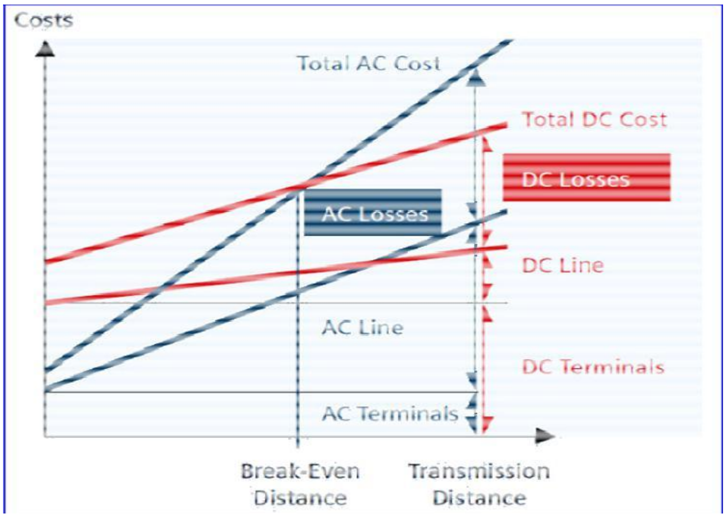

Fig.2. Total cost /distance

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.

AC tends to be more economical than DC for distances less than the 'breakeven distance' but is more expensive for longer distances. The breakeven distances can vary in the range of 500 to 800 km in over-headlines depending on a number of other factors, like country-specific cost elements, interest rates for project financing, loss evaluation, cost of right of way etc. With a cable system, this breakeven distance lies between, 25 to 50 km.

An overhead DC transmission line with its towers can be designed to be less costly per unit of length than an equivalent AC line designed to transmit the same amount of electric energy over the same (long) distance. However, the DC converter stations at each end are more costly than the terminal stations of an AC line and so there is a breakeven distance above which the total cost of DC transmission is less than its AC transmission alternative.

V. ENVIRONMENTAL COMPARISON

The purpose of the power transmission line is to carry energy from generation stations to urban or industrial places. The effect of high voltage on the environment and human being is a topical and even controversial issue in recent year. The environment impact of a DC transmission line is considerably lower than for an equivalent AC one. The HVDC system is basically environment friendly because improved energy transmission possibilities contribute to a more efficient utilization of existing power plants. It is also possible to increase the power transmission capacity for existing rights of way. The environmental aspects of an HVDC transmission line are audible noise, visual impact, electromagnetic compatibility and the use of ground or sea return path in monopolar operation [8]. A comparison between a DC and an AC overhead line is shown in figure 3.

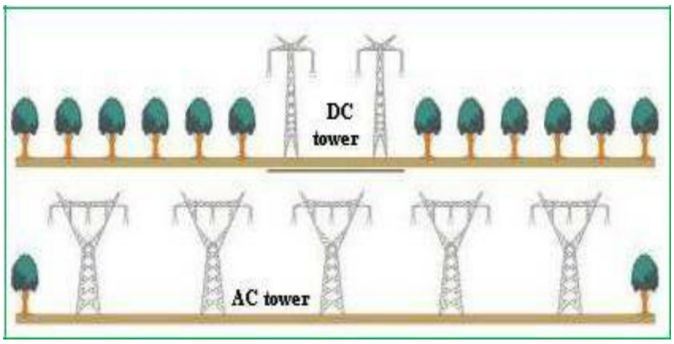

Fig.3. The environmental comparison between HVDC and HVAC systems

In general, it can be said that an HVDC system is highly compatible with any environment and can be integrated into it without the need to compromise on any environmentally important issues of today.

VI. Case study

The electric power sector is very concern interface in the politics of nations in general. A base that cares, researchers in the energy field offer several solutions to the governors, the fight is problem among these solutions, include the most effective solution is connecting the power grids of neighboring paid. This helped presents major advancements in the international electric power transmission sector in alternative example in Europe. According to the technological development in the field of power electronics which gives a more in industry namely generation, transmission and distribution of electricity, the transmission sector of electric energy provides significant benefits to transport the 'high voltage electrical energy in continuous current with respect to that carried by alternative current due to the use of power electronics principle.

The most difficult part for the completion of this study was the lack of data concerning the cost of the several components of the three transmission technologies that are under investigation. This is due to the fact the related industry treats this kind of information as confidential. However, an effort to be as accurate as possible was made and in all cases of cost related matters the references are given. It should be noted that all prices presented in this paper are given in Euros. All prices that were found in another currency were converted to Euros using the exchange OANDA Solutions for business of July 2016 and with the interbank rates at 3%.

In this case we can proposed a transmit the electrical power at the 400kv in the distance more the 800km. in this condition, we proposed a transmit this power by HVAC and HVDC systems.

Direct cost comparisons between AC and DC transmission systems should be conducted before make a decision. In order to compare the cost, all main system elements in HVDC and HVAC systems must be taken into consideration.

The evaluation of the transmission cost for every transmission system that has been introduced in table 1 and table 2, when the all cost comparison elements are showing. Prices are set taking into account all constraints of the market for business overhead electrical power lines in private or public property in the regions; these prices remain applicable in case of change. Under these conditions no claim, based on constraints such as those specified below, shall be valid:

- Hazards caused by the weather, such as persistent rains, etc.
- The constraints of any kind that can meet the manufacturer for the civil engineering works, erection of towers, connection work conductors and optical fiber ground wire.

Also included in these prices:

- The transport equipment prices (loading, unloading ...).
- The mounting price (rental tooling and assembly equipment ...).
- All costs and profits.

Furniture and equipment: office station and dispatching of this project and the content of the station has knowledge of office staff, IT, climate, social as well as the important part concern human resources.

Tab.1. Bordereaux price HVAC line 400 KV

N°	Designation	Unit price	Benefit / Total Amount in %	Quantity [km]	Amount in Euros
1	Execution study	2 351,94	1,17%	820	1951155,31
2	Supply and equipment	111 306,00	55,26%	820	141707230,00
3	Land and insurance transport	6 184,74	3,07%	820	5227181,44
4	Civil engineering work	42 492,50	21,10%	820	42195902,40
5	Installation works	19 766,10	9,81%	820	17798226,60
6	Works unwinding and drawing	18 815,60	9,34%	820	16869841,20
7	industrial commissioning tests	509,60	0,25%	820	418916,68
8	Total off VAT				**226168454,00**
9	VAT		17%		**38448637,17**
10	Total of ATI				**264617091,17**

Ground transportation: returns to aerial building system namely the line in distance over the 800Km, then the assurance of this line of transport based on control and safety protection for computers working.

Civil Engineering Works: fence on geological concern given the foundation and logic weather which conducts studies on materials using civil engineering construction general

- The general amount of our line 400kV HVAC in 820Km, is presented in the following table:
- The cost of a HVDC transmission system depends on many factors, such as:
- Ability to power transmit,
- Transmission support type,
- Environmental conditions and other safety regulatory requirements, etc.

Even when available, the options for the optimal design (different switching techniques, variety of filters, transformers, etc.) make it difficult to give a figure for cost for a HVDC system. However, a typical cost structure for the converter stations could be presented in figure 4:

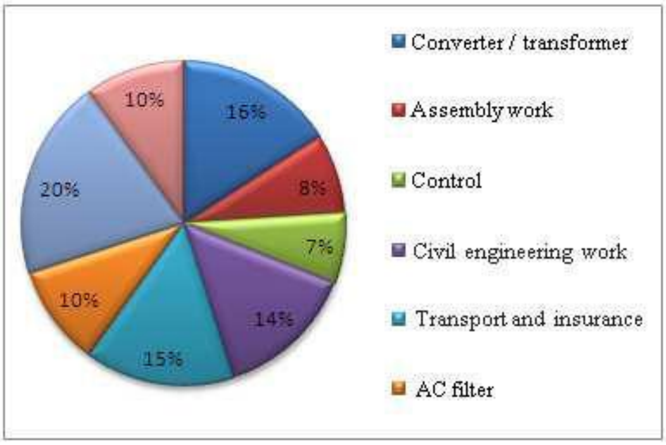

Fig.4. Cost of electronic power equipment

To calculate the amount of our HVDC , we must respect the previous conditions of carriage HVAC, since the AC carriers (eg cat head) than CC carriers, and each line of 220kv (AC) using six drivers but 400kV line (CC) using only two drivers, (see figure 5).

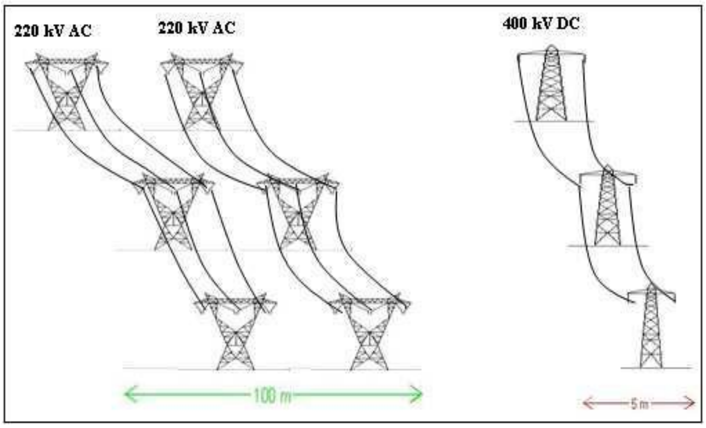

Fig. 5. Numbers of lines comparison between HVDC and HVAC

So, the cable prices, support, assembly works, civil work and transport, they will decrease by the 29.5% for HVAC transport system, the table will be as follows:

Tab.2. Bordereaux price HVDC line 400 KV

N°	Designation	Unit price	Benefit / Total Amount in %	Quantity [km]	Amount in Euros
1	Execution study	2 345,11	1,53%	820	1 952 411,95
2	Supply and equipment	66 589,20	43,55%	820	78 382 813,21
3	Power electronics equipments	31 268,10	20,45%	820	30 883 189,69
4	Land and insurance transport	3 700,06	2,42%	820	3 107 473,20
5	Civil engineering work	25 421,40	16,62%	820	24 310 078,08
6	Installation works	11 825,20	7,73%	820	10 446 216,13
7	Works unwinding and drawing	11 256,50	7,36%	820	9 909 682,29
8	industrial commissioning tests	508,11	0,33%	820	418 022,68
9	Total off VAT				**159 409 887,20**
10	VAT		17%		**27 099 680,83**
11	Total of ATI				**186 509 568,03**

So, the HVAC line is too expensive compared by HVDC line, this is justified by graphically system where the transmission line is exceeded the 500km with the power over the 400Kv (Figure 6)

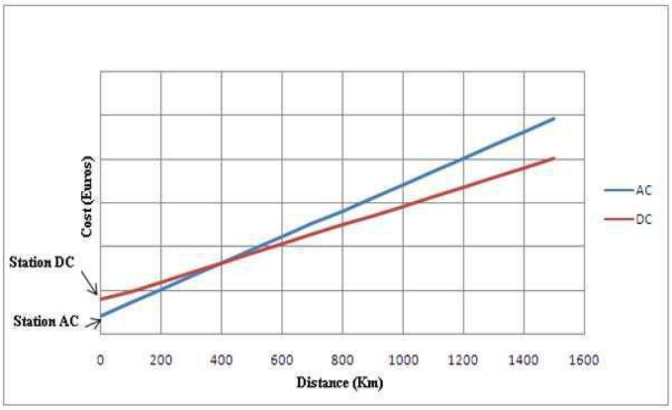

Fig.6. Cost the HVDC systems compared with HVAC system.

For electrical energy is used, the transmission and distribution network must meet the following requirements:

- Ensure customers the power they need.
- Provide a stable voltage whose variations do not exceed 10% of the rated voltage.
- Provide a stable frequency whose variations do not exceed 0.1 Hz.
- Provide energy at an acceptable price,
- Maintain stringent safety standards,
- Ensure the protection of the environment
-

VII. CONCLUSION

Power systems develop on line with the increasing demand on energy. With time, large interconnected networks in the world came into existence. Network interconnections offer technical and economic advantages. These advantages are high when medium sized networks are interconnected.

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. HVDC systems environmentally are often more compatible than comparable AC systems.

HVDC systems remain the best economical and environmentally friendly option for new applications in high voltage transmission systems and for network interconnections. Later the use of HVDC systems has been extended to load-flow control in meshed and interconnected network.

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 to 800 km. The HVDC has less effect on the human and the natural environment in general, which makes the HVDC friendlier to environment

Another interesting conclusion in this paper, drawn was the HVDC transmission systems presented much higher energy unavailability compared to HVAC systems with the same configuration. The last parameter in the final economic model was the investment cost. A research was carried out in order to determine the cost of each component of each transmission technology. Knowing the cost of the component and the configuration of each transmission system allowed the determination of the investment cost for each case and thus the energy transmission cost. The comparison of the results showed that HVDC transmission systems always presented a lower transmission cost than HVAC system and his technology became mature and reliable in consideration environmental and technical requirement.

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