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Technical Analysis of a Proposed HVDC Transmission Line Between Hassi-Messaoud and El-Khroub in Algeria

Abdelghani Guechi[1*], Mohammed Saaidia[2], Nedjem-Eddine Benchouia[1]

[1] Department of Mechanical Engineering, University of Souk Ahras, Souk-Ahras 41000, Algeria
[2] Department of Electrical Engineering, University of Souk Ahras, Souk-Ahras 41000, Algeria

Corresponding Author Email: guechia123@gmail.com

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ABSTRACT

Algeria will probably face great challenges in the energy sector in the near future due to the continuous increase in demand for electrical energy, old and insufficient local power stations and its dependence mainly on fossil energies. However, Algeria is considered as one of the most important countries in terms of solar energy potentials, especially in the center and south of the country, enabling it to address future energy challenges. Moreover, Algeria could become an important solar electrical energy exporter to African and even European countries. In this paper, we are interested by the electrical transmission network that could be suitable for the establishment of solar power plants in the Algerian desert. We propose the use of high-voltage direct current (HVDC) transmission technology based on a line-commutated converter (LCC) to connect one of the potential candidate region with huge potential for solar energy, namely Hassi-Messaoud region, to El-Khroub region as a central distribution node of electrical power at the Northeast of Algeria. A technical analysis of the proposed system is conducted and a comparison against high voltage alternating current (HVAC) transmission technology is performed to evaluate its suitability and effectiveness. The obtained results indicate that implementing a power transmission project via HVDC is technically feasible and suitable option.

1. INTRODUCTION

Energy is considered one of the most important vital elements for any country to achieve sustainable development in addition to economic stability. Due to the increasing industrial and technological development and the rapid population growth in Algeria, the demand for electrical energy is increasing significantly at both industrial and domestic levels, which will make it face a major challenge in the coming years since it relies mainly on fossil fuels for its produced energy. Aware about this challenge, Algeria is gradually moving towards exploiting renewable energies, especially solar energy, in order to meet energy needs, achieve sustainability and reduce dependence on fossil fuels, which results in a reduction in environment harmful emissions.

Algeria is one of the most important countries in the world in the field of photovoltaic energy resources thanks to its enormous potential of solar energy. Thus, Algerian desert; representing about 86 percent of the total area of the country; is located in an area of excellent solar radiation [1], recording one of the highest rates of sunshine in the world ranging between 2,000 and 6,000 watt-hours per square meter [2]. This enormous solar potential makes Algeria a prominent leading force in clean energy production at the national and regional levels. This can be achieved by installing large-scale solar energy systems to generate electricity, which will contribute to meet local needs and give it the ability to export energy to African and European countries. However, as already mentioned, most of the sunny regions are concentrated in the southern part of the country, far from the main industrial and inhabited areas. This fact highlights the problem of transportation technique that could be used to bring the produced power from the production centers to the distant consumers. Characteristics of such connections make it incentive for using the HVDC system to transmit electrical energy to the northern regions of the country or even for export. Moreover, photovoltaic energy produces a continuous current, which makes HVDC technology the first choice in this case [2].

Due to the rapid progress in the field of electrical transmission technology, and after decades of conflict between direct current and alternating current, HVDC technology has become an effective alternative to HVAC technology in transmitting electrical energy over long distances regarding technical, economic and environmental levels. The HVDC systems give the possibility of connecting electricity networks between different countries and with different frequencies, and even between continents. It is also considered as an ideal option with renewable energy sources, especially solar energy that produces continuous current energy. In addition, HVDC transmission lines with high power (more than 200 MW) and long distances (up to 1000 km and more) have much lower losses compared to HVAC. Many studies have proven that transmission losses of HVDC are limited to only 3 percent for transmitted electricity through overhead lines on thousands of kilometers. A group of research papers have presented technical and economic feasibility studies for transmitting electricity via HVDC lines. Researchers conducted a comparative economic study between HVAC and HVDC transmission systems to connect a 2 GW offshore wind farm with the onshore grid in Korea over a distance of 80 km [3]. They showed that an HVDC-CSC transmission system is significantly more economical than other options, namely HVAC and VSC-HVDC transmission systems. A technical and economic feasibility study [4] was conducted on a transmission line in Afghanistan with a capacity of up to 1000 megawatts, a voltage of up to 500 kilovolts, and a distance of 640 kilometers. Through the results of this study it was demonstrated the significant superiority of the VSC-HVDC system on both technical and economic levels compared HVAC system. Researchers discussed the advantages of HVDC transmission system as a potential future option for Pakistan, especially in the transport of wind energy from the provinces of Sindh and Baluchistan to major load centers in Pakistan [5]. Another study [6] in the same country (Pakistan) is presented which was focused on an economic analysis of electricity transmission using HVDC with a capacity of up to 4000 megawatts and a voltage in the range of ±660 kV over a distance of up to 878 km. All studies agree on the technical and economic superiority of the HVDC system Compared to HVAC one. Researchers presented a detailed design and technical analysis of a 500-600 kV HVDC transmission system in Turkey, where they emphasized the importance of this system and calculated resistance, corona losses and maximum electric field stress on different conductor configurations [7]. Based on all these studies and others, it can be said that HVDC is an advanced and efficient technology and is considered as an outstanding option for transmitting electricity over long distances and distributing clean energy from renewable sources.

Despite the fact that Algeria is a rich country in fossil fuels, governments are trying to exploit this richness to prepare the coming era of renewable energies by going trough chalenges like:

- **Heavy Dependence on Fossil Fuels**: Algeria heavily relies on fossil fuels, particularly natural gas, to meet its energy needs. It is estimated that 97% of the electricity produced comes from gas-powered plants. Given the continuously increasing domestic energy demand, Algeria faces the challenge of maintaining its hydrocarbon export capacity, which is crucial for its economy, while simultaneously meeting its growing internal needs (IEA) (Trade.gov).
- **Environmental and Economic Challenges**: Among the key challenges facing Algeria are climate change and the slowdown in renewable energy investments. Despite the significant potential of solar and wind energy, the exploitation of these resources remains limited, with renewable accounting for only about 3% of the country's electricity mix (Trade.gov).
- **Renewable Energy Transition Strategy**: Algeria has set a plan to increase renewable energy production, aiming to reach 22,000 megawatts by 2035, focusing primarily on solar energy.
- **The Role of HVDC Power Transmission Systems**: With the gradual transition to renewable energies, especially solar power, which generates direct current (DC) electricity, the use of high-voltage direct current (HVDC) technology is seen as an ideal choice for transmitting this energy from the southern regions to the densely populated northern areas.

Like it is depicted in Figure 1, this paper proposes the use of high-voltage direct current (HVDC) transmission technology based on a voltage source converter to connect the Hassi-Messaoud power plant, with huge potential for solar energy production, to the El-Khroub regional distribution central.

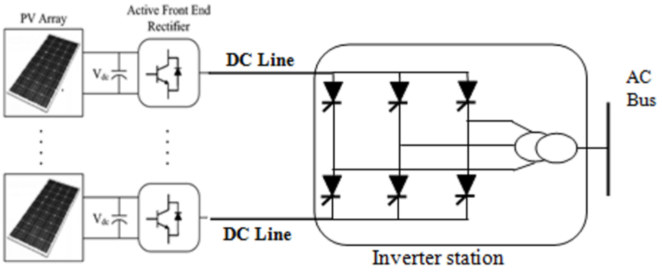

Figure 1. The proposed transmission line

The transmission line is intended to bring 2500MW of electrical power on a distance of about 700 Km using a bipolar DC line at 500 kV. Collected electrical power is boosted by a converter station at the output of a solar grid field. At the end of the transmission line an inverter station is used to obtain three phases alternating current that will be injected in to the classical distribution grid.

A technical analysis of the proposed system is conducted against high voltage alternating current (HVAC) transmission technology to evaluate its suitability and effectiveness. Active, reactive and corona losses are calculated in addition to audible noise and radio interference. The research results indicate that implementing a power transmission project via HVDC is a technically feasible option. This project will contribute to ensure energy security and economic stability in Algeria.

In the following of the paper, we define the HVDC technology and determine its advantages and disadvantages compared to the HVAC transmission system. In the second section, we introduce and compare the LCC-HVDC and VSC-HVDC technologies according to their technical and economic aspects. In addition, we present some of the most important realized worldwide HVDC Projects. In the third section we expose the Algerian existing Power Transmission System and the details of our proposed line transmission followed by a technical analysis. Finally, we discuss the technical analysis results and draw conclusion.

2. HVDC TRANSMISSION SYSTEM

HVDC is an abbreviation for High Voltage Direct Current technology. The HVDC system is used to transmit electrical energy in an unlimited quantity over long distances from one region to another using an electrical current that flows in one direction from power plants to consumption points. This is achieved by converting the alternating current (AC) generated in power stations into a direct current (DC) and when the final point is reached, the current is converted again from DC to alternating current through inverters. The use of the HVDC system is the ideal option when transmitting electrical energy over very long distances compared to the HVAC system, in terms of cost, losses resulting from the line, and many other factors [8]. Around 1954, the first commercial activity of the

HVDC system for transmitting electricity was carried out [9] and its first application on the ground was between the island of Gotland and the Swedish city of Vindellave, which demonstrated excellent performance and effectiveness. In the round 1960s, the first transcontinental HVDC project was completed, linking the United States of America and Canada. After that, the HVDC system witnessed rapid growth throughout various parts of the world, especially from the beginning of the 1980s to the present day.

HVDC technology has a group of main applications, including the use of HVDC technology for interconnections in electricity networks on a large scale, and the ability to use underground and marine cables to transmit electrical energy over long distances under the oceans and underground [10]. In addition to the possibility of linking different alternating current networks together effectively, HVDC offer the possibility to transfer energy between asynchronous regions (i.e having different frequencies) of the world. HVDC technology contributes significantly to the sustainability of power distribution and enhances the stability of electrical networks. Due to the utilization of only two conductors in the distribution, the HVDC system boasts the cost-effective infrastructure. Additionally, it demonstrates an exceptional capacity for the efficient conveyance of substantial power across extended distances, with minimal power dissipation, estimated at approximately 3% per 1000 kilometers [11].

2.1 Features and drawbacks of HVDC system

High transmission efficiency: HVDC system allows electrical energy to be transmitted very efficiently over long distances and with large quantities compared to HVAC system. This is due to the constancy of the electrical current which reduces the energy losses that occur in wires and cables.

Reduced power loss: HVDC system helps to reduce power losses caused by current and voltage interference in electrical lines.

Transmission of energy over long distances: HVDC system can be used to transmit energy over very long distances without the need for frequent amplification stations.

Precise power flow control: The ability to precisely control power flow using an HVDC system allowing improved electrical grid stability.

Space saving: HVDC systems require less facility space than HVAC systems, making them suitable for dense populated areas.

Asynchronous system: The use of the HVDC system enables the connection between two asynchronous networks, which is considered impossible for the HVAC system.

Sustainable technology: Renewable energy sources can be used to generate electricity and transmit it effectively via the HVDC system, especially solar energy, as it generates direct current.

However, HVDC systems still present some drawback that have to be considered:

Infrastructure cost: HVDC setups require complex and expensive infrastructure, including converter stations and special electrical cables.

Required maintenance: The HVDC transmission system requires regular maintenance due to the complex technologies used.

Grid compatibility: Attention must be paid to the compatibility of the HVDC system with the existing electrical grid to ensure that no operational problems occur.

Voltage level changing converters: Because the HVDC system is based on direct current, there are no voltage level changing transformers.

2.2 Converters' configurations for HVDC system

Converters used in the HVDC power transmission system that convert electrical current from alternating current (AC) to direct current (DC) during transmission, and vice versa, during reception are classified into two main sections, which contribute to the diversity of technologies used and meets transmission needs more efficiently. The first category is the current source converter, also known as a line commutator converter (LCC-HVDC), in which the current source is modified to achieve efficient power transfer. The second category is known as voltage source converter (VSC-HVDC), and it relies on transformers capable of self-switching.

2.2.1 LCC-HVDC

For half a century, the classic HVDC (LCC-based) power transmission technology has been considered one of the most notable successes in power transmission. This technology has achieved quantum leaps in power transmission capacity, with increased efficiency and improved reliability, making it an ideal choice for meeting large and complex transmission needs. This technology relies mainly on Thyristors. This device is the main component in LCC-HVDC technology [12]. These devices act as bistable switches, opening and closing the electrical connexion based on a control signal (gate pulse). What distinguishes a Thyristor is its ability to remain in a conductive state even after the first pulse has ended, allowing it to precisely control the flow of current. In HVDC power transmission (LCC) technology, the direction of the DC current is constant and does not change, it travels through a large inductance and is almost constant [13]. This design makes it also known by the term current source converter because the converter acts as a current source for the network to which it is connected. This design reflects the ability to transfer power between different areas with high efficiency and stability. The challenge for LCC technology is that it requires a synchronous high-voltage supply for the Thyristors as a high starting voltage in zero start (black start) situations.

Complete LCC-HVDC converter stations require more space compared to VSC-HVDC stations. This fundamental difference in space is mainly due to the need to have bulky capacitor banks and filter banks as part of the design due to the high reactive power consumption of transformers, which are used to control the harmonics generated by electrical switching. According to sources [14], an LCC substation with a capacity of up to 100 MW can need between 1,600 and 5,000 square meters of space to accommodate the filter banks. This represents an engineering and spatial challenge that must be considered when planning and building HVDC plants with LCC technology. Considering these requirements, the design of VSC-HVDC stations is more flexible and less space-consuming, making them a suitable option in areas where there is a lack of ample space. However, LCC technology demonstrates exceptional power transmission capability, has a current rating of around 6250A and a 10 kV blocking voltage [13]. LCC has the highest voltage and power rating of all HVDC converter technologies. This means that they are well suited for exceptional power transmission lines.

2.2.2 VSC-HVDC

Voltage source converter (VSC-HVDC) based on semiconductor devices is a vital technology in the field of transmission of electricity HVDC systems. The technological progress and development of semiconductor devices led to the development of insulated gate bipolar transistor (IGBT) [15] converters and thus the development of VSC. One of the most important advantages of an IGBT is its ability to control current flow independently of the associated AC voltage. Simply put, this technology can create its own AC voltage in the event of a power outage, increasing its ability to start in black start conditions that include a power outage.

VSC technology still in a stage of continuous development and one of the distinctive characteristics of this converter is that it operates at a high frequency, and this allows it to effectively deal with direct current. The VSC converter current is regulated using pulse width modulation (PWM) technology [13]. Thanks to this approach, the converter capacitance and phase angle can be adjusted synchronously and appropriately with changes of the converter current [16] which contributes to maintain the constant voltage required for efficient electricity transmission. Furthermore, because VSC is bipolar in nature, it necessitates the installation of two cables and use smaller filters compared to LCC. This approach enables VSC to precisely control the flow of power. In addition, the voltage source converter (VSC) is characterized by a high level of flexibility and control, as it has a great ability to adapt itself to network requirements and load changes accurately. Among its advantages is the ability to control active power as well as reactive power independently. Moreover, it has the ability to reverse the direction of power transfer without changing the polarity.

This technology was developed in the 1990s and saw its first VSC-HVDC transmission project in 1997 by ABB [4]. However, despite its advantages, The VSC-HVDC system has not gained a significant advantage over its counterpart LCC technology primarily because it is limited by low device ratings, resulting in higher power losses and increased electrical stress on the insulation of equipment [12]. These factors have restricted its success compared to existing LCC-HVDC. However, VSC-HVDC is a good choice for applications that require flexibility and precise control.

3. HVDC SYSTEM VS HVAC ONE

Comparison is presented here according to different aspects:

3.1 Technical aspect

HVDC transmission outperforms HVAC in terms of technical aspects. Being converter-based, HVDC enables precise power control. It also contributes to manage transients and enhance stability within HVAC networks. Power transmission on long distances is considered one of the most important obstacles faced by high-voltage transmission lines for alternating current. This is due to the high charging current and the increasing percentage of conduction losses. Due to the absence of reactive or capacitive charging effects, HVDC has lower losses and costs. Unlike HVAC networks, that rely on phase angles for power transfer and can become unstable over long distances, HVDC offers precise power control without stability constraints. Moreover, HVDC lines eliminate the need for reactive power, reducing voltage drops and the need for compensation, making them a suitable choice for underwater cable transmission lines. Furthermore, it necessitates a decreased number of cables and effectively exploits the complete transmission capacity within thermal limits [17], thereby diminishing the necessary DC cable's cross-sectional area and, as a result, cutting down on transmission costs. In addition, the necessary Right-of-Way space for DC transmission is significantly reduced compared to its AC counterpart, whether for underground cables or overhead lines bulk power transmission options, and AC line power capacity is inversely proportional to distance, whereas DC line capacity is not. Moreover, HVDC transmission is characterized by fast and accurate control of the entire transmitted power, where it can enhance both transient and dynamic stability within interconnected AC networks, while also effectively limiting fault currents along the DC lines. HVDC offers precise control over reactive and active power in the transmission link, making it indispensable for interconnecting networks with stability issues or differing frequencies 60 and 50HZ [18], which is considered impossible in an HVAC system.

The HVDC transmission system requires inverter and rectifier stations for AC/DC and DC/AC conversion which are very expensive and substantially contribute to the total HVDC transmission expenses while are unnecessary in HVAC transmission stations [17]. To put it concisely, the fixed costs associated with DC transmission, including stations and equipment, are significantly higher than those of AC. but with regard to the losses and cost of the line, the HVDC lines produce much lower losses compared to HVAC, and therefore the total cost of transmitting electric power over long distances will be very low for HVDC lines compared to HVAC, and this is after exceeding the breakeven distance (400 km-500 KM) for both systems.

3.2 Economic aspect

Economically, HVDC transmission is a preferred option for transmitting large amounts of power over long distances due to the multiple advantages it offers. While DC systems require two relatively expensive converter stations [19], HVDC transmission offers greater efficiency and lower line costs per unit length. This is achieved through the ability of an HVDC system to transmit large amounts of power over long distances using fewer numbers of conductors and insulators than HVAC systems. Thus, this reduces the cost of infrastructure and materials used in transportation. In addition, the reduced land area (ROW) requirement for the HVDC system results in an economic and environmental positive impact, as it reduces the need to clear large areas of land for infrastructure construction. The HVDC system uses smaller towers with lower cost compared to HVAC transmission towers of the same capacity and voltage, which leads to a reduction in the total cost as well. In the case of bipolar connections, the power loss is greatly reduced, which enhances the transmission efficiency. Another advantage of the HVDC system is the use of bundled conductors that reduces the formation of corona losses and consequently energy evaporation.

The point at which the economic advantage of an HVDC system is achieved, called the break-even distance (Figure 2), depends on a variety of factors. Among these factors are the cables used, whether they are undersea cables, underground cables, or overhead lines. This part plays an important role in determining the value of the cost. Figure 3 gives an overview of some important factors influencing the total cost comparison between the two systems.

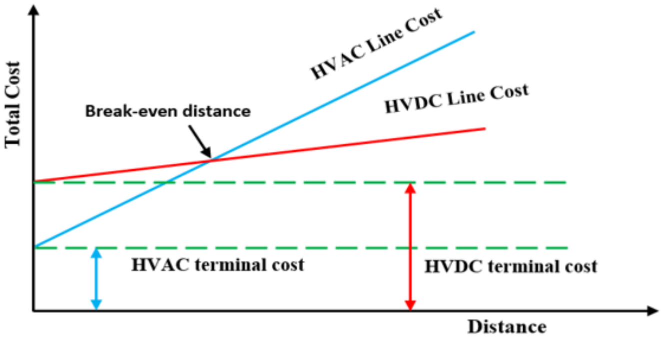

Figure 2. Cost comparison of HVAC vs HVDC systems

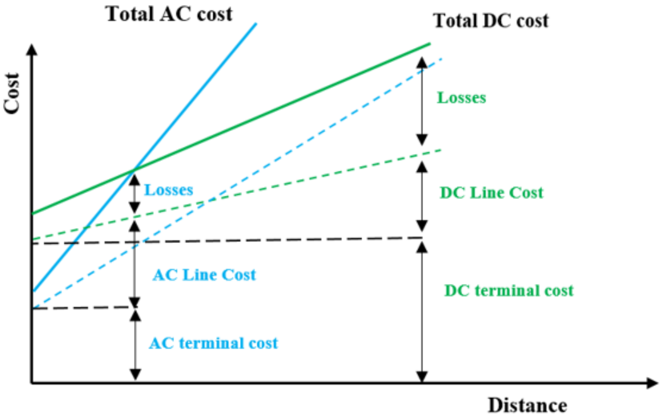

Figure 3. Comparison between costs of HVDC and HVAC transmission systems in terms of transmission line length

In addition, domestic aspects also emerge as influencing factors in the economic equilibrium calculations. For example, permitting requirements and local labor costs play a major role in determining the viability of an HVDC system compared to an HVAC system [18]. The fixed cost of HVDC systems, which means the cost of stations, is more expensive than the cost of stations for HVAC systems, but on the other hand, the cost of transmission lines, maintenance, operation, and energy losses for HVDC systems is less much compared to HVAC, and the difference increases more as the distance increases, given that the cost of energy transmission For the HVAC system, it is inversely proportional to the distance, and more than that, the cost of HVDC stations remains constant with increasing distance, unlike HVAC. As for the break-even distance, its range ranges from 400 to 800 km with regard to overhead lines. In terms of cable transmission, the point at which it becomes economically advantageous is quite different from overhead lines. For submarine cables, it's around 25 km, while for underground cables, it's approximately 50 km in order [19]. What we have said can be illustrated in Figure 2, which shows a comparison of station and line costs and the value of capital losses for direct current versus alternating current.

4. WORLDWIDE HVDC PROJECTS

The importance of high voltage direct current (HVDC) power transmission technology has been rapidly increasing in recent times, as it plays a vital role in enabling efficient and sustainable power transmission over long distances. When examining the distribution of high-voltage direct current (HVDC) transmission systems across the world, we find that the Asian continent significantly takes the lead. So that Asia has an appreciable track record of HVDC projects, The superior implementation of HVDC projects in the Asian regions, especially in China and India, is a strong indication of their superiority in the field of power transmission. These countries have launched HVDC projects to achieve efficient power transmission over long distances, in response to the vast terrain and geography in those regions and also to meet the growing needs for electricity and achieve sustainable economic growth. Half the capacity of HVDC projects is concentrated in the continent of Asia, led by China, where current connections surpass 10,000 MW. Asia's highest average transmission voltage results from the recent increase in ±800 kV HVDC connections established after 2010 [20], then India follows. As for the continent of Europe, it ranks second in its interest in HVDC transmission projects, as Europe accounts for approximately 22% of these worldwide HVDC projects [4]. Europe's concerns are focused on sustainability and lower power and distance connections compared to Asia, due to the continent's different requirements. The European continent is also seeking to enhance its capacity by delivering renewable energy sources to consumption centers using HVDC connections to achieve its environmental goals and sustain economic growth. When looking at the maximum voltage used in HVDC transmission line systems, In HVDC transmission line systems, the highest voltage distribution is found in Asia (1100 kV), followed by South America (800 kV), North America and Europe (600 kV), while other continents (500 kV) in order [21]. In short, HVDC technology is developing significantly around the world and many VSC-HVDC and LCC-HVDC projects have been completed as shown in Table 1.

Table 1. Examples of HVDC projects in the world

Name	Converter Station1	Converter Station2	Year	Line/Cable (Km)	Voltage DC (KV)	Power (MW)	Supplier
Inga-Shaba	Congo, The Democratic Republic of the Congo – Kolwezi	Congo, The Democratic Republic of the Congo- Inga	1982	1700	500	560 upgraded to 1000 on 2017	ABB, General Electric
Gezhouba - Shanghai	China - Gezhouba Dam	China - Nan Qiao	1989	1046	500	1200	ABB, Siemens
Rihand-Delhi	India – Rihand	India - Dadri	1990	814	500	1500	ABB, BHEL
Terranora interconnector (Directlink)	Australia - Mullumbimby	Australia - Bungalora	2000	59	80	180	ABB

Tian-Guang	China - Tianshengqiao	China - Beijiao	2001	960	500	1800	Siemens
Talcher-Kolar	India - Talcher, Odisha	India - Kolar, Karnataka	2003	1450	500	2500	Siemens
Guizhou - Guangdong I	China - Anshun, Guizhou	China - Zhaoqing, Guangdong	2004	980	500	3000	Siemens
HVDC Troll	Norway - Kollsnes	Norway - Offshore platformTrollA	2004	70	60	80	ABB
Three Gorges - Shanghai	China - Yidu	China - Shanghai	2006	1060	500	3000	ABB
Basslink	Australia - Loy Yang	Australia - George Town	2006	370	400	500	Siemens
Estlink	Finland - Espoo	Estonia - Harku	2006	105	150	350	ABB
Ballia – Bhiwadi	India - Ballia	India - Bhiwadi	2010	800	500	2500	Siemens
Caprivi Link	Namibia - Gerus	Namibia - Zambezi	2010	950	350	300	ABB
Valhall HVDC	Norway - Lista	Norway - Valhall, Offshore platform	2011	292	150	78	ABB, Nexans
Mundra - Haryana	India - Mundra	India - Mohindergarh	2012	960	500	2500	Siemens
BorWin1	Germany - Diele	Germany - BorWin Alpha platform	2012	200	±150	400	ABB
HVDC Inter-Island 3	New Zealand - Benmore	New Zealand - Haywards	2013	611	350	735	Siemens
Zhoushan Multi-terminal DC Interconnection	China – Zhoushan Islands	Dinghai, Daishan, Qushan, Yangshan, Sijiao	2014	134	±200	400	C-EPRI Electric Power Engineering
BorWin2	Germany - Diele	Germany-BorWin Beta platform	2015	200	±300	800	Siemens
NordBalt	Sweden - Nybro	Lithuania - Klaipėda	2015	450	300	700	ABB
DolWin2	Germany - Heede	Germany - DolWin Beta platform	2016	135	±320	900	ABB
Xingu-Estreito (aka, Belo Monte 1)	Brazil - Anapu, Pará	Brazil - Ibiraci, Minas Gerais	2017	2077	800	4000	Siemens
BorWin3	Germany - Diele	Germany - BorWin Gamma platform	2019	200	±320	900	Siemens
Xingu-Rio (aka, Belo Monte 2)	Brazil - Pará	Brazil - Rio de Janeiro	2019	2550	800	4000	NARI/XD/ CET
NORD.LINK	Norway - Tonstad	Germany - Wilster	2021	623	525	1400	ABB
IFA-2	France - Tourbe, Normandie	UK - Chilling, Hampshire	2021	204	320	1000	ABB
Matiari to Lahore Transmission Line Project	Pakistan - Matiari, Sindh	Pakistan - Lahore, Punjab	2021	878	660	4000	China Elec. Pow. Equi. and Tech.
ElecLink	France - Les Mandarins	UK - Sellindge	2022	70	320	1000	ElecLink (Getlink)

5. ALGERIAN POWER TRANSMISSION SYSTEM

The energy sector in Algeria depends mainly on fossil fuels, as oil constitutes about 36% of total primary consumption, and gas about 63% [22]. In recent years, Algeria has experienced significant and rapid growth in energy demand. Currently, gas and oil contribute significantly to overall final consumption, accounting for about 87% of it, while electricity's share represents 13%. The share of electricity is expected to increase in the future, reaching 17% by 2040 [22].

The electrical sector in Algeria is based on HVAC technology as the only way of transmitting electricity from production stations to homes, factories and institutions. Due to the availability of fossil fuel resources in the country, the focus came on building electricity production stations close to consumption points [2], which made the transmission of electricity over long distances unnecessary. Figure 4 shows an overview of the transmission lines and distribution of electricity production stations for the Algerian electrical network.

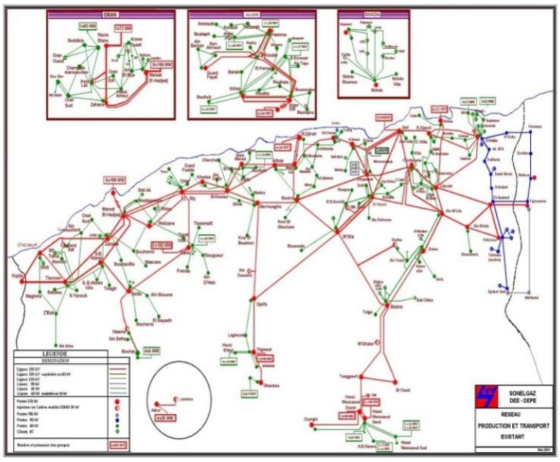

Figure 4. The deployment of Algeria's energy generation and transmission network

However, the increasing demand for electrical energy in Algeria, especially in the northern regions, at both the industrial and domestic levels, will push them to establish new electricity transmission lines in order to strengthen the network and achieve sustainability. This is what makes it face major challenges, especially since it relies mainly on fossil fuels to produce electricity.

In Algeria, clean energy or renewable energy, occupies an important place and a large space in discussions and strategies for the coming decades, especially solar energy. This interest reflects the real challenges facing the country's energy sector, which requires finding a sustainable and effective solution. Algeria has significant potential in solar energy and is expected to play an increasingly important role in the coming years. Its share is expected to reach 37% of total electricity generation in 2040 [22].

This is because Algeria has enormous potential in the field of solar energy due to the wide and sunny areas spread across the country especially the southern desert regions (over 2 million square kilometers) which are rich source of solar radiation.

Figure 5 shows that the sunny regions that have a tremendous ability to produce this type of energy are located in the far south. These trends embody a remarkable development in Algeria's energy policy, which has included renewable energies as one of its top priorities. To achieve this goal, Algerian government has created a specialized subsidiary of the state-owned company SONELGAZ (National Society of Electricity and Gas) which will be in charge of the renewable energies in general and solar power plants in particular. Figure 6 presents the main solar power plants that are already in production.

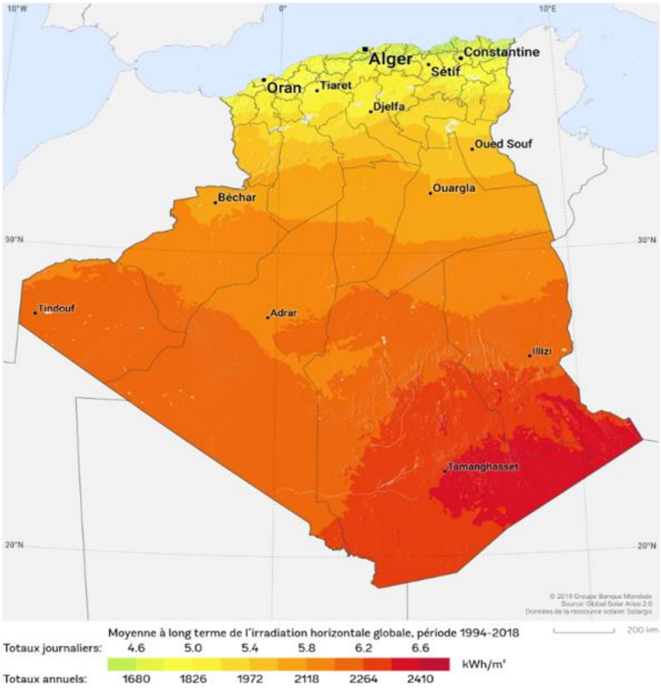

Figure 5. Algeria irradiance map

The installed capacity of solar energy has witnessed rapid growth in Algeria, reaching about 0.5 GW in 2020 [22], and is expected to reach about 22 GW in 2030 [2]. Among its goals are also achieving its electrical safety and environmental sustainability, and even enabling it to export electricity to Europe and others. Because most of the photovoltaic power plants will be located in southern regions far from consumers, and because HVDC technology is characterized by high transmission efficiency over long distances and low costs compared to HVAC technology, this will be an ideal option and strong support for spreading HVDC technology in renewable energy projects in Algeria.

The Algerian desert has enormous potential in the field of renewable energy (photovoltaic) that enables it to achieve sustainability and economic stability and makes it among the largest sources of renewable energy in the world due to the enormous potential of renewable resources it contains, especially since today's global perspective is moving towards exploiting the sun as a source of energy and a number of other energy sources.

Figure 6. Location of Algerian solar power plants

6. THE PROPOSED HVDC TRANSMISSION LINE

Receiving sunlight for more than 3,000 hours every year, Algeria has one of the largest sources of solar energy in the world. Due to the significant increase in demand for electrical energy in the northern regions at both the domestic and industrial levels, it has become mandatory to connect the southern regions to the north of the country and strengthen the country's power grid through the deployment and use of HVDC transmission lines, which will be an important factor in providing energy to the various regions of the country. The proposed transmission line is an energy project that connects the Hassi-Messaoud region (the production center), which is located in the south-east of the country, with the El-Khroub region in the north-east of the country. The proposed power transmission line will have a capacity of 2,500 MW at 500 kV and extends over a distance of approximately 700 km. The proposed line will not have a significant environmental negative impact since the route of the line passes through rural open areas. The proposed line will adopt LCC-HVDC technology. On one side, Hassi-Messaoud was chosen firstly for its solar irradiation capabilities and secondly for the fact that it is a developed zone that already have all necessary facilities that could help to install the new solar power plant. On the other side, El-Khroub already plays a central role as a distributing and transporting electrical power to the rest of the northern states of the country. This project could be a supporting factor to enhance economic and social stability in the country and promote industrial and community development.

According to previous studies on electricals transportation lines, ampirical formulas based on recorded statistical data has been provided for each one of the transportation line parameters especially those related to the different types of line losses, namely Joule losses, Corona losses, Audible noises and Radio interferences. These formulas will be used to calculate these parameters even for HVDC and HVAC transportation lines.

6.1 The HVAC line loss (Joule loss)

For the purpose of calculating power losses, the initial step involved the determination of the transmission line's current using the subsequent approach:

$$I_l = \frac{S}{\sqrt{3} + V_l} = \frac{P}{\sqrt{3} \times V_l \times cos\varphi} = \frac{1500 \times 10^3}{\sqrt{3} \times 500 \times 0.95} = 1823.21\text{A} \qquad (1)$$

$$\mathrm{I_{phase}} = \frac{\mathrm{I_l}}{\sqrt{3}} = \frac{1823.21}{\sqrt{3}} = 1052.632\text{A} \qquad (2)$$

We calculate the current for each conductor using the following relationship:

$$\mathrm{I_1} = \frac{\mathrm{I_{phase}}}{4} = 263.158\text{A} \qquad (3)$$

So that the number 4 (N=4) expresses the number of conductors per phase.

The calculation of active power loss for each phase per kilometer will be:

$$\mathrm{P_{loss}} = \mathrm{I_1^2} \times \mathrm{r_0} \times \mathrm{N} = 12.465\,\text{kW/km} \qquad (4)$$

where:

$\mathrm{r_0} = 0.045\,\Omega/\text{km}$ represents the transmission line electrical resistance of a conductor per kilometer.

Thus, the total active power loss is as follows:

$$\mathrm{P_{t_{loss}}} = \mathrm{P_{loss}} \times \mathrm{n} \times \mathrm{L} = 26.1765\text{MW} \qquad (5)$$

n is the overall number of phases, which equals 3, and L denotes the line's length, which measures 700 kilometers.

The calculation of reactive power loss for each phase per kilometer is:

$$\mathrm{Q_{loss}} = \mathrm{I_1^2} \times \mathrm{x_0}(0.235) \times \mathrm{N} = 65.097\,\text{KVAr/km} \qquad (6)$$

where:

$\mathrm{x_0} = 0.235\,\Omega/\text{km}$.

Thus, the total reactive power loss is as follows:

$$\mathrm{Q_{t_{loss}}} = \mathrm{Q_{loss}} \times \mathrm{n} \times \mathrm{L} = 136.704\text{MVAr} \qquad (7)$$

Finally, the total power loss can be calculated through the following relation:

$$\mathrm{S_{t_{loss}}} = \sqrt{\mathrm{P_{t_{loss}}^2} + \mathrm{Q_{t_{loss}}^2}} = 139.19\text{MVA} \qquad (8)$$

6.2 The HVDC line loss (Joule loss)

The flow of current for each pole within an HVDC transmission line is as follows:

$$\mathrm{I} = \frac{\mathrm{S}/2}{\mathrm{V_{rated}}} = \frac{\mathrm{P}/2}{\mathrm{V_{rated}}} = \frac{2500 \times 10^3/2}{500} = 2500\text{A} \qquad (9)$$

The current passing through each conductor within a pole is:

$$\mathrm{I_1} = \frac{\mathrm{I}}{\mathrm{N}} = \frac{\mathrm{I}}{4} = 625\text{A} \qquad (10)$$

The calculated active power loss per kilometer for a bundle of four conductors on a pole using a 1272 MCM ACSR conductor will be:

$$\mathrm{P_{loss}} = \mathrm{I_1^2} \times \mathrm{r_0} \times \mathrm{N} = 70.3125\,\text{kW/km} \qquad (11)$$

where:

$\mathrm{r_0} = 0.045\,\Omega/\text{km}$ is the reactance per Km of a conductor of HVDC line.

Thus, the total active power loss for both poles over a distance of 700 km was determined as:

$$\mathrm{P_{t_{loss}}} = \mathrm{P_{loss}} \times \mathrm{n} \times \mathrm{L} = 70.3125 \times 2 \times 700 = 98.4375\text{MW} \qquad (12)$$

Within an HVDC transmission system, the aggregate or apparent power loss aligns with the active power loss, given that the absence of frequency results in a null reactive power component.

$$\mathrm{S_{t_{loss}}} = \sqrt{\mathrm{P_{t_{loss}}^2} + \mathrm{Q_{t_{loss}}^2}} = 98.4375\text{MVA} \qquad (13)$$

6.3 Corona loss

During the application of high voltage differences across conductors, the electric current intensity exceeds the breakdown voltage of air at the surface of the conductor which approaches approximately 30 kV/cm [23]. The normally insulating air between the conductor phases becomes non-insulating. Then the atoms surrounding the conductor begin to ionize leading to the transformation of the air medium from an insulator to a virtual conductor [24], which is called ionization of the air surrounding the conductor, moreover accompanied by the discharge of electrons on a significant scale. This generates a buzzing sound due to electrical discharge and a bluish light due to the electrical arc between the conductor and the air atoms. This phenomenon also produces ozone gas and is referred to as the corona discharge phenomenon. Corona discharge generates ions causing losses in both HVAC and HVDC transmission. Differences exist between these systems: AC lines confine ions near conductors due to oscillation in the electric field. On the other hand, DC lines witness the departure of ions sharing the same polarity as the conductor, while ions of opposite polarity are attracted to and neutralized upon contact with the conductor. As a result, positive conductors emit positive ions, filling the surrounding space, and vice versa.

6.3.1 Corona loss performances for HVAC

Early studies on interaction between electrical transportation lines and their envirenment has been conducted [25]. These studies has derived different formulaes which the most used are Peek's formulae and Peterson's formulae [26].

Our fellowing calculations were performed using Peek's formulaes; (14) for fair weather and (19) for foul weather.

For fair weather:

$$\mathrm{P_{co}} = 242.2 \times \frac{1}{\delta}(\mathrm{F}+25).10^{-5}\sqrt{\frac{\mathrm{r}}{\mathrm{d}}}(\mathrm{V}-\mathrm{V_c})^2 \tag{14}$$

where:

F: the frequency.

d: the pole distance.

r: the conductor radius in cm.

V: the phase to neutral voltage of the line.

$\mathrm{V_c}$: the critical disruptive voltage.

The air density factor is calculated as:

$$\delta = \frac{3.92.\mathrm{b}}{273+\mathrm{t}} = 0.952 \tag{15}$$

where:

b and t are the normal atmospheric pressure and temperature, respectively.

Vc is calculated as follows:

$$\mathrm{V_c} = \mathrm{m_0}.\mathrm{r}.\mathrm{g_0}.\ln\left(\frac{\mathrm{d}}{\mathrm{r}}\right).\delta = 234.32\mathrm{KV} \tag{16}$$

where:

$\mathrm{m_0}$ is constant and equal to 1 for polished conductors, and g0 is the reference value of the conductor field value, which depends on air density. For the normal condition $\mathrm{g_0} = 21.2$ kV/cm.

The power loss per Km due to corona loss in each phase of HVAC lines is calculated as follows:

$$\begin{aligned}\mathrm{P_{corona}} = 242.2\mathrm{x}\frac{1}{0.952}\,(50 \\ + 25).10^{-5}\sqrt{\frac{1.755}{1310}}(\mathrm{V}-\mathrm{V_c})^2 \\ = 20.64\mathrm{KW/Km}\end{aligned} \tag{17}$$

The overall corona loss considering all three phases over a 700 Kilometer span is equal to:

$$\mathrm{P_{t_{corona}}} = 3 \times \mathrm{P_{corona}} \times \mathrm{L} = 43.34\mathrm{MW} \tag{18}$$

For foul weather:

The power loss due to corona loss per Km for each phase of HVAC lines is calculated as follows:

$$\mathrm{P_{co}} = 242.2 \times \frac{1}{\delta}(\mathrm{F}+25).10^{-5}\sqrt{\frac{\mathrm{r}}{\mathrm{d}}}(\mathrm{V}-0.8\mathrm{V_c})^2 \tag{19}$$

$$\begin{aligned}\mathrm{P_{co}} = 242.2\frac{1}{\delta}(5+25).10^{-5}\sqrt{\frac{1.755}{1310}}\Big(\frac{500}{\sqrt{3}} \\ - 0.8 \times 234.32\Big)^2 \\ = 71.55\,\mathrm{kW/km}\end{aligned} \tag{20}$$

The overall corona loss considering all three phases over a 700-kilometer span equals:

$$\mathrm{P_{t_{corona}}} = 3 \times \mathrm{P_{corona}} \times \mathrm{L} = 150.26\mathrm{MW} \tag{21}$$

6.3.2 Corona loss performances for HVDC

The study [27] proposed a semi-ampirical formulaes (22) for fair weather and (26) for foul weather that permit to calaculate corona losses in bipolar transportation lines. The proposed formulaes are a analytical formulae which parameters have been derived from statistical data.

For fair weather:

The power loss due to corona loss per Km of HVDC lines is calculated as follows:

$$\begin{aligned}\mathrm{P_{corona}} = 2.9 + 50\log_{10}\left(\frac{\mathrm{E_{max}}}{25}\right) + 30\log_{10}\left(\frac{\mathrm{d}}{3.05}\right) \\ + 20\log_{10}\left(\frac{\mathrm{N}}{3}\right) - 10\log_{10}\left(\frac{\mathrm{H.S}}{225}\right)\end{aligned} \tag{22}$$

where:

H: Height of the conductor in m.

S: Conductors spacing in m.

$$\begin{aligned}\mathrm{P_{corona}} = 2.9 + 50\log_{10}\left(\frac{17}{25}\right) + 30\log_{10}\left(\frac{3.51}{3.05}\right) \\ + 20\log_{10}\left(\frac{4}{3}\right) \\ - 10\log_{10}\left(\frac{27 \times 16}{225}\right)\end{aligned} \tag{23}$$

The corona power loss in KW/Km is given by:

$$\mathrm{P} = 10^{\frac{\mathrm{P_{co}}}{10}} = 10^{-0.39786} = 0.4\,\mathrm{Kw/Km} \tag{24}$$

The total corona loss for 700 Km distance will be:

$$\mathrm{P_{t_{corona}}} = 0.4 \times 2 \times 700 = 0.560\mathrm{Mw} \tag{25}$$

For foul weather:

The power loss due to corona loss per Km of HVDC lines is calculated as follows:

$$\begin{aligned}\mathrm{P_{corona}} = 11 + 40\log_{10}\left(\frac{\mathrm{E_{max}}}{25}\right) + 20\log_{10}\left(\frac{\mathrm{d}}{3.05}\right) \\ + 15\log_{10}\left(\frac{\mathrm{N}}{3}\right) - 10\log_{10}\left(\frac{\mathrm{H.S}}{225}\right) \\ = 4.56 \\ \mathrm{P_{corona}} = 11 + 40\log_{10}\left(\frac{17}{25}\right) + 20\log_{10}\left(\frac{3.51}{3.05}\right) \\ + 15\log_{10}\left(\frac{4}{3}\right) \\ - 10\log_{10}\left(\frac{27 \times 16}{225}\right)\end{aligned} \tag{26}$$

The corona power loss in KW/Km is given by:

$$P = 10^{\frac{P_{co}}{10}} = 10^{0.45616} = 2.8586\,\mathrm{Kw/Km} \tag{27}$$

The total corona loss for 700 Km distance is:

$$P_{t_{corona}} = 2.8586 \times 2 \times 700 = 4\mathrm{Mw} \tag{28}$$

6.4 Audible noise

Audible noise is generated by high-voltage electrical transmission lines due to the presence of the corona. Extra-High Voltage (EHV) lines produce significant audible noise, especially pronounced during adverse weather conditions. This noise covers a broad frequency range, spanning from very low frequencies up to approximately 20 KHz. The audible noise resulting from corona discharge typically has lower amplitude than other environmental noises, but it encompasses a significantly broader frequency spectrum [28]. Audible noise is a significant concern for electrical transmission line designers and reducing noise from overhead lines and substations can be expensive. Corona discharges produce negative and positive ions that cyclically attract and repel due to the alternating AC excitation polarity, generating acoustic pressure waves at double the power frequency along with their harmonics. Furthermore, a broad spectrum of frequencies emerges from the chaotic movement of ions. In HVDC systems, audible noise primarily originates from substations, particularly the converter-transformers [2].

Audible noise (A.N) is not a concern for underground and submarine HVDC transmission cables, but it becomes an issue for overhead lines, particularly during foggy weather. During moderate weather, for AC transmission lines, the A.N level is somewhat low, while it is high in bad and rainy weather. For direct current transmission lines, the audible noise is slightly higher during moderate weather than that produced in bad and rainy weather. Typically, in residential areas, noise from transmission lines should not exceed 40 dB during the night or 50 dB at the day [2]. The AN values for AC and DC transmission lines can be determined by using Bonneville Power Administration BPA or through the general formulas [29]. Our fellowing calculations were performed using BPA's formulaes. The A.N formula for AC transmission lines can be written as follows:

6.4.1 Audible noise for HVAC

$$\begin{aligned} AN_i = {} & 120\log_{10}E + 55\log_{10}d - 11.4\log_{10}R \\ & - 128.4 + 26.4\log_{10}N \end{aligned} \tag{29}$$

E: average maximum bundle gradient (kVrms/cm).

d: diameter of sub-conductor in cm.

R: aerial distance from phase i to the location of the microphone in meter.

N: number of sub-conductors in bundle.

$$E_{max} = E_{av}\left[1 + \left(\frac{d}{D}\right)(N-1)\right] \tag{30}$$

$$D = S/\sin(\pi/N) \tag{31}$$

$$E_{va} = \frac{Q}{(2\pi\varepsilon r)} \tag{32}$$

$$Q = \frac{C.V}{N} \tag{33}$$

where:

D: Bundle diameter cm.

S: bundle spacing cm.

C: Capacitance F/meter.

V: line-to-ground voltage kV, rms.

$$\begin{aligned} AN_1 = {} & 120\log_{10}13.323 + 55\log_{10}3.51 \\ & - 11.4\log_{10}36.4 - 128.4 \\ & + 26.4\log_{10}4 \\ AN_1 = {} & 34.7\mathrm{dB} \end{aligned} \tag{34}$$

With the same method:

$$AN_1 = AN_2 = AN_3 = 34.7\mathrm{dB} \tag{35}$$

AN contribution of three conductors is as shown below:

$$\begin{aligned} SPL &= 10\log\left[\sum_{i=1}^{3} 10^{\frac{AN_i}{10}}\right] \\ SPL &= 10\log_{10}\left[\sum_{1}^{3} 10^{\frac{34.7}{10}}\right] = 39.47\mathrm{dB} \end{aligned} \tag{36}$$

where:

SPL: Resultant sound pressure in dBA.

6.4.2 Audible noise for HVDC

The audible noise (AN) of a DC line was given as:

$$\begin{aligned} AN_i = {} & 86\log_{10}E_{av} + 40\log_{10}d - 11.4\log_{10}R \\ & + K\log_{10}N + AN_0 \end{aligned} \tag{37}$$

K=0 for N=1 or 2; K = 25.6 for N>2.

AN_0= -93.4 for N=1 or 2; AN_0= -100.62 for N>2.

$$\begin{aligned} AN_i = {} & 86\log_{10}14.586 + 40\log_{10}3.51 - 11.4\log_{10}36.4 \\ & + K\log_{10}4 - 100.62 \\ AN_i = {} & 18.96\mathrm{dB} \end{aligned}$$

6.5 Radio interference

As is the case with audible noise, corona discharge is responsible for generating radio frequency interference resulting from HVDC conductors. Corona discharges generate rapid voltage and current surges along transmission lines, producing radio frequency noise near the lines. HVDC conductors generate radio interference only from those with a positive polarity, while for HVAC transmission lines, radio interference is generated by all three AC phases [30]. Based on this, it is possible to use bipolar HVDC transmission lines and quadric-polar to increase power transport witho ut increasing interferences. This advantage is not applicable to HVAC transmission technology, where all conductors produce interferences, and thus an increase in radio interference.

Weather conditions play a role in increasing or decreasing this radio interference. For high-voltage AC transmission lines, the level of radio interference tends to increase during bad or rainy weather, with the increase reaching up to 20 dB. This is in contrast to high-voltage DC transmission lines, where radio interference is more intense during fair weather. Furthermore, HVDC transmission line converters may introduce disturbances in kHz or even MHz interference regions [31], which can be mitigated by implementing appropriate valve shielding rendering HVDC radio interference comparable to AC solutions [32]. In general, radio interferences generated by HVAC lines are more severe than those generated by HVDC lines.

6.5.1 Radio interference for HVAC

$$\begin{aligned}\mathrm{RI_{ac}} = 119.56\log_{10}\mathrm{E_{max}} + 3.97\log_{10}\mathrm{N} \\ + 43.57\log_{10}\mathrm{d} - 81.89 \\ - 19.05\log_{10}\mathrm{R} - 25.07\log_{10}\mathrm{f} \qquad (38)\end{aligned}$$

$$\mathrm{RI_{ac}} = 56.52\mathrm{dB}\left(\frac{\mu\mathrm{V}}{\mathrm{m}}\right)$$

6.5.2 Radio interference for HVDC

$$\mathrm{RI_{dc}} = 51.7 + 86\log_{10}\left(\frac{\mathrm{E_{max}}}{25.6}\right) + 40\log_{10}\left(\frac{\mathrm{d}}{4.62}\right) \qquad (39)$$

$$\mathrm{RI_{dc}} = 31.64\mathrm{dB}$$

7. RESULTS' ANALYSIS AND DISCUSSION

In this section, obtained results in the precedent section will be drawn graphically in a comparative manner to highlight the pros and cons of the HVDC system compared to the HVAC system.

In Figure 7, the HVAC system shows significantly lower active losses than the HVDC system, being 26.1765 MW versus 98.4375 MW respectively. While HVAC records significant Reactive Power losses up to 136.704 MVAr, there are no reactive losses in the HVDC system (0 MVAr).

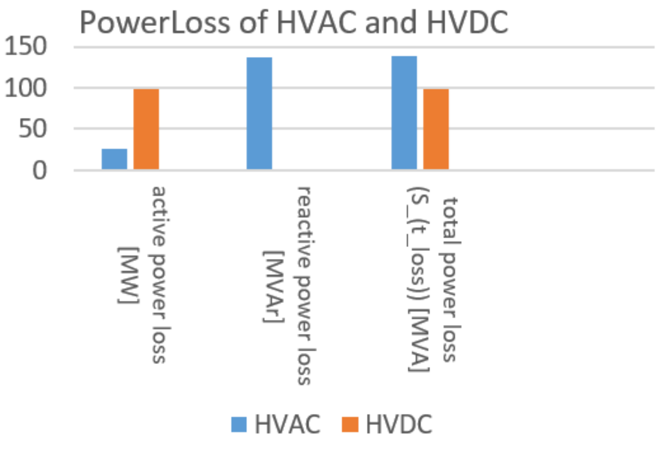

Figure 7. Power loss comparison between HVAC and HVDC transmission systems

Total power losses (S) are the sum of active losses and reactive losses, which is 139.19 MVA for HVAC system and only 98.4375 MVA for HVDC system. From this information, we note that the total losses (S) of the HVDC system are much lower than the total losses of the HVAC system. This indicates that the HVDC system is more efficient in terms of energy losses compared to the HVAC system, as much of the energy is directed to converting response losses in the HVAC system while the HVDC system significantly reduces these losses.

In Figure 8, it is shown that HVDC system significantly outperforms HVAC in terms of corona discharge losses in both good and bad conditions. HVDC losses are much lower compared to HVAC. During good conditions, HVDC losses are 0.560 Mw while HVAC losses are 43.34 MW. This indicates that HVDC is much more efficient in reducing corona losses in good weather conditions. Even in bad weather conditions, HVAC losses reach 150.26 MW while HVDC losses are still much lower with 4 MW. This shows once again the efficiency of HVDC in dealing with corona discharge losses in bad weather conditions. Thus, it can be said that HVDC is the most efficient option in this context and allows electricity to be transmitted over long distances with lower losses.

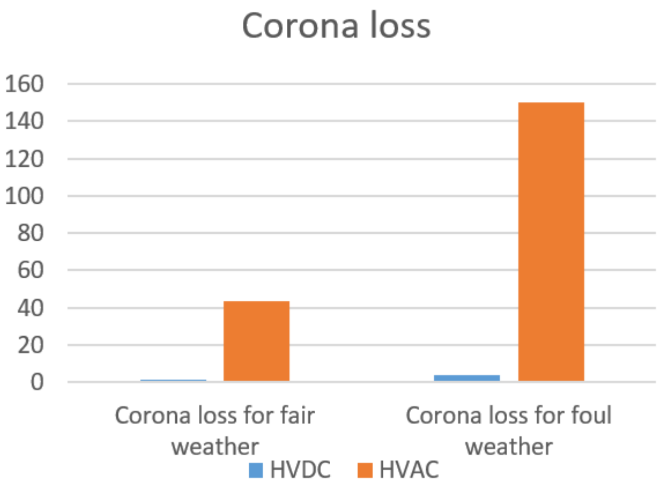

Figure 8. Corona discharge loss comparison in moderate and windy weather of the HVAC and HVDC transmission systems

Figure 9 shows that HVDC significantly outperforms HVAC in terms of audible noise production. The noise level of an HVDC system is much lower than that of an HVAC system. The audible noise production of an HVDC system is very low; at 18.96 decibels (dB), making it suitable for applications where the impact on the acoustic environment is minimal. While the HVAC system produces a high level of audible noise at a rate of 39.47 decibels (dB), making it less suitable for noise-sensitive environments or close to residential areas.

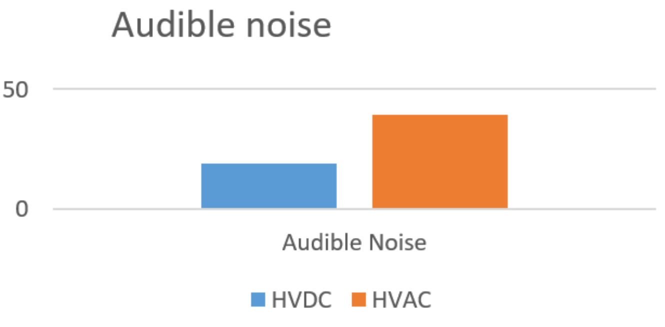

Figure 9. Comparison for audible noise of the HVAC and HVDC transmission systems

Figure 10 illustrates a comparison of Radio Interference (RI) values between HVDC and HVAC transmission lines. Following the calculations, the obtained results for HVDC lines revealed an RI value of 31.64, while HVAC lines exhibited a value of 56.52. The lower RI value of 31.64 dB for HVDC suggests a comparatively reduced level of electromagnetic interference, implying a potentially lesser impact on nearby communication systems or electronic devices. Conversely, the higher RI value of 56.52 dB for HVAC indicates a more pronounced radio interference level, underscoring the necessity for additional measures or considerations to alleviate potential interference effects on surrounding radio communication and electronic equipment.

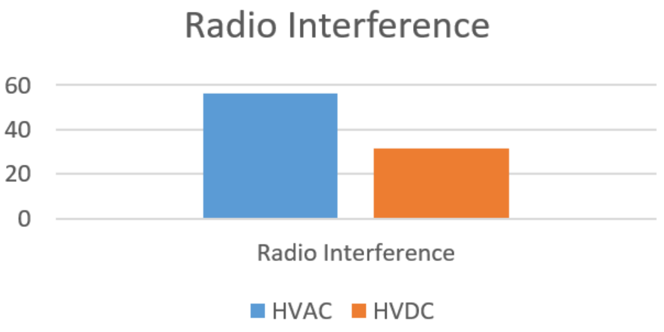

Figure 10. Comparison for radio interference of the HVAC and HVDC transmission systems

All studied parameters have influence on transportation performances of the transmission line and also have envirenmental influences. These values are influenced by the own characteristics of the conductors (length, section, material), the envirenmental conditions (weather, cleannes of the conductor) and also by the characteristics of the transported electrical power (power level, power quality, ...). Lowest values will always enhance line performances and envirenmental integration.

These results play an important role in selecting the appropriate electrical transmission system depending on the surrounding environment and acoustic needs of the specific application. HVDC technology is of interest in situations where auditory noise is required to be minimized.

However, implementation of such huge and important project could face some predictive challenges and barriers like:

Lack of Technical Expertise and Local Capabilities Implementing HVDC systems requires precise technical knowledge of complex technology, which includes designing converter stations, controlling electrical flow, and maintaining the system as a whole.

Aging Electrical Infrastructure Algeria's electrical infrastructure is based on the traditional HVAC system, which presents a significant technical challenge in transitioning to HVDC. Connecting HVDC to HVAC or fully transitioning to HVDC would require the development of complex converter stations, network integration, or the construction of new designed infrastructure for HVDC.

High Initial Costs HVDC technology requires massive investments in building converter stations, substations, and underground or submarine cables, which are much more expensive than HVAC technology in terms of initial costs.

Regulatory and Legal Challenges It is crucial to update the current legal framework to accommodate the new technology, especially regarding the regulation of electricity markets and electrical interconnections with neighboring countries. HVDC systems could be ideal for exporting electricity to Europe or neighboring African countries. These challenges can be addressed by reforming energy policies and enhancing regional cooperation at the energy level.

To overcome such challenges, solutions could be:

Cooperation with international companies: To successfully implement HVDC projects, Algeria should benefit from the expertise of international companies such as Siemens and ABB.

Technical training: Establish local training programs in collaboration with international academic institutions to develop local expertise in the operation and maintenance of HVDC systems.

Project financing: The cost challenge could be mitigated through international partnerships with financing institutions or development banks.

Infrastructure modernization: Long-term planning for the modernization of electrical infrastructure and the integration of HVDC technologies.

8. CONCLUSION

Due to the fact that Algeria is an oil and gas producing country, its electricity production is completely based on these two fossil resources. However, the last two decades have seen a political, economic and social will to turn towards the exploitation of clean energy resources such as solar energy to build the future energy policy of the country. The abundance of this type of resource is found especially far towards the south of the country, which raises the problem of transporting the electricity produced to potential consumption areas in the north of the country.

In this research paper we try to deal with this challenge by proposing to install an electrical transporting line based on the HVDC technology. We define the starting and ending stations, the potential of the line, the transported power and the type of HVDC line. Moreover, we gave the pros and cons of this HVDC line compared to an equivalent HVAC one. We demonstrated that the proposed HVDC system is economically and environmentally a good option for transmitting electrical energy from the producing areas at the south of the country to the consuming areas at north.

Technical and environmental challenges and barriers like lack of local technical expertise, aging electrical infrastructure, elevated initial costs and lack of regulatory policies have also been highlighted and indications on how to deel with them have been proposed.

This project will, not only contribute to enhance energy security and economic stability of Algeria, but also influence scientific and technologic institutions like universities and research centers through the emergence of new training and research areas. It could also participate to the development of industrial manifatures that are related to the chain supply of electrical and electronic devices related to the HVDC technologies.

As perspective of the present research work, an extended and detailed study of such proposed system has to be carried out at the level of the concerned company (SONELGAZ in our case) to ensure the integration of all technical, economic and even environmental real factors in the study to guarantee the success of the establishment of such project.

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