IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 7 February 2023, accepted 26 February 2023, date of publication 2 March 2023, date of current version 7 March 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3251411

RESEARCH ARTICLE

Increasing Transmitted Power With Cost Mitigation via Modified EHV Power Lines in Egyptian Grid

AHMED TALEB MOHAMED[1], **AHDAB EL-MORSHEDY**[1], **ELSAYED TAG-ELDIN**[2], **AHMED EMAM**[1], **AND MOHAMED MAHMOUD SAMY**[3]

[1]Faculty of Engineering, Cairo University, Giza 12613, Egypt
[2]Faculty of Engineering and Technology, Future University in Egypt, New Cairo 11835, Egypt
[3]Faculty of Engineering, Beni-Suef University, Beni Suef 62511, Egypt

Corresponding author: Ahmed Taleb Mohamed (ahmedtaleb@cu.edu.eg)

ABSTRACT The main goal of this work is to mitigate the cost of modified EHV line of the Egyptian transmission network. The existing HVAC line is replaced by four configurations, the first one is double circuit operating with an AC potential and bipolar DC circuit of B1500 kV while the second one is a double circuit operating with 500 kV AC circuit and B1500 kV bipolar circuit with required conductor and/or tower modification. The third one is a double DC circuit working with two B1500 kV. The fourth configuration is working with three B1500 kV bipolar circuits. The study shows the increase in transmitted power percentage and the cost mitigation for each suggested configuration relative to the existing AC line. Starting from the break-even distance of each configuration to 500 km, each configuration result will be analysed. Configuration 1 has the shortest break-even distance at 148 km. The power percentage increased from 3% to 5% and the cost mitigated by 22.17%. Break-even distance of configuration 2 is 171 km. Configuration 2 has power percentage increase from 30% to 32% and the cost reduced by 22.45%. Above 212 km break-even distance, configuration 3 has the best cost mitigation percentage of 28.60% and the power percentage increased from 7% to 9%. Configuration 4 records the highest increase in the power percentage range of 60% to 64% and cost reduction of 27.72% after 221 km break-even distance.

INDEX TERMS Hybrid energy systems, electric fields, Egypt electric grid, transmitted power increase, cost mitigation.

I. INTRODUCTION

According to the plans of the Egyptian government and responding to the directives of the political administration by maximizing the use of hybrid energy systems, the latest technologies and methods improve the performance of the Egyptian electricity network. The increase in the generation capacity of the Egyptian electricity power network must be followed by upgrading the transmission lines. In the presence of many challenges to make the best use of the existing corridors, the idea of this research came. Maximizing the use of existing transmission lines and converting them into hybrid and HVDC lines helps to face these limitations. There are many reasons for improving the capacity of existing transmission lines. The increasing demand for power transmission is due to the growth of the generation capacity of the network. The permission to obtain new transmission right of way is very difficult. The period for constructing new transmission lines is very long. Utilization of existing lines is a more efficient way. Hybrid and HVDC overhead lines introduce a solution of this problem [1].

There are many causes make the transformation of an AC transmission line to a hybrid or HVDC is attractive. Hybrid and HVDC transmission lines have advantages compared to the existing HVAC transmission lines. The using of hybrid and HVDC power grids improves the power transferred through these networks, minimizes the amount of land used for corridors, improves the electrical grid's stable operation,

The associate editor coordinating the review of this manuscript and approving it for publication was Alexander Micallef.

helps to minimize expenses, minimizes electrical grid losses, and minimizes the backup capacity required in the Egyptian grid [1]. The comparison between AC upgrading alternatives and DC conversion in terms of prospective capacity increase versus costs [2].

Recently it is too hard to obtain corridors for establishing transmission lines. For that cause upgrading the existing overhead lines is the best solution. The conversion of existing AC lines into DC lines represents an alternative to upgrading the power-carrying capability for the existing transmission lines with the same rights of way (ROW). This needs to study the electrical fields under the suggested configurations [3], [4], [5]. The effect of electrical fields of the existing 500 kV transmission line must be taken in consideration. There are some suggested methods to reduce the electrical fields effect on human bodies and the needed rights of way (ROW) [6], [7], [8]. To meet the excessive of electric load demand, Compensation of networks utilizing static and flexible AC transmission systems (FACTS) equipment is the second sort of solution [9]. The implications of several parameters, including HVDC voltages on modified lines, structure changes, insulation, and wires were considered [10], [11].

A novel method of overcoming the present shortage of suitable right-of-way for long-distance power transmission is to convert the existing AC lines to HVDC systems. In such situations, an HVAC system is changed to be bipolar HVDC. Conversions of this type permit the transmission capacity of a current ROW to be increased considerably. Since existing towers often permit an increase in the phase voltage, many studies have been executed in the past to examine the methods of switching HVAC to be HVDC lines [2]. The switching of a current HVAC lines to HVDC is generally seen as an efficient method to uprate the power transfer capacity of the existing transmission system [12], [13]. This paper introduces a comparison between AC and DC technologies for power transmission. The technology is reviewed, and different conversions are analyzed. Also, increased power-carrying capability and loss reduction are studied [14].

Because of the cost and the operational limitations of previous technologies, most utilities have only considered HVDC for new, high-power and long-distance transmission. HVDC will uprate the active power transmission capacity up to four times relying on the permissible DC voltage. The AC current working situations and could theoretically transmit 3.5 times the overall energy in a corridor utilizing the current lines and structures, depending on the thermal limits of the lines [11], [13]. The International Council on Large Electric Systems (CIGRE) was included. A study shows that the extending of capacity via HVAC to HVDC is typically only charming when installing novel transmission lines is not conceivable [15]. This paper presents a comparative assessment of the relative cost and performance of installing a novel HVAC corridor versus switching those corridors to hybrid and HVDC.

Many situations in which the switching from HVAC to HVDC is likely to be the preferred strategy when taking long-term demand projections into account. With future improvements in the cost and performance of solid-state power electronics the range of situations in which conversion to HVDC is attractive can be expected to grow. This analysis considers transmission capacity upgrades range from 2 to 64% (limited by the lines' thermal capability) [11], and compares the expected costs for section lengths between break-even distance and 500 km. The system cost analysis contains conductor, ROW costs, the cost of any novel or expanded supporting structures, and the cost of line losses. Generally, if the distance of the proposed line is increased over 280 km length, the HVDC lines are assumed to be less estimate comparing the HVAC for point-to-point transmission [16], [17].

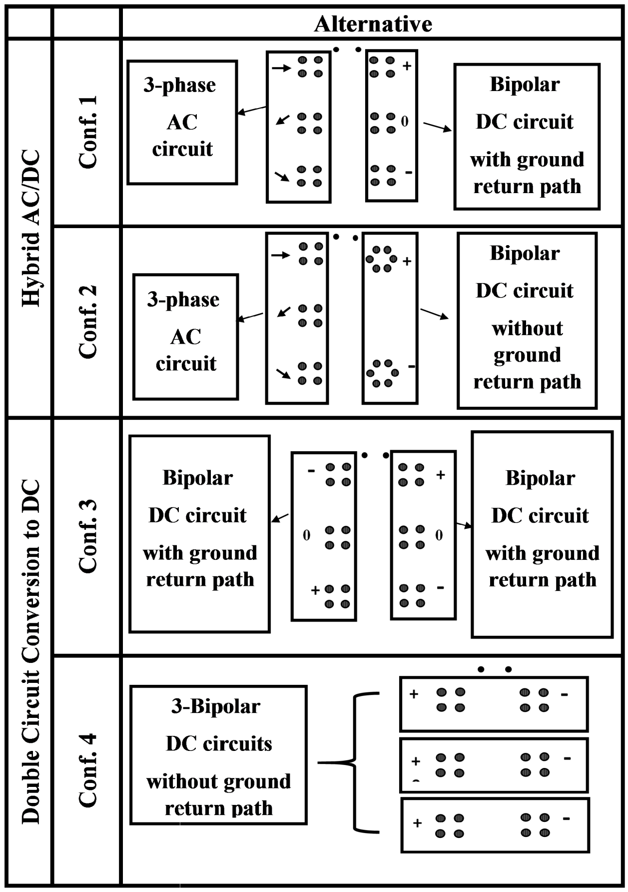

FIGURE 1. Four power line configurations are suggested for the existing 500 kV AC double circuit line in the Egypt electric utility [1].

II. THE PROPOSED DOUBLE CIRCUIT LINE CONFIGURATIONS

This section describes the presented double circuit configuration under study. Figure 1 shows the four power line configurations suggested for the existing 500 kV AC double circuit line in the Egypt electric utility as shown in Figure 2. The baseline consists of a 500 kV HVAC double-circuit, with four bundles per phase and a diameter of 0.0306 m for each bundle, the space between bundles is 0.5 m, and the phases heights from the ground plane H1, H2, and H3 are 36.1,

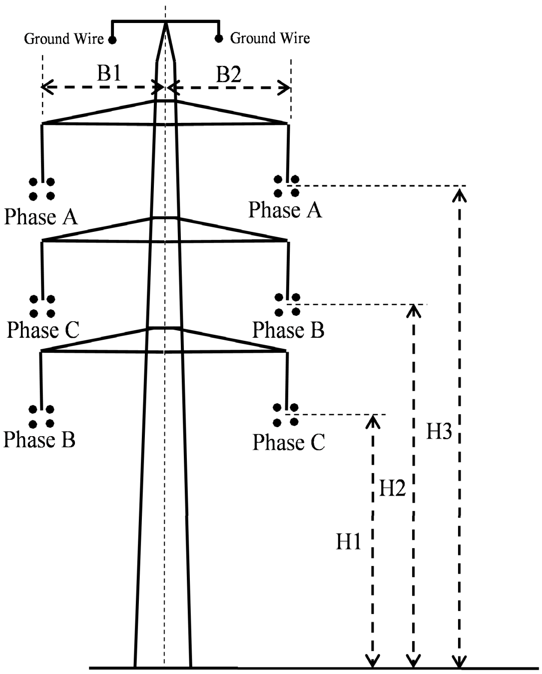

FIGURE 2. The existing line with double AC circuits of 500 kV with phase spaces and heights above ground elevation.

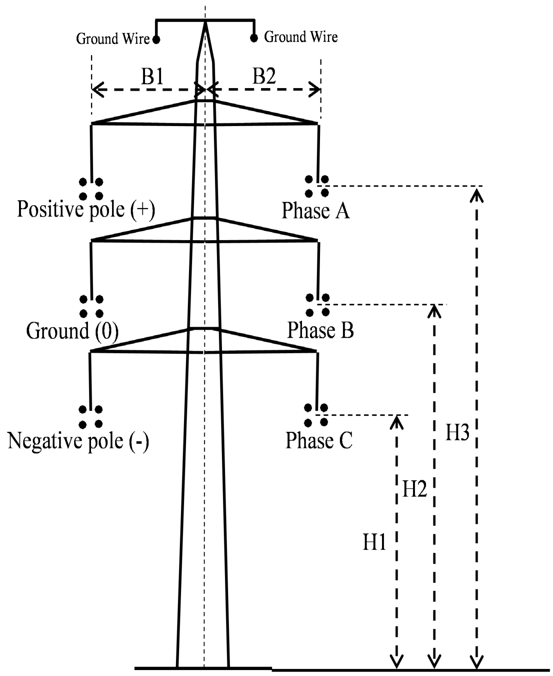

FIGURE 3. The first suggested hybrid configuration.

50.2 and 63.6 meters respectively, The B1 or B2 tower arm span is 12.8 meters [1].

A. THE FIRST PROPOSED CONFIGURATION

The common case of a hybrid configuration transforms one 3-phase AC circuit into a bipolar DC circuit and the remaining phase serves as a metallic emergency ground return path. The most proposed DC options. The first alternative is the use of the upper and the lower AC phases for its DC poles as shown in Figure 3. The first alternative consists of an 500 kV AC circuit, with four sub-conductors per conductor. For the B1500 kV, the DC circuit is the same as the replaced AC circuit without modification [1].

B. THE SECOND CONFIGURATION

It uses all AC thermal capacity by physically using conductors of one AC phase to form 6-conductor positive pole and 6- conductor negative pole as shown in Figure 4. The cost and time needed for that reconstruction leave the circuit with no ground return path other than that afforded by the earth (if that is permitted) or by upgrading the shield wire conductivity [1]. The second configuration is constituting an 500 kV AC circuit and B1500 kV DC circuit.

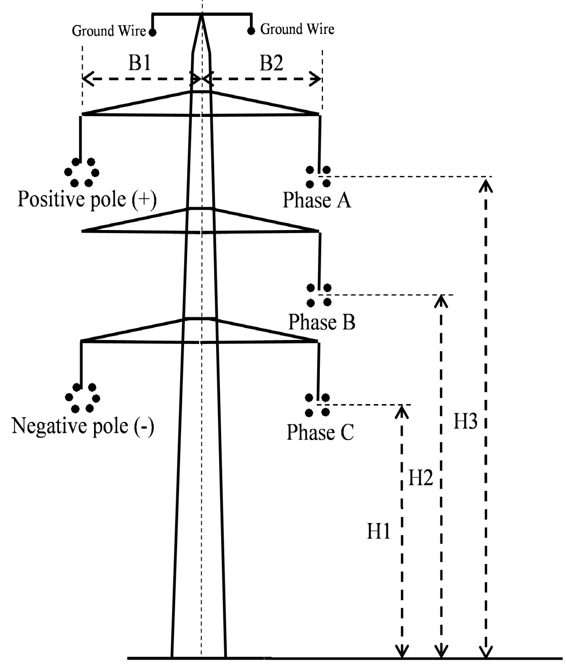

FIGURE 4. The second suggested hybrid configuration.

The third configuration is constituting double HVDC circuits of B1500 kV.

C. THE THIRD CONFIGURATION

It represents a double AC circuit conversion consisting of two separate bipolar DC circuits as shown in Figure 5. Each transformed circuit will get the same capacity and redundancy properties. Loss of any pole of the bipolar alternatives causes the bipolar operation to shut down, retaining the grounded phase as an emergency return for mono-polar operation [1].

D. THE FOURTH CONFIGURATION

It is using a full thermal capability of all conductors and has no redundancy except for what can be provided for by ground return or other options discussed above. The fourth configuration is constituting triple HVDC circuits of B1500 kV. The fourth configuration is presented in Figure 5. Alternatives In

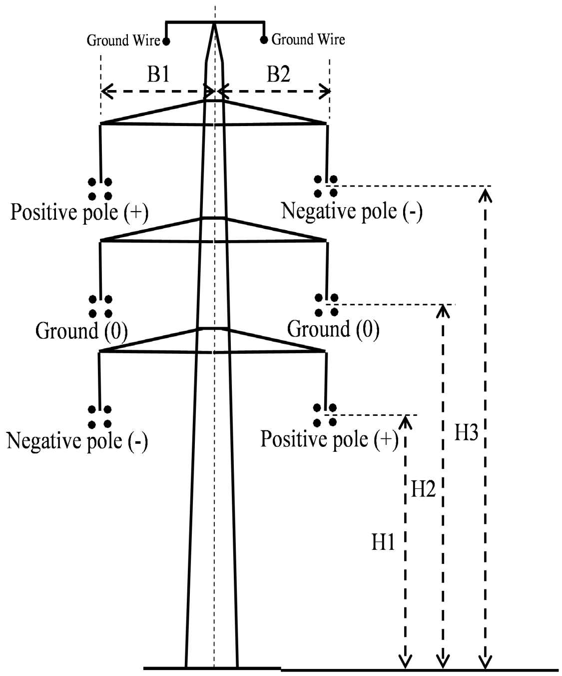

FIGURE 5. The third suggested pure HVDC configuration.

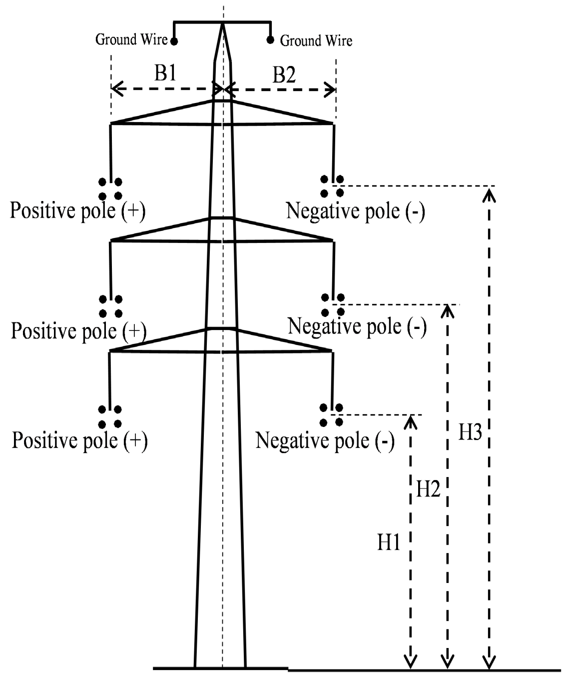

FIGURE 6. The fourth presented circuit.

Figure 1, vary in cost and terminal converter stations requirement. The succeeding parts of this paper will discuss how the DC capability of existing AC lines can be maximized by recognizing limits imposed both by technical and operational issues and by environmental impact management [1].

III. MATERIAL AND METHODS

The research compares the upgrading scenarios with the existing double-circuit 500-kV line. Costs are evaluated and compared for various AC and DC scenarios that could be adopted to increase the amount of transmitted power via the current corridor, based on standards established by the Western Electricity Coordinating Council (WECC) [18]. There are a hundred kilometers of 500-kV network sections in Egypt [19].

Electric power and cost calculations are simulated and computed by MATLAB programming codes. The study needs MATLAB as a mathematical tool to operate self built trusted codes. The codes were built based on the basic rules of power and cost calculations. These codes were operated by MATLAB to get the results. There aren't an influence from other parameters and conditions must be taken in the study, so that MATLAB is enough software for operating the codes. The technical and the theoretical analyses depends on basic concepts for power and cost calculation.

A. TRANSMISSION CAPACITY CONFIGURATIONS

1) BASELINE TRANSMISSION CONFIGURATION

The analysis compares options to upgrade the power limit of the used 500-kV double-circuit line, each circuit has 4- conductor bundles per phase. Each conductor is 553.8 mm^2 - 490/65 ACSR conductor and operates at a temperature of 50 °C [19]. The cases were divided into two different Hybrid AC/DC configurations and two different HVDC configurations.

2) SUGGESTED CONFIGURATIONS

These alternatives used the same corridor ROW, towers, and line wires. The B1500-kV HVDC bipolar circuit and 500-kV AC circuit require the same ROW, and structures of HVDC transmission [3], [12], [20], [21]. These scenarios only need additional area for the required converter stations.

B. POWER TRANSMISSION CAPACITY

Assume that there are two transmission circuits: the first one is the HVAC circuit and the other is the HVDC circuit. Both circuits have the same length and conductor sizes. The thermal limit loading for the two lines is the same so that the DC I_{dc} equals the RMS AC I_{ac}. The alternating current and direct current insulation resist a similar peak potential value to neutral. The potential V_{dc} is equal to the RMS AC voltage multiplied by the square root of (2) [21], [22], [23]. The DC power per conductor is:

$$P_{dc} = V_{dc} I_{dc}. \quad (1)$$

and the AC power per conductor is:

$$P_{ac} = V_{ac} I_{ac} cos(\phi). \quad (2)$$

where: V_{ac} is the phase AC potential (kV). V_{dc} is the pole DC potential (kV). I_{dc} is the DC current per conductor (pole) (amp). I_{ac} is the AC current per conductor (phase) (amp). $cos(\phi)$ is the power factor in case of AC transmission [21], [23].

Based on the thermal capacity of the lines, the peak of received power per conductor at any point is computed [14], [18].

$$P_{Received} = V_c I_c cos(\phi) - I_c^2 R_c. \tag{3}$$

where: $P_{Recieved}$ is the received power per conductor at any point (MW/km). V_c is the conductor-to-neutral voltage (kV). I_c is the conductor current (amp). R_c is the conductor resistance (Ω/km). For AC transmission circuit, $V_{ac} = 500/\sqrt{3}$ kV, $I_{ac} = 640$ amp, $\cos(\phi) = 0.9$ and $R_{ac} = 0.073\ \Omega/km$. For DC transmission circuit, $V_{dc} = \sqrt{2}(500/\sqrt{3})$ kV, $I_{dc} = 640$ amp, $\cos(\phi) = 1$ and $R_{dc} = 0.066\ \Omega/km$.

The power transferred per conductor is multiplied by number of bundles (n_b), number of phases/poles (n_p) and number of circuits (n_{ckt}) to determine the transmitted power through the line. For the 500-kV double-circuit HVAC transmission existing line, the first configuration and the second configuration, the number of bundles, phases and circuits are (4), (3) and (2), the delivered power per AC conductor is multiplied by the number of bundles (4), phases (3) and circuits (1) and the delivered power per DC conductor is multiplied by the number of bundles (4), poles (2) and circuits (1) respectively.

For third configuration and fourth configuration, the delivered power per DC conductor is multiplied by the number of bundles (4), poles (2) and circuits (2), the delivered power per DC conductor is multiplied by the number of bundles (4), poles (2) and circuits (3) respectively. AC substation losses is assumed 0.5%, but the HVAC/HVDC Terminals is assumed with 0.75% of power losses at each terminal [24]. We assume the lines operate at 0.9 power factor for AC circuit.

C. THE CAPITAL COST

Certain types of undertakings as defined in the MTEP require cost assessments to legitimize the feasibility study for their proposal to the MISO Board of Directors. MISO gives quotes for these specific kinds of undertakings to assess choices. MISO's transmission cost assessment guide for MTEP depicts the methodology and cost information that MISO utilizes in fostering its quotes. This present record's suspicions what's more expense information are investigated yearly with partners. All material charges are incorporated inside the expense subcategories [25].

The WECC Transmission Expansion Planning Policy Board of trustees subsidized on the capital expenses for transmission and substations [20]. The expense furthermore execution parts distinguished in those examinations were adjusted in this investigation. The capital expenses in ($) for every setup with power (megawatts) and distance (kilometers) are given by

$$Cost_{Total} = \{Cost_{Terminals} + Cost_{Lines} + Cost_{Losses}.\} \tag{4}$$

where: $Cost_{Total}$ is the configuration total cost ($/km). $Cost_{Terminals}$ is the cost of two ends converter stations with filters ($). $Cost_{Lines}$ is the transmission lines cost ($/km). $Cost_{Losses}$ is the cost of power losses ($/km).

1) AC/DC AND DC/AC CONVERTER TERMINALS COST

The power-related expenses depend on the measuring prerequisites for AC/DC and DC/AC converter stations with filters. The converter is estimated similar on each end point. ABB organization presents a financial examination of capital expenses and misfortunes for various DC transmission choices for a theoretical 750-mile, 3,000-MW transmission system [24]. by Extrapolation, the ratings and the cost of required converter stations with filters can be estimated based on ABB projects. The costs of converter station per end for configuration 1, configuration 2, configuration 3 and configuration 4 are 420 M$, 680 M$, 1070 M$ and 1720 M$ respectively.

2) TRANSMISSION LINES COST

The MISO cost calculation guide includes costs for both AC and DC power lines. Both types of power lines depend on some similar project costs (such as land costs and conductor costs), and some costs that depend on the scope of work (i.e., structure costs). The study identifies base expenditure per kilometer for various new transmission configurations, which include needed lands, development of structures and connectors [25]. The capital expense per distance computation for configurations is computed from the following formula [20],

$$Cost_{Trans}(\$/km) = \{Cost_{Cond} + Cost_{ROW} + Cost_{Towers}.\} \tag{5}$$

where: $Cost_{Trans}$ is the total cost of transmission line ($/km). $Cost_{Cond}$ is the cost of conductors ($/km). $Cost_{ROW}$ is the needed land cost ($). $Cost_{Towers}$ is the cost of tower structures ($/km).

From previous formula, three parts of transmission line can be noted. Cost breakdown of each scenario was analysed. For higher transmitted power by construction new HVAC line, all parts of transmission line cost will be needed. The total cost per km for new HVAC line is 3.9044 M$/km. For the first, third and fourth Configurations, the existing lines will be used without any additional cost. For configuration 2, conductors arrangement will be modified. The cost per km for that modification is 0.4754 M$/km.

3) ENERGY LOSSES COST

Ohmic and transformation losses across the configurations due to the distinctions and terminals is calculated. The power lost will be represented for 25-y systems costs. Losses are due to the straight increment of line resistance with distance and converters terminals. These losses are converted to energy consumption (MWhr). Yearly losses for 25 years, beginning in the present, are determined utilizing this strategy. The future value (F) of these expenses is registered utilizing a rate of 10%. The future value equals [26],

$$F_n = P(1 + r)^n. \tag{6}$$

where: F_n is Future value or accumulated amount, P is Present value or one-time investment today, r is Interest rate per periods, and n is Number of years from today.

A 60 percent capacity factor, or line usage, for example, refers to a peak consumption of 60 percent of hours at full load and a minimal usage of 60 percent of hours at full load. $((0.6 * FullLoad) + (0.6^2 * FullLoad))/2 = 0.48 * FullLoad$ would be the average of these numbers. A load adjustment factor of 48% is what this is known as [20].

Using the transmission configuration, conductor and full load adjustment (FLA) 0.595 would correspond to a maximum utilization of 70 percent of hours at full load [20], transmission line losses are calculated according to the following equation [20]:

$$E = \Big\{[P_{C.L} + (I_c^2 * R_c * n_b * n_p * n_{ckt})] * (FLA) * 8760 * Cost_{MWhr} * (1 + r)^n\Big\} \quad (7)$$

where: E is Energy losses cost per km, $Cost_{MWhr}$ is MWhr cost and $P_{C.L}$ is Converter power losses.

IV. THE RESEARCH FINDINGS AND DISCUSSION

A. ACHIEVABLE TRANSMISSION CAPACITY

The right column of table 1 shows a very simplified power rating percentage index, $\bar{P}$, which is the MW rating of the converted configuration assuming the full thermal use of the conductors divided by the MW rating of the primary current configuration, by converting to a simple dipole configuration energized with a DC voltage equal to the peak line-to-ground AC voltage. This indicator is a rough approximation because configuration selection and other factors often affect the DC voltage that can be maintained under DC operation and may also affect the limited load reliability of parallel or adjacent AC circuits [1].

The updated designs are looked at as expansion in conveyed power under ordinary working conditions. Figure 7 illustrates the increases in conveyed power for all proposed designs relative to the baseline, but the total conveyed power decreases with distance for all cases due to Ohmic losses. The increases in conveyed power percentage over different distances are clear as shown in figure 8, and the percentage increase in conveyed power is higher at longer distances relative to the AC baseline due to the losses in the AC baseline being higher than in the proposed designs.

From table 1, within the existing corridor and over the distance; the first, second, third, and fourth configurations can provide an increase of (2% to 5%), (29% to 32%), (5% to 9%) and (57% to 64%) respectively. The feasibility of accomplishing expansions in conveyed power over various distances with each kind of updated AC design was discussed. Rate expansion in the power transmission limit above the current 500 kV double-circuit line is determined by the ideal power expansion. Ohmic losses are subtracted from power.

B. COST COMPARISON

The overall cost was estimated as the amount of development capital expenses and the 25-y net future worth (F) of line losses, accepting a discount energy cost of 68.6$ each megawatt hour, most extreme planned burden (i.e., load adjustment factor 0.595), and 10% discount rate. Figure 9 shows the total cost per (Gigawatt) calculation results for each configuration.

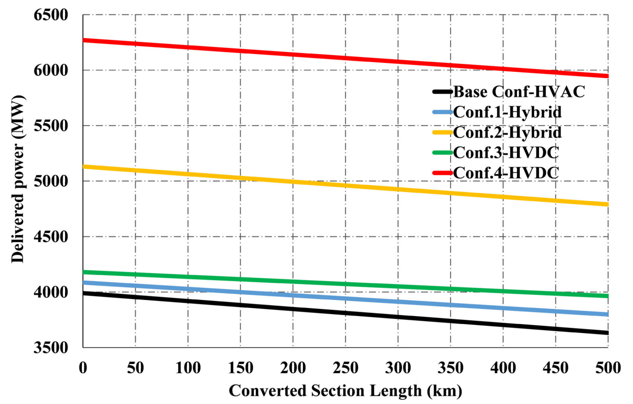

FIGURE 7. Decrease in conveyed power rate over various distances with each kind of AC update due to ohmic losses.

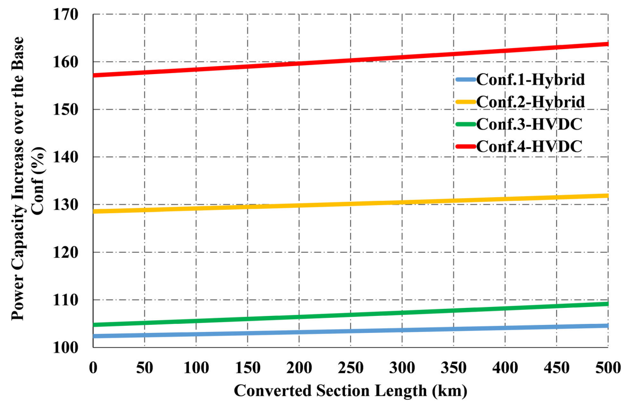

FIGURE 8. Increases in conveyed power rate over various distances with each kind of AC update scenario.

TABLE 1. Increments in conveyed power rate over various distances with each kind of AC update scenarios.

Alternatives	$\bar{P}$(Received Power Percentage) (%)
Configuration 1	102:105
Configuration 2	129:132
Configuration 3	105:109
Configuration 4	157:164

A DC line has a cheaper cost per unit length than an AC line of equivalent power capacity and reliability, but the cost of terminal equipment for a DC line is substantially higher than for an AC line. As shown in the Figure 9, the slope of each curve is the cost per unit length of the line. The break-even distance is defined at the AC transmission curve intersection point with the DC transmission curve. If the transmission distance is less than the break-even distance, AC transmission is less expensive than DC; if the distance is greater, DC transmission is less expensive.

Figure 9 explains the overall cost per gigawatt evaluation consequences for each configuration and calculate the break-even distance for the lines. The first, second, third,

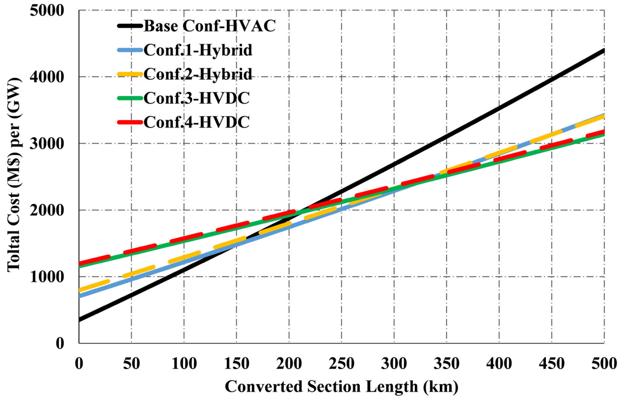

FIGURE 9. Comparison of projects cost for proposed configurations and baseline configuration.

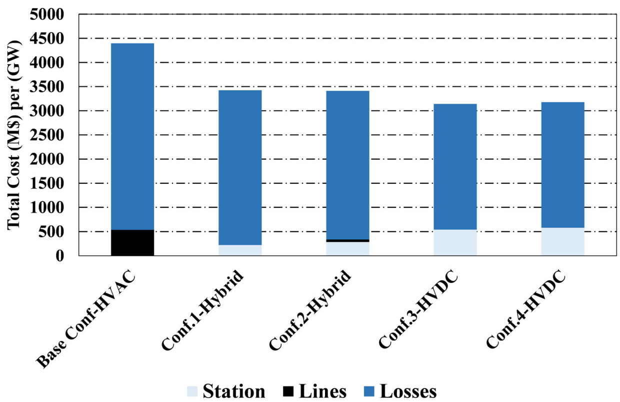

FIGURE 10. Cost breakdown comparison of various configurations.

and fourth configurations can provide lower costs than the baseline after 148, 171, 212, and 221 km respectively. it is noticed that after 323 km the cost of configuration 3 is less than that of configuration one and configuration four is cheaper than configuration 2. Given the relative novelty of DC transmission, there is a prospect for a greater decrease in the unit cost of DC line terminals with increasing experience and volume of production than in the cost of AC equipment. The result would be to decrease the break-even distance [23].

Figure 10 clears the cost breakdown of each configuration, which divides into main three parts. these parts are the terminal station cost, transmission line construction or modification cost, and energy losses cost over 25 years. Converter stations costs for configuration 1, configuration 2, configuration 3, and configuration 4 are 41.15%, 52.83%, 100.48%, and 107.68% of the baseline configuration new transmission line construction cost respectively. Energy losses costs over 25 years for configuration 1, configuration 2, configuration 3, and configuration 4 are 82.94%, 79.71%, 67.36%, and 67.36% of the baseline configuration energy losses cost respectively. Overall costs at 500 km for configuration 1, configuration 2, configuration 3, and configuration 4 are 77.83%, 77.55%, 71.40%, and 72.28% of the baseline configuration total cost respectively.

TABLE 2. Power percentage increase and cost discount ranges over converted section length starting from break even distance update scenarios.

Option	Converted Section Length (km)	Power Percentage Increase Range (%)	Reduction Cost Percentage Range (%)
First Configuration	148 :500	103:105	0:22.17
Second Configuration	171:500	130:132	0:22.45
Third Configuration	212:500	107:109	0:28.60
Fourth Configuration	221:500	160:164	0:27.72

For transmitting power at long distance (more than 221 km), You may say that configuration 4 is the best configuration which gives maximum transmitted power to be (60% to 64%) greater than the AC line value, with cost less than that of AC line (100% to 72.28%) as shown in the table 2.

V. CONCLUSION

The existing Egyptian 500 kV double circuit line is studied carefully to find solutions for increasing the transmitted power with cost reduction. Different alternatives are introduced. Four different hybrid and HVDC configurations are suggested by using the existing lines to mitigate the cost. For power calculations, the power per conductor technique is used to compute the transmitted power over each configuration. The cost for modification with each configuration was calculated by basic economics rules. Each configuration was analysed to calculate the break-even distance, the power percentage increase and the cost mitigation percentage. The suitable configuration depends on the transmission distance of converted section, the power increase percentage is required and the available package for converting that section.

REFERENCES

[1] J. Lundquist, L. Barthold, A. Beutel, A. Britten, D. Douglass, J. Iglesias, V. Jankov, J. Jardini, D. Muftic, and S. Steevens, "Guide to the conversion of existing AC lines to DC operation," é Technical Brochure 583-Working Group B2 41, Tech. Rep., 2014.

[2] P. Pramayon et al., "Increasing capacity of overhead transmission lines needs and solutions," Cigré, Paris, France, Tech. Rep. TB JWG B2/C1.19, 2010.

[3] A. T. Mohamed, A. Elmorshdy, A. M. Emam, and M. M. Samy, "Optimum configuration for higher transmission ratings for proposed hybrid overhead power lines in Egypt electric utility," in *Proc. 22nd Int. Middle East Power Syst. Conf. (MEPCON)*, Dec. 2021, pp. 665–671.

[4] A. Elmorshdy, M. M. Samy, and A. M. Emam, "Field profiles underneath and between proposed hybrid power lines in Egyptian grid," in *Proc. 21st Int. Middle East Power Syst. Conf. (MEPCON)*, Dec. 2019, pp. 724–730.

[5] M. Samy, A.-E. M. El-Zein, and M. Abdel-Salam, "Electric field profiles and right-of-way widths as influenced by grounded shield wires underneath EHV direct current transmission lines," in *Proc. Int. Conf. Electr. Eng. (ICEENG)*, vol. 6. Cairo, Egypt: Military Technical College, 2008, pp. 1–12.

[6] A. Z. E. Dein, O. E. Gouda, M. Lehtonen, and M. M. F. Darwish, "Mitigation of the electric and magnetic fields of 500-kV overhead transmission lines," *IEEE Access*, vol. 10, pp. 33900–33908, 2022.

[7] R. M. Radwan, A. M. Mahdy, M. Abdel-Salam, and M. M. Samy, "Electric field mitigation under extra high voltage power lines," *IEEE Trans. Dielectr. Electr. Insul.*, vol. 20, no. 1, pp. 54–62, Feb. 2013.

[8] A. Z. El Dein, "Mitigation of magnetic field under Egyptian 500 kV overhead transmission line," in *Proc. 4th Int. Power Eng. Optim. Conf. (PEOCO)*, Jun. 2010, pp. 215–220.
[9] V. Komoni, I. Krasniqi, G. Kabashi, and A. Alidemaj, "Increase power transfer capability and controlling line power flow in power system installed the facts," Tech. Rep., 2010.
[10] L. Colla, M. Rebolini, S. Malgarotti, and U. Zanetta, "Analysis on the possible conversion of overhead lines from AC to DC," in *Proc. Cigre*, vol. 2, 2010.
[11] D. M. Larruskain, I. Zamora, O. Abarrategui, and Z. Aginako, "Conversion of AC distribution lines into DC lines to upgrade transmission capacity," *Electr. Power Syst. Res.*, vol. 81, no. 7, pp. 1341–1348, Jul. 2011.
[12] M. Häusler, G. Schlayer, and G. Fitterer, "Converting ac power lines to DC for higher transmission ratings," *ABB Rev.*, pp. 4–11, 1997.
[13] M. Moradi-Sepahvand and T. Amraee, "Hybrid AC/DC transmission expansion planning considering HVAC to HVDC conversion under renewable penetration," *IEEE Trans. Power Syst.*, vol. 36, no. 1, pp. 579–591, Jan. 2021.
[14] L. Reed, M. G. Morgan, P. Vaishnav, and D. E. Armanios, "Converting existing transmission corridors to HVDC is an overlooked option for increasing transmission capacity," *Proc. Nat. Acad. Sci. USA*, vol. 116, no. 28, pp. 13879–13884, Jul. 2019.
[15] R. Adapa, L. Barthold, and D. Woodford, "Technical and economic incentives for AC to DC line conversion," Int. Council Large Electr. Syst., Paris, France, Tech. Rep., 2010.
[16] M. M. Samy, "Computation of electromagnetic fields around HVDC transmission line tying Egypt and KSA," in *Proc. 19th Int. Middle East Power Syst. Conf. (MEPCON)*, Dec. 2017, pp. 1276–1280.
[17] (2022). *HVDC (High Voltage Direct Current)*. [Online]. Available: https://www.siemens-energy.com/global/en/offerings/power-transmission/portfolio/high-voltage-direct-current-transmission-solutions.html
[18] R. Thrash, *Overhead Conductor Manual*. Carrollton, GA, USA: Southwire Company, 2007.
[19] *Environmental and Social Impact Assessment (ESIA) for 6th of October 500 Substation and its Interconnecting Overhead Transmission Lines*, EcoConServ, Cairo, Egypt, 2020.
[20] R. Pletka, J. Khangura, A. Rawlins, E. Waldren, and D. Wilson, "Capital costs for transmission and substations," Western Electr. Coordinating Council, Salt Lake City, UT, USA, Tech. Rep., 2014, p. 35.
[21] T. Gonen, *Electrical Power Transmission System Engineering: Analysis and Design*. Boca Raton, FL, USA: CRC Press, 2019.
[22] A. Clerici, L. Paris, and P. Danfors, "HVDC conversion of HVAC lines to provide substantial power upgrading," *IEEE Trans. Power Del.*, vol. 6, no. 1, pp. 324–333, Jan. 1991.
[23] E. W. Kimbark, *Direct Current Transmission*, vol. 1. Hoboken, NJ, USA: Wiley, 1971.
[24] M. P. Bahrman and B. K. Johnson, "The ABCs of HVDC transmission technologies," *IEEE Power Energy Mag.*, vol. 5, no. 2, pp. 32–44, Mar./Apr. 2007.
[25] *Transmission Cost Estimation Guide for MTEP21*, MISO, 2021.
[26] R. L. Weil, K. Schipper, and J. Francis, *Financial Accounting: An Introduction to Concepts, Methods and Uses*. Boston, MA, USA: Cengage Learning, 2013.

AHMED TALEB MOHAMED was born in Egypt, in January 1994. He received the B.Sc. (Hons.) and M.Sc. degrees in electrical engineering from Cairo University, Giza, Egypt, in 2017 and 2022, respectively.

He is currently an Assistant Lecturer with the Faculty of Engineering, Cairo University. His research interests include electric and magnetic fields, hybrid grids, high-voltage engineering, machine drives, and power electronics.

AHDAB EL-MORSHEDY received the B.Sc., M.Sc., and Ph.D. degrees in electrical engineering from Cairo University, in 1971, 1974, and 1978, respectively. From 1971 to 1974, she was a Teaching Assistant, from 1974 to 1978, she was an Assistant Lecturer, from 1978 to 1983, she was an Assistant Professor, and since 1983, she has been an Associate Professor with the Department of Electrical Engineering, Cairo University. From 1979 to 1981, she was a Postdoctoral Researcher and a Research Fellow with The Ohio State University, Columbus, OH, USA, on a sabbatical leave. Her research interests include voltage transients, insulation coordination problems of EHV transmission lines, the characteristics of polluted insulators, and substation grounding.

ELSAYED TAG-ELDIN was the Dean of the Faculty of Engineering, Cairo University, where he achieved many unique signs of progress in both academia and research on the impact of emerging technologies in electrical engineering. He is currently with the Faculty of Engineering and Technology, Future University in Egypt, on leave from Cairo University after nearly 30 years of service to the Faculty of Engineering, Cairo University. He was a PI of several nationally and internationally funded projects. He has many publications in highly refereed international journals and specialized conferences on the applications of artificial intelligence in protection of electrical power networks.

He is on the editorial boards of several international journals.

AHMED EMAM received the B.Sc., M.Sc., and Ph.D. degrees in electrical engineering from Cairo University, Giza, Egypt, in 1998, 2002, and 2010, respectively.

He is currently a Teacher with the Faculty of Engineering, Cairo University. His research interests include electric and magnetic fields, transient over voltage, and digital protection.

MOHAMED MAHMOUD SAMY received the B.Sc. degree in electrical engineering from the Faculty of Engineering and Technology, Banha University, Banha, Egypt, in 1995, the M.Sc. degree in electrical power and machines from Zagazig University, Zagazig, Egypt, in 2007, and the Ph.D. degree from Cairo University, Giza, Egypt, in 2011.

He is currently an Associate Professor with the Electrical Engineering Department, Faculty of Engineering, Beni-Suef University, Beni-Suef, Egypt. He is also on leave as a Visiting Professor from the Faculty of Engineering, Albaha University, Albaha, Saudi Arabia.

Prof. Samy was elected as a Technical Program Committee (TPC) Member of the Third International Conference on Energy Engineering and Environmental Protection (EEEP2018). In 2012, he was awarded the prize of Best Ph.D. Thesis in electrical engineering from the Faculty of Engineering, Cairo University.