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On the Conversion of an Existing Practical AC Transmission System to DC

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ABSTRACT. The technical factors that should be considered in the conversion of an existing practical AC transmission system to DC in order to increase its power transfer capability (PTC) are discussed. Economical considerations in this AC/DC transmission conversion are also discussed. Possible conversion schemes of single-circuit and double-circuit AC lines are identified. An analytical methodology based on assumed design constraints is developed and new indices are proposed to evaluate the effectiveness of the AC/DC transmission conversion. The main objectives of the proposed methodology are to determine the design levels of current, voltage and uprated power for the converted DC system and to provide main ratings and basic characteristics of the rectifier and the inverter stations. Provided in this paper are results of the application of the proposed methodology and effectiveness indices to the existing 500 kV High Dam-Cairo AC double-circuit transmission line in Egypt as an alternative to increase its PTC.

1. Introduction

There have been several practical alternatives to increase the power transfer capability of an existing AC transmission system. These alternatives include using series capacitor compensation[1], conversion of AC transmission to DC transmission[2], and 6-phase operation of existing 3-phase double circuit lines[3].

This paper discusses technical and economical considerations that should be taken into account in the conversion of an existing practical AC transmission system to DC operation in order to increase the power transfer capability of the existing rights-of-way.

The obvious saving by this conversion approach is that a new line does not have to be built. This saving should then be weighed against several costs including the cost of the DC terminal equipment and evaluation of the extra losses due to the higher current capacity.

The economics of conversion has been emphasized due to the fact that AC transmission line costs tend to increase directly with inflation whereas the DC converter costs have shown less of an increase due to the technological advancements in the converter equipment[2].

There are two reasons for increasing the power transfer capacity by the conversion to DC: i) The line design can stand higher DC voltage to ground, and ii) The conductors can be operated at a higher current limited only by thermal limit and loss considerations in contrast to stability limitations applicable to AC lines.

Proposed in this paper are an analytical methodology based on assumed design constraints and two new indices for the technical and economical evaluation of the effectiveness of the AC/DC transmission conversion of any existing practical system.

This paper presents the results of the application of the proposed AC/DC transmission conversion methodology and effectiveness indices to the existing High Dam-Cairo 500 kV double-circuit line in Egypt as an alternative to increase its power transfer capability.

The paper describes two proposed conversion schemes and gives main ratings and basic characteristics of the proposed converted DC system.

The information presented in this paper should be of great interest to power system planners and electric utility engineers.

2. Possible Conversion Schemes

2.1 Single-Circuit Conversion

Since the DC line requires only two conductors converting a single circuit line leaves us with one extra conductor that could be made parallel with one pole conductor and thereby reduce the losses, or it could be used for metallic return and thereby can eliminate ground electrodes and have lower interference. See Fig. 1-a for this conversion[2].

For single-circuit conversion, insulators are added and no conductors are added.

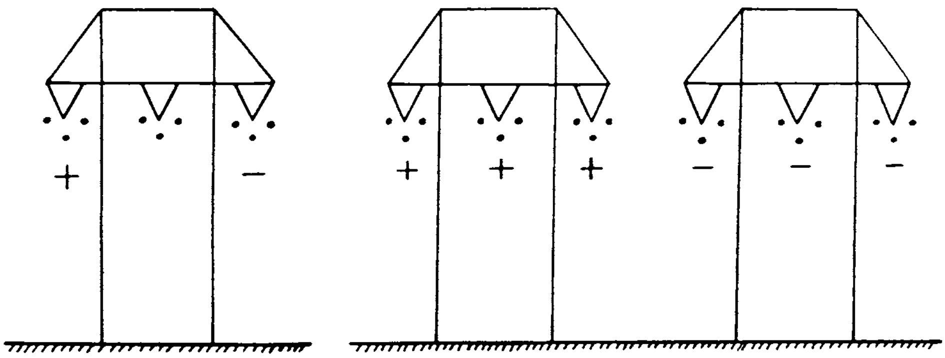
A single-circuit conversion leads to one bipolar DC line of power transfer capability equals P.

2.2 Double-circuit Conversion

A double circuit is natural for conversion in that it will offer the same number of conductors on positive and negative poles as shown in Fig. 1-b[2].

The double-circuit AC transmission system will be converted to three parallel DC bipolar lines of PTC equals $3P$.

For double-circuit conversion, insulators are added and no conductors are added.



(a) Conversion of one AC circuit to bipolar DC line.

(b) Conversion of a double AC circuit to 3 bipolar DC lines.

FIG. 1. Configuration of possible conversion schemes.

3. Technical Considerations

3.1 Limiting Factors

Of great importance to the conversion of AC transmission to DC are the considerations of both factors affecting line loadability and insulation levels for AC and DC transmission. For AC transmission, there are three considerations that affect loadability; thermal, voltage drop and stability. Importantly for DC, only thermal and voltage drop limitations apply. The following technical limiting factors should be considered in the conversion of AC transmission to DC operation :

(a) Thermal limitation: Stability limits usually restrict the maximum power that can be transmitted by an AC line to some fraction of its thermal capacity. A DC line can be loaded up to its thermal limit although a margin is usually maintained for emergency capacity, and also the cost of losses at maximum capacity may not be economically acceptable.

There is another small advantage for the DC transmission which we can benefit from, and that is the absence of skin effect associated with the DC current and therefore lower resistance and as a consequence increased current for the same temperature rise.

As a rule, the current carrying capacity and temperature limit of the existing conductors should not be exceeded when the same conductors are used to carry the uprated level of power obtained by the conversion to DC transmission.

(b) Voltage drop limitation: Since a converted DC line will carry as high DC current as possible, evaluation of power losses and voltage drops must be considered. Voltage drop limitation sets a limit on how much current can be carried over the converted DC line.

A voltage drop of 0.625-1.25 percent per 100 km of the DC line is taken as the limit used in the proposed conversion methodology and is the same limit recommended in Reference [2].

(c) Insulation level limitation: Insulation level is one of the important factors which normally set a limit on how much voltage can be applied to the converted DC line.

Assuming that the direct voltage for the breakdown of an insulator is equal to the peak value of the alternating voltage to cause breakdown, the insulation level of the existing AC line = $K_1 \sqrt{2}\ (V_L / \sqrt{3}\ )$ and the insulation level of the converted bipolar DC line = $K_2\ V_d$ where K_1 and K_2 are AC and DC switching surge factors in per unit respectively, V_L is the AC line-to-line voltage, and V_d is the DC voltage per pole to ground.

The DC voltage which can be applied would at least be equal to the peak AC voltage to ground. There is, however, another aspect to the voltage capability for DC and that is that the switching overvoltages on a DC line are much lower than on the AC line. On fairly long AC lines the switching surge factor (SSF) may be between 2.0 and 2.4. For DC lines the SSF may be at the most 1.7. It is very likely that in the AC/DC transmission conversion more insulators in a string than previously used will be required.

Research tests in Britain[4] have indicated that due to atmospheric conditions about 10 percent greater leakage path is required for DC than was used for AC.

3.2 System Equations

For an existing multiple-circuit AC transmission system, the following equations are used to calculate the operating level of active power (P_{ac}), and the power losses (P_{Lac}) :

$$P_{ac} = n_c\ (\sqrt{3}\ V_L\ I_{ac} \cos \phi) \tag{1}$$

$$P_{Lac} = n_c\ (3\ I_{ac}^2\ R_{ac}) \tag{2}$$

where n_c = number of circuits.

$\cos \phi$ = power factor.

$$\text{Or } P_{ac} = n_c \{ V_L^2 / B \cos (BA - \delta) - A\ V_L^2 / B \cos (BA\text{-}AA) \} \tag{3}$$

where $A\underline{/AA}$ and $A\underline{/BA}$ are the generalized constants per one circuit of the AC line, and δ is the transmission angle in degrees.

For one bipolar line of the converted DC system, the DC power ($P_{dc\,1}$) and the power losses ($P_{Ldc\,1}$) are given by the following equations :

$$P_{dc\,1} = P = 2\ V_d\ I_d \tag{4}$$

$$P_{Ldc\,1} = 2\ I_d^2\ R_{dc} \tag{5}$$

For n_b-bipole DC system, we have

$$P_{dc} = n_b P = n_b (2V_d I_d) \tag{6}$$

$$P_{Ldc} = n_b (2 I_d^2 R_{dc}) \tag{7}$$

It should be noted that for single-circuit conversion, $n_c = 1$ and $n_b = 1$, and for double-circuit conversion $n_c = 2$ and $n_b = 3$.

3.3 Definitions of DC/AC Ratios

In order to develop the methodology of converting an existing AC transmission system to DC, the following DC/AC ratios are defined :

$$\text{Power loss ratio } (\lambda) = \frac{\text{DC power losses of the converted DC system}}{\text{AC power losses of the existing AC system}}$$

$$= P_{Ldc} / P_{Lac} \tag{8}$$

$$\text{Power ratio } (\beta) = \frac{\text{DC power of the converted DC system}}{\text{AC power of the existing AC system}}$$

$$= P_{dc} / P_{ac} \tag{9}$$

$$\text{Resistance ratio } (\psi) = \frac{\text{DC resistance per pole}}{\text{AC resistance per phase}}$$

$$= R_{dc} / R_{ac} \tag{10}$$

$$\text{Insulation level ratio } (\gamma) = \frac{\text{DC insulation level}}{\text{AC insulation level}}$$

$$= K_2 V_d / (K_1 \sqrt{2} (V_L / \sqrt{3})) \tag{11}$$

3.4 Analytical Expressions of λ, β, and γ

Substituting Equations (1), (2), (6), (7), and (10) into Equations (8), (9), and (11), the following analytical expressions are obtained for λ, β, and γ :

$$\lambda = (2/3) (n_b / n_c) \psi (I_d^2 / I_{ac}^2) \tag{12}$$

$$\beta = (2 / \sqrt{3}) (n_b / n_c) (V_d / V_L) (I_d / I_{ac}) (1 / \cos \phi) \tag{13}$$

$$\gamma = (\sqrt{3} / \sqrt{2}) (K_2 / K_1) (V_d / V_L)$$

$$= (\sqrt{3} / 2) (K_2 / K_1) \beta (\sqrt{n_c} / \sqrt{n_b}) (\sqrt{\psi} / \sqrt{\lambda}) \tag{14}$$

4. Economical Considerations

Conversion of an existing AC transmission system to DC leads to an increase in the amount of power than can be carried over the existing right-of-way from P_{ac} to P_{dc} as calculated from Equations (1) and (6) respectively. For steady state stability considerations, the angle δ is assumed to be 25 degrees.

It is assumed that this advantage of increasing the PTC is economically equivalent to the cost of an AC transmission line of an operating level of power equals the difference ($P_{dc} - P_{ac}$), and of the same length ℓ in km, and same rated voltage V_L in kV of the original existing AC line. It should be mentioned that this approach of economically expressing the increase in the PTC was used for series-capacitor compensations[5]. But at maximum loading condition.

If SC_{line} is the specific cost in US$/MW/km of the line at operating conditions, then the increase of the PTC is financially equivalent to a saving of

$$S_1 = SC_{line} * \ell * (P_{dc} - P_{ac}) = H_1 (P_{dc} - P_{ac}) \qquad (15)$$

where $H_1 = SC_{line} * \ell$, and ℓ is the line length in km

The saving given by Equation 15 should be weighed against the cost of the DC terminals, the cost of the reactive power compensation required, the cost of the extra losses due to the higher current carried over the converted DC lines, and the cost of adding new insulators to the existing line. In the following, formulas are given for the calculation of these costs :

4.1 Cost of DC Terminals

Literature review has shown that no attempt has been done to develop a cost function for DC terminals. However, Reference [2] provides a curve showing the specific cost of the DC terminal in US$/converter/KW versus the terminal size in MW. In this paper, curve fitting techniques[6] are used to develop a cost formula for DC terminals based on that curve of Lindh[2] which is shown in Fig. 2.

The developed specific cost function is expressed by

$$SC_{conv} = A\, R_{conv}^{-B} \qquad (16)$$

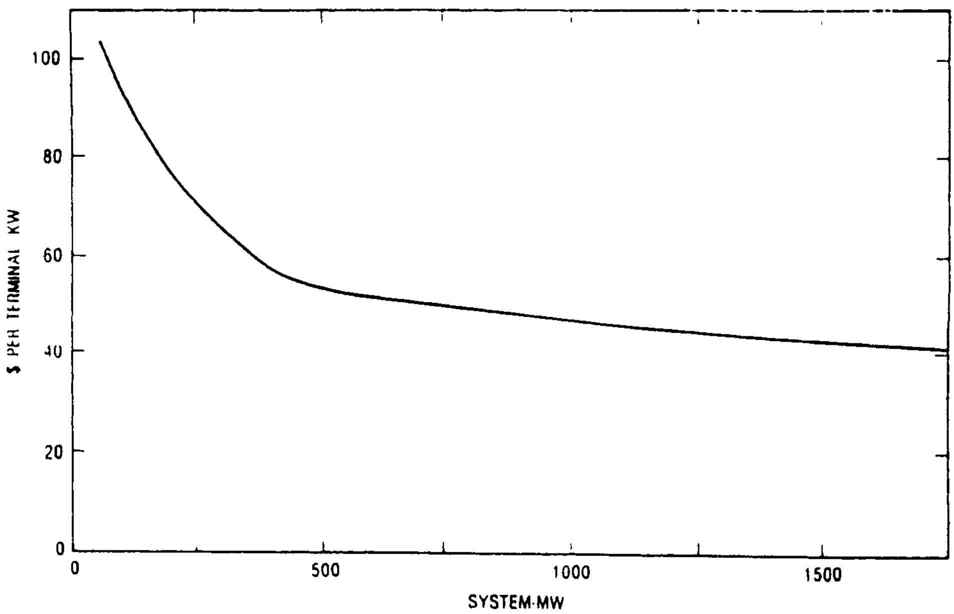


FIG. 2. Price terminal / KW vs DC terminal size.

where, SC_{conv} = specific cost in US$/converter/KW

R_{conv} = rating of converter in MW

A = constant = 346.0

B = constant = 0.29

Cost of a DC converter (C_{conv}) in US$ is given by

$$C_{conv} = SC_{conv} * R_{conv} * 10^3$$

$$= A\, R_{conv}^{1-B} * 10^3 \tag{17}$$

If n_t is the number of DC converters in series per pole, then the cost of DC converters per bipole (C_{bp}) is

$$C_{bp} = 4\ n_t\ C_{conv} \tag{18}$$

For the converted DC system with n_b bipoles, the total cost of DC terminals (C_t) in US$ is given by

$$C_t = 4\ n_b\ n_t\ C_{conv}$$

$$= (\,4\ n_b\ n_t\ A * 10^3\,)\ R_{conv}^{1-B} \tag{19}$$

But R_{conv} is related to the DC system power (P_{dc}) by

$$P_{dc} = 2\ n_b\ n_t\ R_{conv} \tag{20}$$

Substituting Equation (20) into Equation (19), we get

$$C_t = H_2\ P_{dc}^{1-B} \tag{21}$$

where, $H_2 = 2^{1+B}\ (\,n_b\ n_t\,)^B\ A * 10^3$

For a specific DC system, H_2 is constant.

4.2 Cost of Reactive Power Compensation

It is assumed in this paper that reactive power requirements are provided by static capacitors. If SC_c is the specific cost of the compensating capacitors in US$/MVAR, then the cost of the reactive power compensation (C_{react}) is given by

$$C_{react} = SC_c * Q_c \tag{22}$$

where, Q_c = rating of capacitors per terminal in MVAR.

It is a well known fact that the reactive power demand at each terminal of a DC line is typically 50-60 percent of the MW rating of the terminal[7]. Therefore, Q_c can be expressed as

$$Q_c = K_r\ R_{conv} \tag{23}$$

where K_r is a constant having a typical value of 50-60%.

The total cost of reactive power compensation required for the converted DC system is given by

$$C_r = 2 \; K_r \; SC_c \; P_{dc} = H_3 \; P_{dc} \tag{24}$$

where, $H_3 = 2 \; K_r \; SC_c$

4.3 Cost of Losses

If SC_{loss} is the specific trasmission loss cost in US\$/MW, then the cost of the extra losses due to the higher current in the DC system is expressed as

$$C_{loss} = SC_{loss} \; (P_{Ldc} - P_{Lac}) \tag{25}$$

where P_{Lac} and P_{Ldc} are as given by Equations (2) and (7) respectively.

Using Equations (6), (7), (10) and (11), P_{Ldc} is expressed as

$$P_{Ldc} = K_3 \; (P_{dc}^2 \; / \; \gamma^2) \tag{26}$$

where, $K_3 = \frac{3}{4} \; (\frac{K_2}{K_1})^2 \; \frac{\psi}{n_b} \; (R_{ac} \; / \; V_L^2)$

Substituting Equation (26) into Equation (25), we have

$$\begin{aligned} C_{loss} &= SC_{loss} \; K_3 \; (P_{dc}^2 \; / \; \gamma^2) - SC_{loss} \; P_{Lac} \\ &= H_4 \; (P_{dc}^2 \; / \; \gamma^2) - SC_{loss} \; P_{Lac} \end{aligned} \tag{27}$$

where, $H_4 = K_3 \; SC_{loss}$

4.4 Cost of Adding New Insulation

The cost of adding new insulation to the existing line can be estimated as follows

$$\frac{\text{cost of DC insulation}}{\text{cost of AC insulation}} = \frac{\text{DC insulation level}}{\text{AC insulation level}} = \gamma \tag{28}$$

If SC_{insu} is the specific cost of insulation in US \$/kV/km, then the cost of AC insulation (C_{insu}) is

$$C_{insu} = SC_{insu} \; V_L \; \ell \tag{29}$$

Therefore the cost of adding new insulation (C_{as}) is

$$C_{as} = (\gamma - 1) \; C_{insu} = (\gamma - 1) \; SC_{insu} \; V_L \; \ell \tag{30}$$

4.5 Net Saving

The net saving (S) achieved by AC/DC transmission conversion is obtained by

$$S = S_1 - C_t - C_r - C_{loss} - C_{as} \tag{31}$$

where: S_1, C_t, C_r, C_{loss} and C_{as} are as given by Equations (15), (21), (24), (27), and (30) respectively.

Therefore, the analytical expression of S is

$$S = H_1 (P_{dc} - P_{ac}) - H_2 P_{dc}^{1-B} - H_3 P_{dc} - H_4 (P_{dc}^1 / \gamma^2) + SC_{loss} P_{Lac} - (\gamma - 1) C_{insu} \quad (32)$$

5. Proposed Conversion Effectiveness Indices

Compensation effectiveness indices have been used[8] to measure the effectiveness of applying series/shunt compensation to AC transmission systems. In this paper, the effectiveness of AC/DC transmission conversion is evaluated by using new proposed indices, called "conversion effectiveness indices", that are defined in the following :

a) Power capacity improvement index (E_p) in percent

$$E_p = (P_{dc} - P_{ac}) / P_{ac} * 100 \quad (33a)$$

$$= (\beta - 1) * 100 \quad (33b)$$

b) Cost reduction index (E_c) in percent

$$E_c = (S / S_1) * 100 \quad (34)$$

In the above Equations (33-34), P_{ac}, P_{dc}, β, S_1, and S are given by Equations (1), (6), (13), (15) and (32) respectively. By substituting these equations in Equations (33) and (34), the following analytical expressions are obtained for the above proposed indices

$$E_p = ((2 / \sqrt{3}) (n_b / n_c) (V_d / V_L) (I_d / I_{ac}) (1 / \cos \phi) - 1) * 100 \quad (35)$$

$$E_c = [1 = \frac{H_2 P_{dc}^{1-B} + H_3 P_{dc} + H_4 (P_{dc}^2 / \gamma^2) - SC_{loss} - P_{Lac} + (\gamma - 1) C_{insu}}{H_1 (P_{dc} - P_{ac})} * 100 \quad (36)$$

The effectiveness of AC/DC transmission conversion is evaluated through the analysis of indices E_p and E_c. The effectiveness index E_p is introduced to measure the improvement in the power transfer capability of the existing right-of-way due to the AC/DC transmission conversion. Also E_p helps in comparing different conversion schemes as far as the PTC is concerned. The effectiveness index E_c helps to express the reduction of costs (or net saving) gained by the AC/DC transmission conversion. It is also used to economically compare different conversion schemes.

6. Proposed Conversion Methodology

The proposed conversion methodology can be applied to any existing practical AC transmission system in order to increase its PTC by conversion to DC. The main objectives of this methodology are to determine the design levels of voltage, current, and power of the converted DC system according to assumed design constraints, to evaluate the effectiveness of the transmission conversion, and to determine basic characteristics and ratings of the proposed DC system.

6.1 Design Constraints

Based on the above mentioned technical and economical considerations, the following design constraints should be satisfied in the analytical procedure for the AC/

DC transmission conversion :

a) According to voltage drop limitation we should have

$$I_d\ R_{dc} \leq K_v\ *\ \ell\ *\ V_d \tag{37}$$

In Eqn. (37), K_v = constant = (0.625 – 1.25) * 10^{-4}, V_d in kV, ℓ in km, R_{dc} in ohms, and I_d in kA.

b) Based on the above equation, the power loss of the DC system must satisfy the constraints.

$$P_{Ldc} \leq K_v\ *\ \ell\ *\ P_{dc} \tag{38}$$

$$\lambda \leq K_v\ *\ \ell\ (\ P_{dc}\ /\ P_{Lac}\ ) \tag{39}$$

In Eqns. (38) and (39), ℓ in km, and P_{dc}, P_{Ldc} and P_{Lac} are in MW.

c) According to thermal limitation we have the constraint

$I_d \leq$ current carrying capacity of the existing conductors (c.c.c.) (40)

d) Power ratio β should be > 1 (41)

e) Calculation of DC voltage in Reference [2] was made based on an insulation level ratio (γ) = 1.0, but in the proposed methodology γ is assumed to be 1.1 in accordance with the discussion of the limiting factors of Section (3).

f) Conversion effectiveness indices E_p and E_c must be positive.

6.2 Analytical Procedure

For an existing AC transmission line, the following data are known: Line's parameters (ℓ, θ, R_{ac}), V_L, PTC_{ac} . P_o, I_{ac} and P_{Lac} at the normal operating condition, c.c.c. of line's conductors, and cos ϕ is assumed to be 0.85. For the conversion to DC transmission the following analytical steps should be followed :

1) V_d is calculated from Equation (11) assuming that γ = 1.1, K_1 = 2.0, and K_2 = 1.7.

2) Calculate I_d by using Eqn. (37) and check its value according to Eqn. (40).

3) Use the calculated values of V_d *and* I_d to find P_{dc} according to Eqn. (6). It should be noted that n_b = 1 and 3 for single-circuit and double-circuit conversions respectively.

4) Calculate P_{Ldc} and λ, and check their values by using Equations (38) and (39) respectively.

5) Calculate β and E_p and check that they satisfy the above constraints.

6) Having determined V_d, I_d, and P_d, proceed to calculate ratings and basic characteristics of the proposed rectifier and inverter stations for each bipole, to propose control schemes, to determine reactive power compensation at both terminals of the proposed DC system, and to design AC and DC harmonic filters.

7) Calculate all different cost items according to Section (4), then find the effectiveness index E_c and check that it is positive.

7. Application to a Practical System

The analytical methodology and conversion effectiveness indices proposed in this paper are applied to investigate the possibility of increasing the PTC of the existing 500 kV High Dam-Cairo AC transmission line in Egypt by conversion to DC.

7.1 System Data

The 500 kV High Dam-Cairo transmission system (shown in Fig. 3) has the following data :

Two circuits (on two separate towers, 150 m apart)

Three bundles per phase.

Each circuit has horizontal spacing with 12 m between adjacent phases. The line has three sections: High Dam-Nagh Hamady (236 km), Nagh Hamady-Samalout (343 km), and Samalout-Cairo (209 km).

Total length = 788 km

R_{ac} = 0.0217 ohm/km/ct

Series inductive reactance = X = 0.3020 ohm/km/ct

Shunt capacitive susceptance = $B = 3.9 * 10^{-6}$ mho/km/ct.

The economical data are assumed to be as follows

SC_{line} = US$ 1000 / MW / km

SC_c = US$ 10^5 / MVAR

SC_{loss} = US$ 10^6 / MW

SC_{insu} = US$ 1.0 / kV / km

7.2 Results of Possible Conversion Schemes

There are two possible conversion schemes to increase the power transfer capability of the existing 500 kV double-circuit transmission interconnection in the Egyptian Unified Power System. The proposed schemes are :

7.2.1 Scheme I: One-Circuit Conversion

One circuit only will be converted to DC and the other circuit remains AC for load tappings at Samalout and Nagh Hamady. The DC line will have two terminals (point-to-point DC line): The rectifier terminal will be connected to the 500 kV bus at the High Dam generating station and the inverter terminal will be connected to the 500 kV bus at Cairo.

Figure 4 shows a sketch of system configuration for scheme I.

The following design values are obtained for scheme I :

$$V_d = \pm\ 500 \text{ kV},\ I_d = 1800 \text{ A, and } P_{dc\,1} = P = 1800 \text{ MW}$$

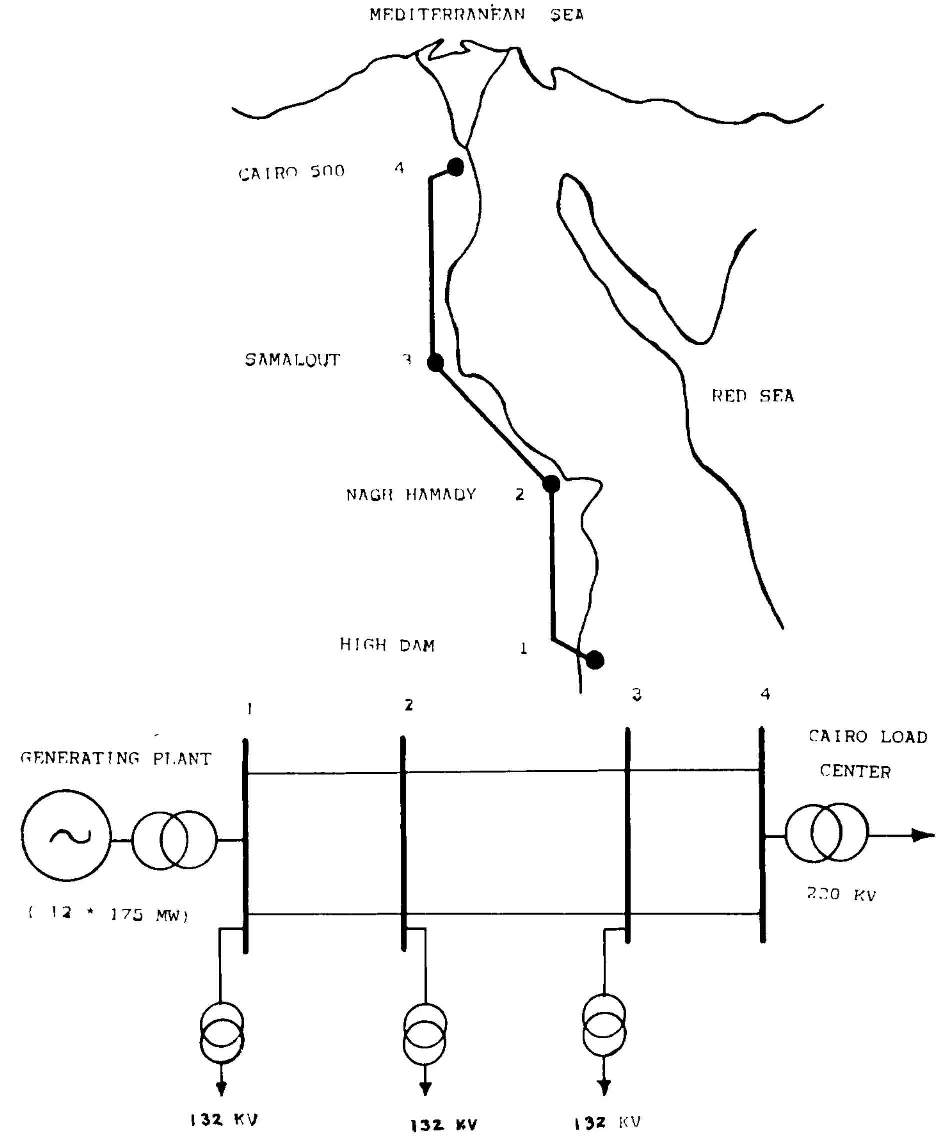


FIG. 3. High dam-Cairo 500 kV transmission system.

Comparing with the surge impedance loading (SIL) of one circuit of the 500 kV AC transmission system, which is estimated to be 900 MW one can conclude that a substantial power transfer capability can be obtained by converting it to DC.

7.2.2 Scheme II: Double-Circuit Conversion

The double-cicruit AC transmission system will be converted to three parallel DC bipolar lines (BP1, BP2 and BP3).

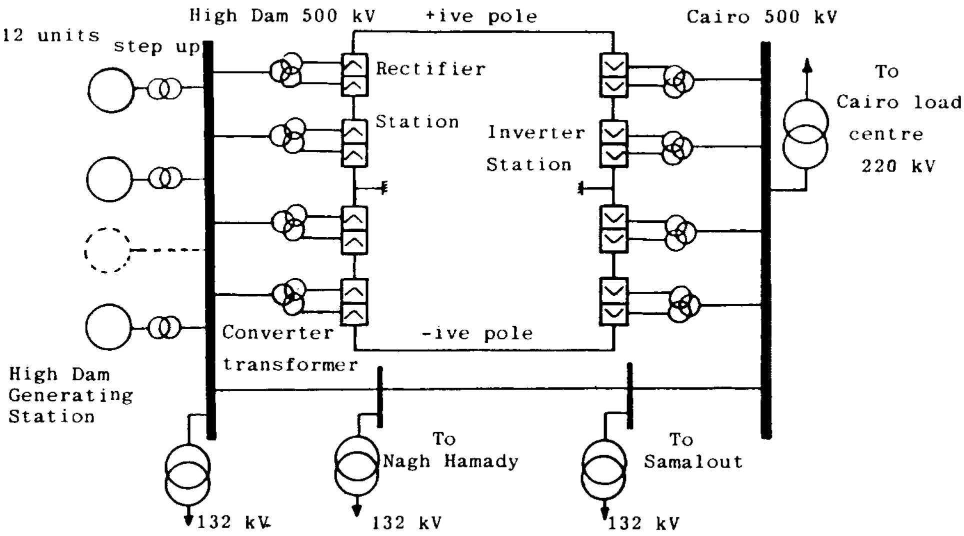


FIG. 4. Scheme I : One circuit conversion (2-terminal DC system).

For the DC system: The rectifier stations will be connected to the 500 kV bus at the High Dam generating station and the inverter stations will be connected to Cairo 500 kV AC bus supplying the main load centre. On bipole 1 two smaller inverter stations will be connected to the 132 kV buses at Nagh Hamady and Samalout to supply smaller loads and thus we will have a multi-terminal DC (MTDC) parallel connected system.

Figure 5 shows a sketch of system configuration for scheme II.

The values of DC voltage and DC current calculated and used for scheme I are used here for scheme II.

Since scheme II has three bi-polar lines, the power transfer capability of it = 3P = 5400 MW.

7.3 Main Data and Basic Characteristics

Calculations were made, based on the practical experience and data of all DC links allover the world, to estimate the ratings of DC converter stations and to figure out the most important characteristics of the proposed converted DC lines. The estimated ratings are applicable to scheme I (one bipolar DC line) and each bipolar line of scheme II.

Table 1 summarizes system details given per bipolar DC line. In order to limit the length of the paper, results concerning control scheme, reactive power compensation, and harmonic filters of the proposed converted DC system are not included.

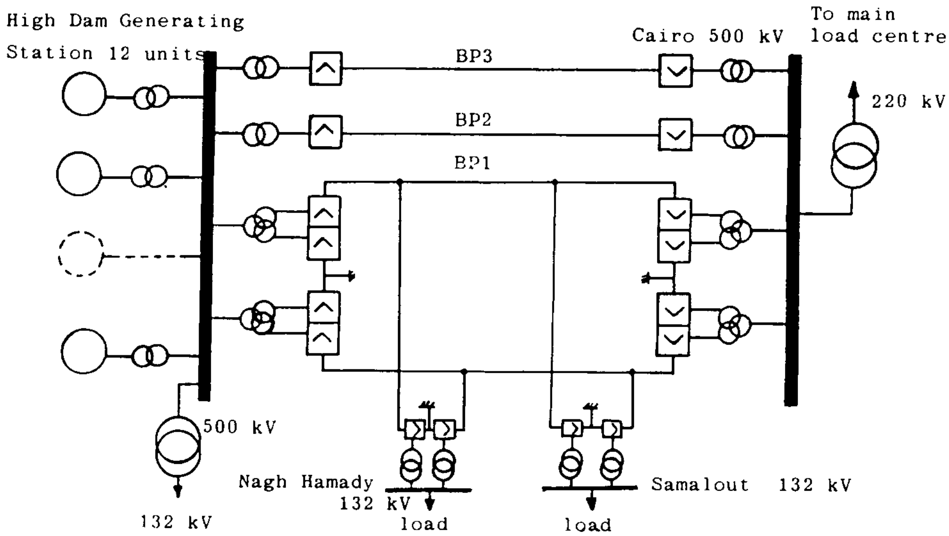


FIG. 5. Scheme II : Double circuit conversion (MTDC operation).

TABLE 1. Summary of important details of the proposed bipolar DC line.

Item	Valve
Nominal voltage	± 500 kV
Nominal current	1800 A
Nominal power	1800 MW
Number of valve groups	2 in series / pole
Type of converter unit (valve groups)	12 pulse
Valve type	Thyristors
Valve cooling	Water
Valve insulation	Air
No. of converter units per bipolar line	8
Voltage per converter arm	125 kV
No. of thyristors in series/converter arm	170
No. of thyristors in parallel/converter arm	4
Total no. of thyristors per bipolar line	65280
Monopolar operation	Yes
Number of transformers per hole	4
Rectifier transformer ratings :	
Secondary line voltage	177.66 kV
Secondary line current	1470 A
Primary line voltage	500 kV
Primary line current	346 A
MVA rating	300 MVA
Inverter transformer ratings :	
Secondary line voltage	108.84 kV
Secondary line current	1470 A
Primary line voltage	500 kV
Primary line current	320 A
MVA rating	278 MVA

7.4 Discussion of the Effectiveness Indices E_p and E_c

The conversion effectiveness indices E_p and E_c are used here to compare between the two possible conversion schemes described before for the existing 500 kV double-circuit AC transmission line. As table 2 shows, both indices E_p and E_c are positive for the two schemes. Also E_p and E_c for scheme II are higher than those for scheme I. It is shown that E_p is considerably increased from 251.70% for scheme I to 427:55% for scheme II and E_c is slightly increased from 52.23% for scheme I to 57.10% for scheme II, although the net saving S is considerably high for scheme II compared to scheme I.

TABLE 2. Main technical and economical results of the possible conversion schemes of the studied 500 kV transmission line.

	One-circuit conversion (Scheme - I)	Double-circuit conversion (Scheme - II)
P_{ac} (MW)	511.80	1023.60
P_{dc} (MW)	1800.00	5400.00
S_1 (US$)	1015.10 * 10^6	3448.60 * 10^6
S (US$)	530.22 * 10^6	1969.00 * 10^6
E_p (%)	251.70	427.55
E_c (%)	52.23	57.10

S_1 = Cost of an equivalent AC line.
S = Net saving.

The above discussions prove that the double-circuit conversion is economically and technically recommended over the one-circuit conversion.

8. Conclusion

This paper presents an analytical methodology to increase the power transfer capability of an existing practical AC transmission system by conversion to DC. Technical and economical considerations that should be taken into account are discussed. Two new indices are also proposed to evaluate the effectiveness of the AC/DC transmission conversion. Results of the application of the proposed methodology and effectiveness indices, to the existing 500 kV High Dam-Cairo transmission line, indicate that the power transfer capability can be greatly increased by conversion to DC.

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تحويل خط نقل قائم وعملي للقوى الكهربائية من التيار المتغير إلى التيار المستمر

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المستخلص . تمت مناقشة العوامل الفنية التي يجب أخذها في الاعتبار في عملية تحويل خطوط نقل القوى الكهربائية الموجودة ، والتي تعمل بالتيار المتغير ، إلى خطوط نقل تعمل بالتيار المستمر من أجل زيادة قدرتها على نقل القوى الكهربائية . يناقش هذا البحث أيضًا الاعتبارات الاقتصادية في هذا التحويل ويحدد نظم التحويل المختلفة الممكنة في حالة خطوط النقل ذات الدائرة الواحدة وذات الدائرتين . يحتوى هذا البحث على منهاج تحليلي مقترح مبنى على أساس حدود تصميم مفروضة ويستخدم مؤشرات جديدة لمعرفة وتقييم فعالية عملية تحويل النقل من التيار والمتغير إلى التيار المستمر . يقدم هذا البحث نتائج تطبيق المنهاج التحليلي المقترح ، وكذا المؤشرات على خط القاهرة - السد العالي جهد ٥٠٠ ك . ف . كوسيلة لزيادة قدرته على نقل القوى الكهربائية .