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SPI Method to Study the Load Flow of Networks AC-DC Power System

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ABSTRACT

Following the electronic power development with respect to electronic components and electronic commands, the use of the electronic converters took an advantage, in these last years, in the field of electric power transport. The DC transmission has many advantages compared to the AC transmission. In this paper, we considered the load flow computation of a 7-bar network with a line functioning in D.C. We used the Substitution Power Injection method (SPI) as incorporated in the Newton-Raphson algorithm. The MATLAB tool is used for programming the SPI method.

Keywords: *load flow, Newton-Raphson, transmission DC, SPI.*

1. INTRODUCTION

The philosophy of the DC transmission existed since the advent of electricity. The technology of that time did not allow mastering the current transport.

In 1950, the first work on the DC transmission started in Russia with an experimental line of 116 km from Moscow to Kasira at 200 kV [5]. The first commercial DC line, which was established in 1954, was a 98km cable between the Gotland Isle and the Swedish continent [5].

Nowadays and following the evolution of the semiconductor technology the alternative transmission appears to be behind the continuous transmission [7]:

a. With a DC transmission we can establish a connection between two networks operating at different frequencies.

b. The power flows are better controlled.

c. For the same transmitted power, the DC transmission presents less tension drop than with the AC transmission.

d. Beyond 50km, the AC transmission is not practical because of the capacitive effect, then with the DC transmission can about it exceed this critical length without problem [2].

e. For long distances, the cost of a facility for the continuous transmission is cheaper than the one for the alternative transmission [8].

The computation of the load flow for AC networks is a classical problem; however, the inclusion of converters in power systems involves a computation algorithm.

In this study we present a method for mixed networks AC/DC based on the consideration of SPI and the Newton-Raphson algorithm.

2. PRESENTATION OF THE NEWTON-RAPHSON METHODE

For a network with N bars, active and reactive power in each bar is given by:

$$P_i = V_i.\sum_j Y_{ij}.V_i.\cos(\delta_i - \delta_j - \theta_{ij})$$

$$Q_i = V_i.\sum_j Y_{ij}.V_i.\sin(\delta_i - \delta_j - \theta_{ij})$$

The solution of power flow amounts to solving the equation system (1):

$$[\Delta Y] = [J].[\Delta X] \quad (1)$$

With:

$$[J]=\begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & . & \frac{\partial P_2}{\partial \delta_N} & \frac{\partial P_2}{\partial V_2} & . & \frac{\partial P_2}{\partial V_N} \\ . & . & . & . & . & . \\ \frac{\partial P_N}{\partial \delta_2} & . & \frac{\partial P_N}{\partial \delta_N} & \frac{\partial P_N}{\partial V_2} & . & \frac{\partial P_N}{\partial V_N} \\ \frac{\partial Q_2}{\partial \delta_2} & . & \frac{\partial Q_2}{\partial \delta_N} & \frac{\partial Q_2}{\partial V_2} & . & \frac{\partial Q_2}{\partial V_N} \\ . & . & . & . & . & . \\ \frac{\partial Q_N}{\partial \delta_2} & . & \frac{\partial Q_N}{\partial \delta_N} & \frac{\partial Q_N}{\partial V_2} & . & \frac{\partial Q_N}{\partial V_N} \end{bmatrix}$$

$$[\Delta Y]=\begin{bmatrix} P_2^{SP}-P_2^{cal} \\ . \\ . \\ P_N^{SP}-P_N^{cal} \\ Q_2^{SP}-Q_2^{cal} \\ . \\ . \\ Q_N^{SP}-Q_N^{cal} \end{bmatrix} \quad [\Delta X]=\begin{bmatrix} \delta_2^{SP}-\delta_2^{cal} \\ . \\ . \\ \delta_N^{SP}-\delta_N^{cal} \\ V_2^{SP}-V_2^{cal} \\ . \\ . \\ V_N^{SP}-V_N^{cal} \end{bmatrix}$$

3. MODELING OF THE DC TRANSMISSION

For the modeling of a DC transmission (see Figure 01), we must consider [9]:

- AC voltages of the network are balanced and sinusoidal.
- All the harmonics generated by rectifier and inverter are filtered. Mode and the filtering means are ignored in this study.
- Control mode of the rectifier and the inverter are not included in the computation. In other words, we are only interested in the active and reactive power transfers.

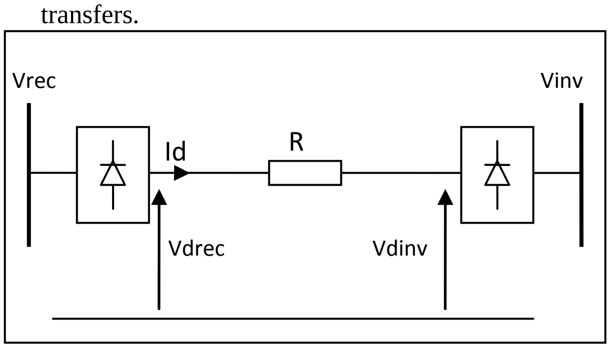

Figure 1: Single Line Diagram of a DC Transmission

3.1 Equation of the Inverter

The operation of a converter can be described by the following equations:

$$V_{d0inv} = k.V_{inv} \tag{2}$$

$$V_{dinv} = V_{d0inv}.\cos\gamma - R_{inv}.I_d \tag{3}$$

$$k = 2.\sqrt{3}/\pi \tag{4}$$

Where, V_{d0inv} represents the voltage of the inverter in case the current of the DC line is zero.

γ: The firing angle of inverter. $R_{inv} = 3.X_{inv}/\pi$, Reactance switching of the inverter.

The active and reactive power can be determined

$$P_{inv} = V_{dinv}.I_d \tag{5}$$

$$Q_{inv} = V_{dinv}.\tan\varphi_{inv} \tag{6}$$

Where, φ_{inv}: the phase difference between AC voltage and AC current is fundamental.

$$\varphi_{inv} = \arccos\frac{V_{dinv}}{V_{d0inv}} \tag{7}$$

3.2 Equations of the Rectifier

$$V_{d0rec} = k.V_{rec} \tag{8}$$

$$V_{drec} = V_{d0rec}.\cos\alpha - R_r.I_{drec} \tag{9}$$

$$P_{rec} = V_{drec}.I_{drec} \tag{10}$$

$$Q_{rec} = V_{drec}.\tan\varphi_{rec} \tag{11}$$

$$\varphi_{rec} = \arccos\frac{V_{drec}}{V_{d0rec}} \tag{12}$$

$$R_{rec} = 3.X_{rec}/\pi \tag{13}$$

3.3 Equations of the Line

Voltages at the end are given by:

$$V_{drec} = V_{dinv} + R.I_d \quad (14)$$

4. COMPUTATION METHOD "SPI"

The SPI method [6] is to transform the problem of power flow AC/DC in an AC problem by eliminating the DC line, and, is represented by the injection or consumption of active and reactive power.

On the other hand, the independence of the injection or consumption of active and reactive power of the AC voltage converters [4], we can write:

$$P_k = P_k^{AC} - P_{rec} \quad (15)$$

$$P_m = P_m^{AC} + P_{inv} \quad (16)$$

$$Q_k = Q_k^{AC} - Q_{rec} \quad (17)$$

$$Q_m = Q_m^{AC} + Q_{inv} \quad (18)$$

k: is the rectifier bus.
m: represents the inverter bus.

Starting with an initial solution X^0, the state's electricity transmission network without DC is determined, and the result is considered as an initial solution for computing DC. This computation is repeated until one arrives at DY< ε.

The algorithm of the method is illustrated in Figure 03.

5. APPLICATION

The method SPI-Newton-Raphson is tested on a network of 7 buses (Figure 02) under the environment of Matlab M-file.

The DC transmission is performed between bus 5 and bus 7, with the characteristics given in Table 02.

First, we determined the electrical state of our test network the DC transmission. Second, we replace the line between bus 5 and 7 by a line running in DC.

The results obtained are summarized in table 03 and 04.

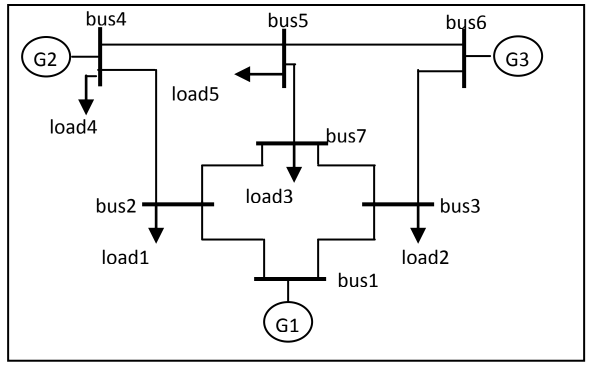

Figure 02: 7 bus test network

The results were obtained with an error 0.0001 and from the 2nd iteration for the first case, and the 5th iteration for the second case.

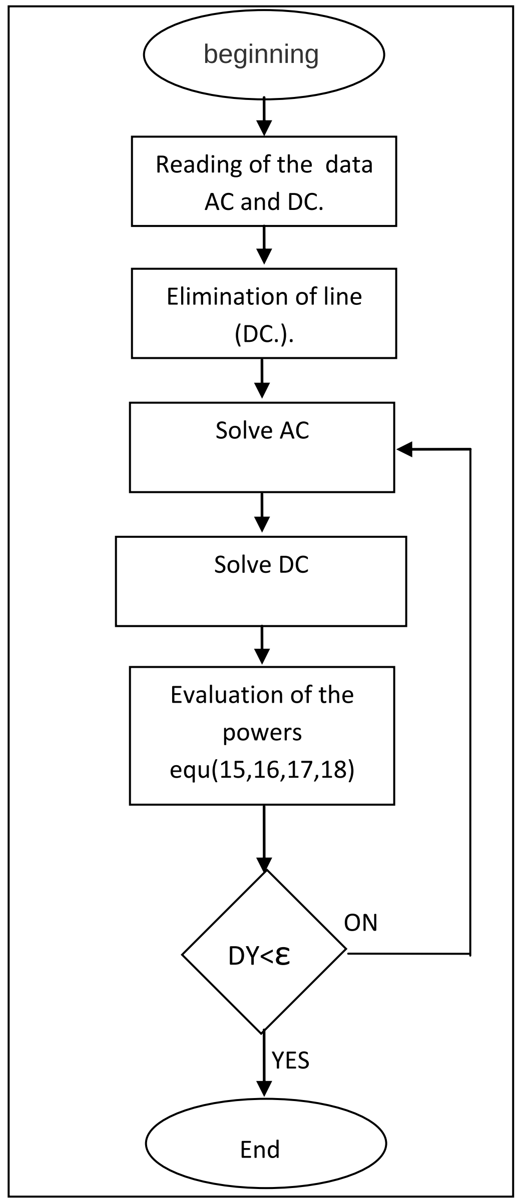

Figure 3: Calculation Algorithm

Table 1: Characteristics of the Network Test

bus	V	δ	P_G	Q_G	P_L	Q_L
1	1.03	0	-	-	0	0
2	-	-	0	0	0.7	0.4
3	-	-	0	0	1.5	0.9
4	1.02	-	1.8	-	1.1	0.6
5	-	-	0	0	1.3	0.8
6	1.02	-	1.8	-	0	0
7	-	-	0	0	1.8	0.8

Table 2: Caractéristique de la Transmission DC

	rectifier	inventer
bus	7	5
Control angle	19	22
commutation reactance	0,4 Ω	0,8 Ω
resistance of the DC line	0,5Ω	

Table 3: Results without the DC Transmission

bus	V (pu)	δ (deg)	P (pu)	Q (pu)
1	1.03	0	3.0871	0.4041
2	0.9526	-8.48	-0.7	-0.4
3	0.9555	-8.35	-1.5	-0.9
4	1.02	-8.34	1.8	1.917
5	0.9774	-9.33	-1.3	-0.8
6	1.02	-7.18	1.8	1.9492
7	0.9372	-10.16	-1.8	-0.8

Table 4: Results with the DC Transmission

bus	V (pu)	δ (deg)	P (pu)	Q (pu)
1	1.03	0	2.73535	0.9823
2	0.9208	-7.46	-0.7	-0.4
3	0.9357	-6.47	-1.5	-0.9
4	1.02	-4.62	1.8	1.617
5	1.0128	-4.67	-1.3	-0.8
6	1.02	-3.53	1.8	1.5196
7	0.8766	-10.57	-1.8	-0.8

Table 5: Impedance of the Lines

line	R	X
1-2	0.063	0.129
1-3	0.03	0.08
2-4	0.02	0.1
2-7	0.012	0.052
3-6	0.01	0.05
3-7	0.012	0.063
4-5	0.017	0.05
5-6	0.012	0.04
5-7	0.02	0.063

6. INTERPRETATION OF RESULTS

In the first case (without the DC transmission), the total generated active power is in the range of 6.6871 pu, reactive power is 4.2703 pu. The loss of active power is 1.3871 pu with consumption of reactive power in the range 1.3703 pu.

In the second case (with the DC transmission), the generated active and reactive powers are respectively 6.3535 pu and 4.1188 pu, active power loss is 1.0535 pu and reactant consumption is 1.2188 pu.

The results show that the integration of a DC transmission AC improved the network performance, in other words the active loss and reactant consumption, in terms of a percentage relatively to the generated powers, was greatly improved when using a DC transmission.

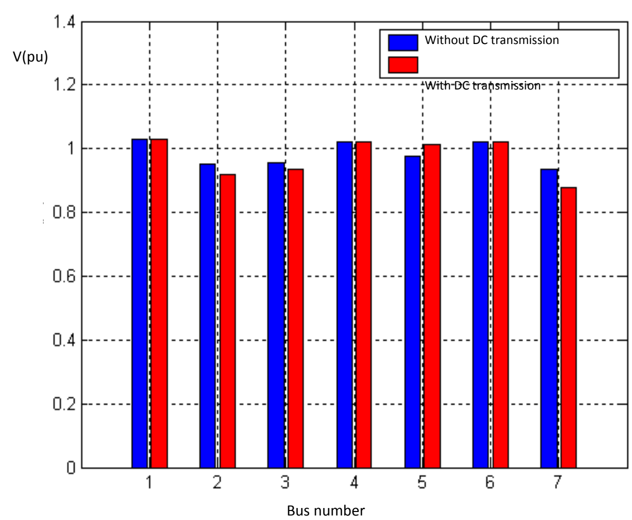

Figure 3: The Voltage in pu

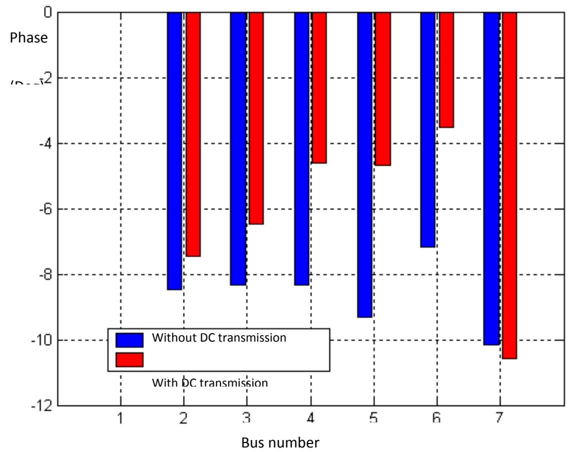

Figure 4: The Phase in Degrees

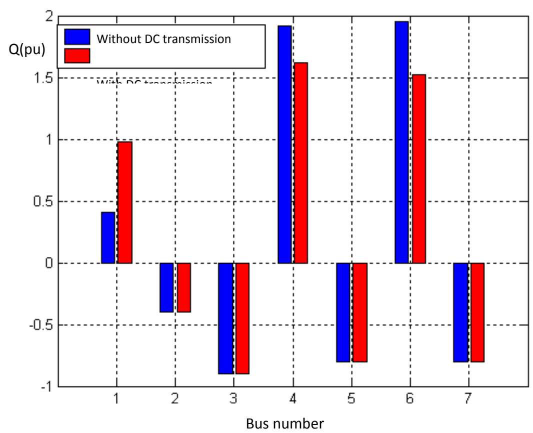

Figure 5: The Reactive Power in pu

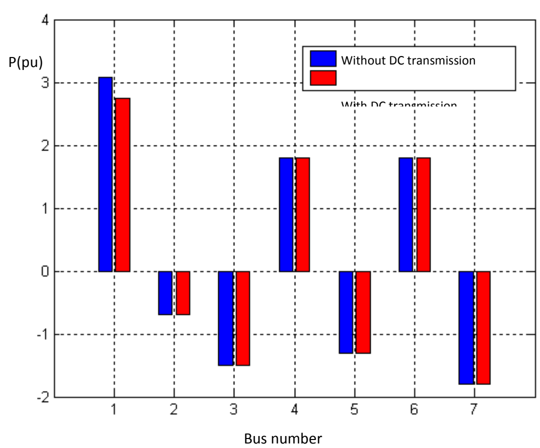

Figure 6: The Active Power in pu

7. CONCLUSION

In this paper, we presented a method for computing the load flow problem suitable for the implementation of a DC transmission network in AC.

The test of the algorithm as a program in MATLAB M-file on a network of bus 7 showed that the insertion of a DC transmission has improved network performance, losses as a percentage are decreased due to the insertion of a line current.

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