Study of the Load Flow in Electrical Supply Networks AC/DC

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Abstract- *The study of the Power flow is very significant, because it makes it possible to provide information of large importance; in order to better plan, to control and ensure finally the correct operation of the electrical supply networks. In our article, we present a method of calculation of the flow of powers in a mixed electrical supply network in high voltage (AC/DC). This method called also method SPI: (Substituted Power Injection) makes a small modification to the level of the bus of connection DC. The calculation of the active and reactive powers at the final bus of system AC-DC, are obtained by the subtraction of the powers of the converters and those which are specified with the bus of connection DC. This method will be applied to the 14 bus networks.*

Indexed Terms- *load flow, fast decoupled, HVDC, method SPI, Converters.*

I. INTRODUCTION

Since its existence, the power system was produced, transported and distributed in AC current. But in the last few years, the incorporation of subsets of transmission high voltage in D.C. current HVDC in networks of transmission in AC current brought a significant change in the transport of the electric power. The technical and economic factors were modified and must obey decision and selection criteria for a good mixed farm. The lines of high voltage in D.C. current are much more preferable with those in AC current because they are more economic and more reliable, in particular applicability such as :

- Interconnection between two very distant blocks, where transport by air line proves to be impossible
- Connection between two systems with different frequencies.

The basic of the power flow in a system (AC/DC) has the same interest as that in the threephase systems in AC current. It will enable us to know the energy state of the system in any point and constantly, in order to exploit it well. The knowledge of the bus tensions of the network is very significant because they make it possible to calculate exactly the power flow between the buses. The resolution of the problem of the load flow in a system (AC/DC) is different with that which we knew in the systems (AC); we must, for that, to introduce new parameters and to make other modifications in the methods of basic to simplify the complexity of the problem. [2],[3]

II. FORMULATION OF THE PROBLEM

2.1. Introduction

The operating condition of the combination of the DC system of power alternate is defined by the following vectors:

$\overline{V}$: Vector of magnitude voltage of the AC system. θ : Vector of magnitude voltage of the AC system (except the slack bus, where $\theta_{ref} = 0$)   X : Vector of the variables of the DC system .

Maybe, then the total vector of operation:

$$[\ \overline{V}\ ,\overline{\theta}\ ,\ \overline{X}\ ] \tag{1}$$

On the level of the final bus of the converter (rectifying or inverter), the equations of variations of active and reactive powers can be written like this:

$$\int\left| \text{PtermSP} - \text{Pterm(ac)} - \text{Pterm (dc)} = 0 \right. \tag{2}$$

$$\left\{ \begin{matrix} \\ {}^{SP} \\ Q_{term} - Q_{term}(ac) - Q_{term}(dc) = 0 \end{matrix} \right.$$

With:

$P_{term}(ac)$, $Q_{term}(ac)$: Active and reactive power injected with the final bus according to the variables of the AC system.

$P_{term}(dc)$, $Q_{term}(dc)$: Active and reactive power injected with the final bus according to the variables of the DC system.

$P_{term}{}^{SP}$, $Q^{SP}{}_{term}$: Active and reactive power specified with the final bus for the AC system .

The powers injected $P_{term}(DC)$ and $Q_{term}(DC)$ is according to the V_{term} tension and of the variables of the DC system like this:

$$P_{term}(DC) = f(\overline{V}_{term}, X)$$

$$Q_{term}(DC) = f(\overline{V}_{term}, X) \qquad (3)$$

The equations deriving starting from the conditions specified from the AC are given by:

$$\begin{bmatrix} \Delta P(\overline{V},\theta) \\ \Delta P_{term}(\overline{V},\theta,X) \\ \Delta Q(\overline{V},\theta) \\ \Delta Q_{term}(\overline{V},\overline{\theta},\overline{X}) \end{bmatrix} = 0 \qquad (4)$$

Where the variations with the final bus are indicated separately. The equations independent connected to the conditions of the DC system are indicated by:

$$\Delta R \overline{V}\, X(\overline{{}_{term}},\ )_k = 0 \qquad (5)$$

k: a number of converters

The equations (4) and (5) of the DC system are taken independent of the angles θ AC, by the choice of an angle of reference for the variables of the DC system.

The general problem of the alternate-continuous of power flow (AC/DC) is translated by Resolution of the system:

$$\begin{bmatrix} \Delta P(V, \theta) \end{bmatrix}$$

$$\begin{bmatrix} \Delta P_{term}(\overline{V}, \overline{\theta}, \overline{X}) \\ \Delta Q(\overline{V}, \theta) \\ \Delta Q\ term\ (\overline{V}, \theta, X) \\ \Delta R(\overline{V}_{term}, X) \end{bmatrix} = 0 \qquad (6)$$

The index "term" relates to the AC bus of the converter.

The choice of the variables and the formulation of the equations are based on several assumptions which are generally acceptable in the analysis of the permanent state of the system. These assumptions are summarized with this:

-       The tensions with the final nodes are balanced and sinusoidal.

-       The operation of the converter is balanced perfectly

-       The current and the tension righting are supposed to be smooth

-       The losses due to the transformer (connected to the converter), and the magnetizing admittance are negligible.

2.2. Variables of the converters:

The equivalent circuit of the converter is given by figure 1: [4], [7]
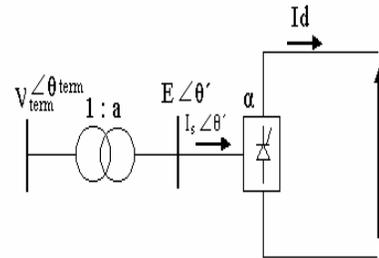
Fig. 1 DC System
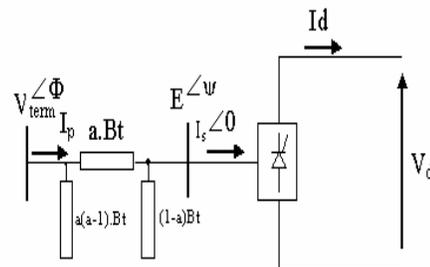
Fig. 2 Equivalent circuit of one phase
(Angles refer with the DC System)

The variables defined in figure (2) are the following:

$V_{term} \angle \Phi$: Nodal tension of the final node (phase compared to the reference of the DC system). E^{ψ} : voltage on the level of the converter (angle referring to the DC system). I_p, I_s : Primary currents and secondary of the transformer respectively.

α   : The firing angle of the thyristor.
a   : Ratio of transformation.
V_d : The average value of the DC tension .
Id   : The converted current (DC)

Among these ten variables, nine are associated to the converter. The last, represents the magnitude of the final tension V_{term}. The whole of the variables makes it possible to make a better choice of vector (X) for the formulation of the equations (3) and (5). The minimal number of variables necessary to define the system operation is given by the number of independent variables, the other variables or parameters of the system are dependent between them. However the requirements of control of the converters in high voltage direct current (HVDC) are of such nature, that a series of variables or their functions are specified conditions. If we use a minimal number of variables, then the specifications of control must be translated by equations which are related to these two variables. Sometimes these equations contain noncomplex linearity and consequently, they present difficulties in their derivation, and obviously in the implementation of the program. Moreover, the expressions which are in (2) can be complex and it make the programming more difficult. For these reasons, we recommends a series of no minimal variables, i.e. all the variables which are sensitive to the action of control. The whole of the following variables makes it possible to obtain simple expressions for all the strategies of control.

$$X = [\ V_d\ \ I_d\ \ a\ \ \cos(\alpha)\ \ \Phi] \qquad (7)$$

The variable (Φ) is introduced to simplify the expression of Q_{dc}, because this is very significant in the single formulation. The variable (Φ) can be neglected since it does not appear in the equations of control and finally to linearize the equations, we can use ($\cos\alpha$) in the place of α

The model of the DC system became:

$$\overline{\Delta R}(\overline{X}, V_{term})_k = 0 \qquad (8)$$

With:

$$\Delta R(1) = V_d - k_1.a.V_{term}\ .\ \cos\varphi \qquad (9)$$

$$\Delta R(2) = V_d - k_1.a.V_{term}.\cos\alpha - \frac{3}{\pi}.I_d.X_c \qquad (10)$$

$$\Delta R(3) = f(V_d, I_d) \qquad (11)$$

$$\Delta R\ (4) = \text{equation of control} \qquad (12)$$

$$\Delta R\ (5) = \text{equation of control} \qquad (13)$$

$$X = [\ V_d\ \ I_d\ \ a\ \ \cos(\alpha)\ \ \Phi] \qquad (14)$$

The expressions of Pcd. and Qcd. are given by:

$$Q_{term}(dc) = V_{term}.I_p.\sin\varphi \qquad (15)$$
$$Q_{term}(dc) = V_{term}.k_1.a.I_d.\sin\varphi$$

$$P_{term}(dc) = V_{term}.I_p.\cos\varphi$$
$$P_{term}(dc) = V_{term}.k_1.a.I_d.\cos\varphi \qquad (16)$$
$$P_{term}(dc) = V_d.Id$$

2.3. Incorporation of the equations of control

Each additional converter in the DC system adds two independent variables to the system and, two equations are added at the control strategy of the system in order to defining the operating condition. [4], [5]

For example, for a traditional DC line of two final connections comprising two converters, and thus requiring four equations of control; the four equations must be expressed according to ten variables (five for each converter, rectifier).

Some strategies of control refer to the characteristics of the power transmission (ex : constant power, or constant current), other strategies introduces the constraints like the angle of lag, or extinction minimal.

Example of specification of the equations of control:

- Specification of the ratio of transformation: $a - a^{sp} = 0$

2.4. Operation out of Inverter

All the equations presented previously are applicable in inverter mode. However during conversion, the For (n) equations:

[A]: represent the jacobien matrix DC system which is given by:

$$\begin{bmatrix} \dfrac{\partial \Delta R(1)}{\partial X1} & \dfrac{\partial \Delta R(1)}{\partial X2} & \dfrac{\partial \Delta R(1)}{\cdots} & \dfrac{}{\partial Xn} \\ \\ \dfrac{\partial \Delta R(2)}{} & \dfrac{\partial \Delta R(2)}{} & \cdots & \dfrac{\partial \Delta R(2)}{} \end{bmatrix} \qquad (22)$$

And whose elements are the derivative partial of the ΔR compared to variables X. In iterative calculation, the Jacobin takes various values has each iteration and the process stops when the criterion of convergence is checked i.e. $\Delta R < \varepsilon$ with ε precision of basic.

2.5. The line DC is represented by the following diagram:
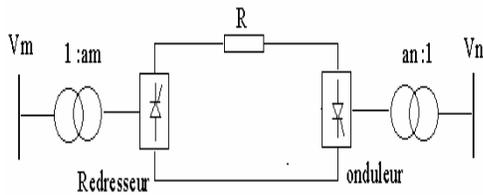
Fig. 3 Diagram of DC line
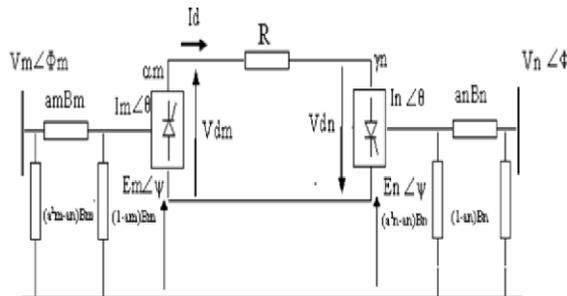
Fig. 4 Diagram of equivalent DC line

III.   DC NETWORK SEVERAL TERMINALS

3.1. Introduction

The basic algorithm was developed into the parameter and not as an angle of starting (γ). [4], [5] By convenience, the equation of ΔR. (2) of (10) must be written like this:

$$\Delta R(2) = V_d - k_1.a.V_{term}.\cos\gamma + \frac{3}{\pi}.I_d.X_c \qquad (17)$$

This equation is valid in rectifying mode or inverter. The tension continuous V_d (calculated by the equation (17) will be negative; and the equation of control will be :

$\Delta R(1) = Vdm - k1.am.Vm.\cos\varphi m$

$\Delta R(2) = Vdn - k1.an.Vn.\cos\varphi n$

$\Delta R(3) = Vdm - k1.am.Vm.\cos\alpha m + \dfrac{3}{\pi}.Id.Xcm$

$\Delta R(4) = Vdn - k1.an.Vn.\cos\gamma n + \dfrac{3}{\pi}.Id.Xcn$

$\Delta R(5) = Vdm - Vdn - R.Id \qquad (19)$

$\Delta R(6) = V_{dn}^{SP} - Vdn \quad$ (Equation of control)

$\Delta R(7) = \cos\alpha m^{SP} - \cos\alpha m$ (Equation of control)

$\Delta R(8) = \cos\gamma n^{SP} - \cos\gamma^n$ (Equation of control)

$\Delta R(9) = Vdn.Id - PdmSP$ (Equation of control)

Vector X is given by :

$$\overline{X} [V = dm\ Vdn\ m\ n\ d\ a\ a\ I\ \cos\ \gamma n\ \cos\alpha m\ \varphi m\ \varphi n]^t \qquad (20)$$

The application of the Newton Raphson method requires a linearization for the determination of the corrections on the variables, in our case it is the vector ΔX. The incrementing ΔX is obtained by the solution of the system as follows:

$$[\overline{\Delta R}] = [A].[\overline{\Delta X}] \qquad (21)$$

preceding sections, for two termini. Each converter moreover adds five continuous variables and a whole of the five corresponding equations. Thus the dimension of the Jacobean matrix is increased by five variables [2], [3].

Example: we consider the system presented by the figure above, where there are three converters, of which two functions out of rectifier and the other

functions out of inverter. Consequently the DC system must be represented by fifteen independent equations.
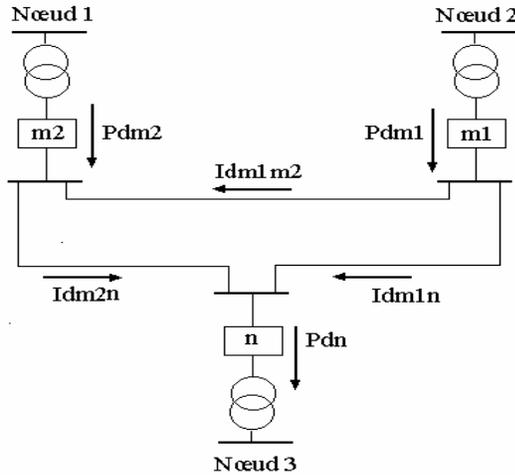
Fig. 5 DC system at three terminals

The Vector X became: —
$X =[V_{dm1\ dm2\ n\ dm1\ dm2\ dn\ m1\ m2\ n}\ V\ V\ I\ I\ I\ a\ a\ a\ \cos\alpha_{m1}\ \cos\alpha_{m2}\ \cos\gamma_{n\ m1\ m2\ n}\ \varphi\ \varphi\ \varphi\ ]$

The Size of Jacobian matrix of the DC system must be (15x15).

3.2. Methods of calculation

Several methods were worked out for the same end i.e. calculation of the power flow of power system AC/DC. Two of them are known. They are based on the principle of the substitution:
- the substitution of the powers injected (SPI) [4].
- the substitution of the parameters of the DC line (SPL).

These methods will transform system AC-DC to the equivalent system (AC). Only the first method will be studied in detail and will be applied to network test of fourteen bus.

Algorithm of the SPI method's:

a) Introduction of the data of the network and calculation of the power complexes converter.

b) Modification of the specified powers injected on the level of the bus of connection AC/DC by using the equations (24) and (25).

c) Elimination of connection (DC) and transform system AC/DC into an equivalent AC system.

d) Execution of the method decoupled for the solution of the problem for AC system.

e) If there is a change in the variables of control of system (DC.), then it is necessary to return at the stage " a ".

f) If there is an unspecified change in the data of operation, it is necessary to make the modification of the powers injected starting from the equations (24) and (25) and to return at the stage "c ";else print the results and stop.

This method is completely simple and can be easily implemented. It also allows us, in a real time, to obtain the solution for a system AC/DC with several power stations and it does not raise any difficulty with regard to its convergence.

IV. APPLICATION

The present method is applied to of the 14 bus test power system.
The programming language Matlab is used to implement the SPI method. The results obtained are given by the various tables which follow.

Parameter	Converter	Inverter
bus	4	5
Reactance of Commutation(pu)	0.10000	0.0700
Angle of lighting (degree)	12.000	18.000
Resistance of the line (pu)	0.0137	

Tab. 1 Table of line data in DC system

P_L [MW]	Q_L [MVAR]
8.5566	4.3348

Tab. 4 Table of the losses of powers

CONCLUSION

This work enabled us to discover another form of transport of the electric power. It is that of transport in HVDC (High Voltage of Direct Current). The detailed study of the SPI method and its application enabled us to become aware of the various advantages which this means of transport allows. We can quote in extreme cases the particular case of the interconnection between the networks of various frequencies. The results obtained confirm the interest transport in D.C. current brings. Also let us note that the nodal voltages are practically maintained at their limits value what explains weak voltage drops and consequence a significant reduction in losses of active powers. The numerical method used with calculation of the transit of powers in an electrical supply network AC/DC is very easy to implement and does not present any difficulty at the point of seen its convergence. However, we make a point of announcing, that transport in HVDC starts to become extensive in The world market of Power systems; what enables us to hold a reflexion quite particular to this type of problems to consider a detailed and effective study. A significant lack of data was marked what was for us a large obstacle to emphasize method SPI especially when they were the networks of big size.

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