CONTROLLABLE FLEXIBLE A.C. TRANSMISSION SYSTEMS

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***Abstract* - The theoretical ground and design realization of alternating current power lines of the new type - Controllable Flexible A.C. Transmission Systems (CFACTS) are considered. Earlier lines of such type had been known as Controlled Self - Compensating High Voltage Transmission Power Lines (CSHVL), as well as Controlled Compact Transmission Power Lines. The CFACTS design principles and the basic CFACTS design directions are presented. The design version, connection diagram and control methods are described. The basic characteristics of CFACTS (10, 35, 110 kV) which already built and maintained long as well as CFACTS (220-1150kV) parameters , obtained on the basic of the design are given. It to shown that the basic characteristics of CFACTS are better than those for the usual power lines. CFACTS provide natural power of the line increase by 20 to 50 per cent, 2-3 times larger total power flow density in a line cross-section, parameters and power flow controllability, ecological effect decrease, economy of capital expenses by 10 to 30 per cent and adduced ones expenditure by 10 to 20 per cent per transmitted power unit.**

1. INTRODUCTION

The prospects of the development of electric power engineering are associated with the further increase of the electrification level. This approach requires the growth of power flows and further extension of the electric power network and an increase in the number of generating plants, the utilization of new power sources, including remote ones, and long and super - long power transmission lines construction. In order to succeed in solving the problems mentioned above, it is necessary to study the questions dealing with the increase of high - voltage transmission line capability, operating conditions control, the improvement of reliability and the technical and economic parameters of all of the power-supply system. Under the actual conditions of the scale of electric power line construction, especially of high and ultra-high voltage power lines, the problems concerned with the reduction of the ecological effect of those kinds of lines and the decrease of the area of plough used for the lines construction become, of great importance. New types of power lines and other equipment, aimed to overcome the main problems, mentioned above. The concept of CFACTS [1-3] is one of novel approaches in this field. At present, on the basis of investigations and design carried out by a number of institutes the CFACTS 10, 35, 110 kV pilot models are constructed and their electrical tests are performed. Besides, the mechanical and electrical tests of CFACTS 110, 220 and 500 kV are owed out. Some versions of CFACTS 500 kV are designed, technical and economic estimates for CFACTS 750 and 1150kV are performed, and the system efficiency of CFACTS designed for various voltages and aimed at the possible application to further development of the networks is estimated.

BASIC RESULTS

As to their design realization, CFACTS are power lines formed by some three - phase single - circuit transmission lines which are separated by a minimum permissible space, Fig. 1.

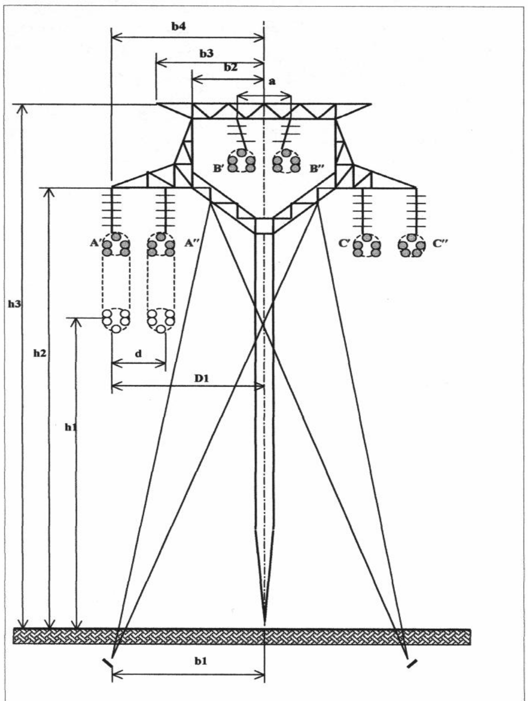

Fig 1. An intermediate tower of the double circuit CFACTS such “Seagull” on guis for classe of voltage 220, 330, 500 kV.

The CFACTS include phase-shifting devices (providing the control of shift angle of three-phase voltage systems for different circuits as well as compensating devices) required for the additional control of the normal and emergency operating conditions, Fig. 2, 3. Owing to the new technical improvements, the specific conditions are provided under which the enhanced electromagnetic mutual effect of single-circuit power lines involved arises. This effect lea do to the change of the primary parameters by 20 to 40 per cent. If the sign of the effect is chosen in the right way, the power line capability increases. The control of the shift angle between the voltage systems, corresponding to different circuits, and, as a consequence of the equivalent parameters values is performed by means of phase-shifting transformers (PST) or switching networks. In conjunction with the application of the compensating devices, this method provides the wide range control of the parameters, describing both a power line and a power network as a whole, Fig. 4a, 4b, 5, 6.

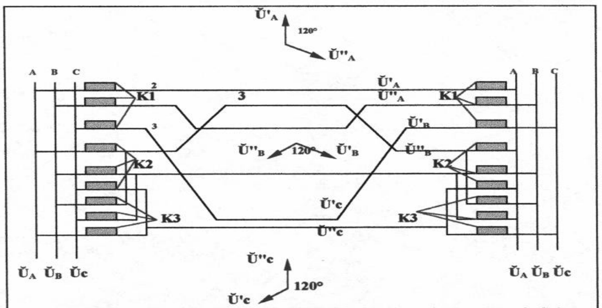

Fig . 2. The scheme of the double circuit CFACTS with discontinuous control of phases from 0 up to 120 el. deg.

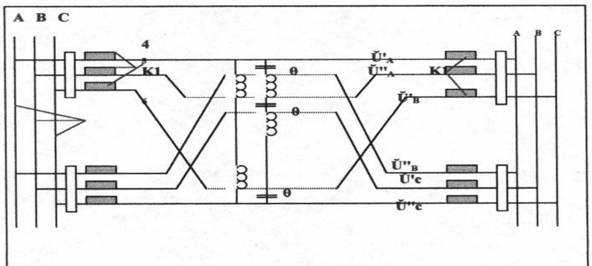

Fig. 3. The diagram of the double circuit CFACTS with possibility of regulation in a wide range.

The studies showed that the reduction in air gap between CFACTS circuits can be made

through the different circuit phases arrangement at the minimum permissible phase-to-phase distance, the phases being associated in pairs for the double circuit CFACTS and in triplets for the triple circuit ones, etc. The phases design can be different. They own attain single conductors or be split, the split phase components being arranged in the circular way or otherwise, forming a plane in accordance with the requirement of the component charge balance [3,4]. The reduced phase-to-phase distance, chosen on the basis of the phase-to-phase limit voltage – e. g. in the case of the double circuit CFACTS a double phase operating voltage must be accepted - and switching and lightning surges magnitudes can be equal to d = (0.2 - 0.4) D, where D is a phase -to-phase distance, used in practice for single-circuit power lines and multi-circuit ones now. Besides, it is necessary to take the tower elements out of the gap between the phases with reduced phase-to-phase distance. In some cases the insulating spacers must be installed between the phases which reduced clearance in the span. Mechanical tests of the CFACTS at 10, 35, 110, 220, 500 kV confirmed the reliability and efficiency of the present design. The different circuit phases - e. g. in the case of CFACTS 500 kV are located on the tower at the distance of

5.0 m, but the span of the phase-to-phase gap is reduced, using insulating elements - lightened insulator chains, plastic insulating structures, etc.- and equal to 4.0 m [5]. The investigations showed that for the split phases their mechanical stability can be provided without

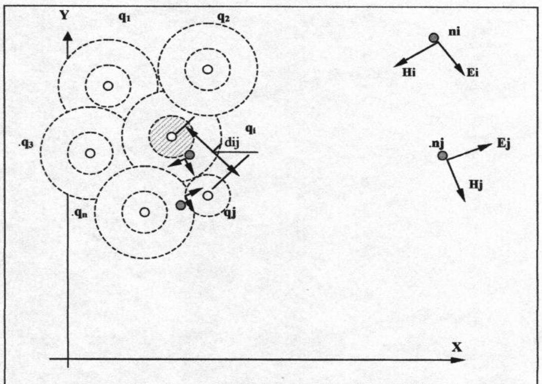

Fig. 4a. A configuration of a field of a transmission line containing a lot of wires

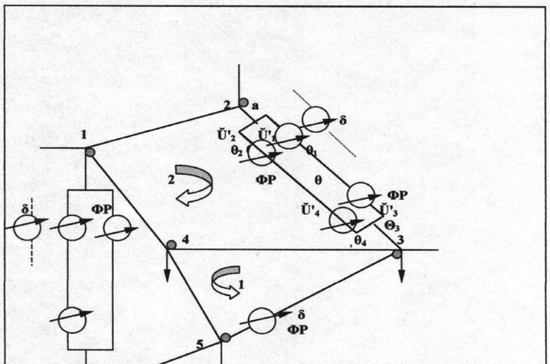

Fig. 4 b. A fragment of the scheme of the network with the double circuit CFACTS.

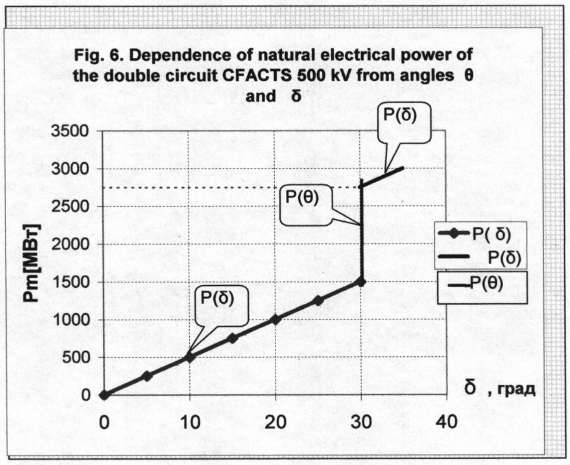

Fig. 6. Dependence of natural electrical power of the double circuit CFACTS 500 kV from angles θ and δ

the use of insulating phase-to-phase structures by means of the proper choice of different distances between the components along the spans. This approach makes the equipment lighter. The other overall dimensions of the line in question are considered to be equal to those for usual power lines.

The versions of CFACTS circuit diagrams are given in Fig. 2, 3. They represent the different methods for the choice and control of the phase shift between voltage systems, corresponding to different circuits, as well as

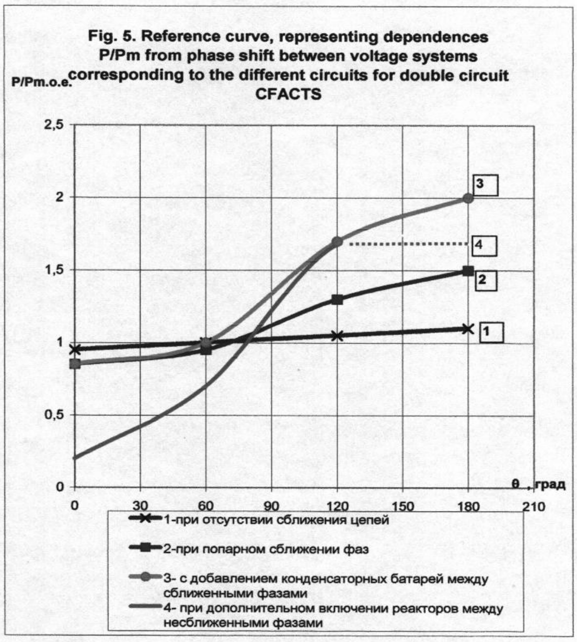

Fig. 5. Reference curve, representing dependences P/Pm from phase shift between voltage systems corresponding to the different circuits for double circuit CFACTS

the methods of compensating devices connection. The "anti phase" operating conditions for voltage systems (θ = 180 el. d.) can be realized through the application of power transformers with the different vector groups, the change of the phase shift between the different voltage systems can be obtained by switching - over the phase, corresponding to one of the circuits. The phase-shifting devices, connected to the line terminals and the intermediate nodes, make it possible to perform the wide range control. The connection of compensating devices can be usual, i.e. according to "phase-ground" arrangement, but sometimes it can be made between the phases with reduced phase-to-phase gap, corresponding to the different circuits. In the latter case the voltage difference, applied to these phases, changes within wide range. The application of the circuit described diagram, increases the line parameters control range. The Fig. 5 displays the characteristic curves, representing CFACTS capability as a function of phase shift between the voltage systems, corresponding to the different circuits. The same dependencies are correct for CFACTS charging power as well. The power line, characterized by wide control range is able to have a very important effect on a complex power system, because this kind of line can control active and reactive power both under the normal and emergency operating conditions. It follows from some investigations that without phase control it is impossible to obtain the required distribution of power flows in complex electric power networks and provide the economical and reliable work of the system in question. The phase control not only allows the changing of CFACTS parameters, due to phase shift between the voltage systems, corresponding to the different circuits (below we will call it quadrature - axis phase shift- θ), but results in the change of the shift angle for node-to node voltage (i.e. direct-axis phase shift, denoted as- δ). Thus, the various application of phase -shifting devices is possible. The diagram of a network section, including CFACTS and phase - shifting transformers (PST), is shown in Fig. 4. The dependence of double-circuit CFACTS-500 kV limit power (Pm) on angles θ and δ, mentioned above, is represented in Fig. 6.

The PST are able to control of the parameters of the lines and power system operating conditions. If the PST are equipped with high-speed control systems, it is possible to control transient phenomena in power systems (e. g. electromechanical ones). The study of PST and CFACTS continues [6,7].

Besides, concrete steps have been taken to make practical use of the basic ideas of CFACTS. The designs, carried out, make it possible to construct CFACTS at the level up to 500 kV, and shift angle θ = 120 el. deg. between the voltage systems as well as to estimate the other version of CFACTS of various voltage classes. On fig. 7 is exhibited the double circuits CFACTS by the voltage 110 kV, which is constructed also long time is in operation in the power system of Republic of Moldova.

Parameters of the CFACTS by the voltage 10 to 1150kV, obtained on the basis of performance design and pre-design estimates are listed in tables 1 and 2.

CONCLUSION.

By comparison with the traditional double circuit' or two Single - circuit lines the CFACTS in question provide the following technical and economical advantages.

1. Economy of capital expenses by 10 to 30 per cent and of adduced expenses by 10 to 20 percent transmitted power unit.
2.

2.Increase by 2-4 time of total power flow density within the line cross-section, formed by tower height and width. The basic technical and economic parameters of CFACTS versions are determined and compared with those for the usual power lines The CFACTS

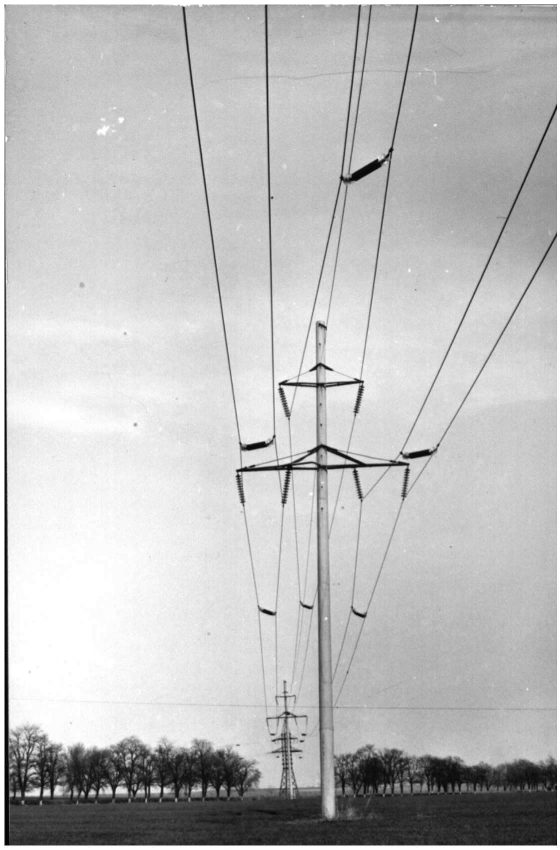

Fig.7. The double circuit CFACTS of voltage 110 kV.

3. The line natural load increase by 20 to 50 per cent, accompanied by transmission line capability growth.

4. The decrease of ecological effect, due to the lowering of the maximum electric field intensity below the line by 15 to 40 per cent and almost by double the reduction of the domain, formed by equipotent surfaces at ground level. 5. The decrease of ploughed land area, used for the line construction, by 30-35 per cent.

6. Nearly 2-fold reduction of magnetic field intensity in the neighborhood of the power lines which is accompanied by less effect on communications and other facilities.

7. The CFACTS, equipped with the facilities, designed for the control of phase shift between

voltage systems, corresponding to the different circuits, enabling the control of operating conditions and power flows in the system. System reliability and controllability improvement.

Table 1. Technical parameters of the constructed pilot double circuit controlled high-voltage lines (10, 35, 110 kV) (in Republic of Moldova)

Parameters	Measurement unit	Voltage, kV		
		10	35	110
Length of lines	km	9,5	8,7	34
Calculated load	MW	3	12	70
Conductors		AC-70	AC-90	AC-150
Phase shift between voltage systems corresponding to the different circuits	el. deg.	120	120	0-120
Distance between the phases with reduced phase-to-phase clearance, corresponding to the different circuits	m	0,3	0,6	1,1
Inductive resistance (at θ=120 el. deg.)	Ohm/km	0,308	0,34	0,37

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Table 2. Technical parameters of some version of double circuit CFACTS at the 220, 330, 500, 750, 1150 kV

Parameters	Measurement unit	Votage, kV				
		220	330	500	750	1150
Length of lines	km	100-300	200-400	300-600	400-800	500-3000
Conductors		2x AS-300	3xAS-300	5xAS-300	AS-300	13xAS-300
Distantbetween the phases with reduced phase-to-phase clearance	m	2,2	3,0	4,0	6,0	10,0
Wave impedance of:						
at θ=0 el. deg.	Ohm	375	367	338	342	338
at θ=120 el. deg.	Ohm	222	214	183	191	209
at θ=180 el. deg.	Ohm	206	199	170	177	195
Natural electrical power of:						
at θ=0 el. deg.	MW	258	592	1478	3282	7820
at θ=120 el. deg.	MW	416	965	2567	5742	12146
at θ=180 el. deg.	MW	468	1090	2929	6334	13580

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