Possible Operation Modes of Moldovan, Ukrainian and Romanian Electrical Power Systems Joint Work

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Abstract. Types of intersystem controlled tie-lines, that may allow the joint work of power systems of Moldova, Ukraine and Romania, are proposed in this paper. The use of intersystem controlled ac transmission lines based on compact one-circuit overhead transmission lines (OHTL) and two-circuit controlled self-compensated OHTL (CSCTL) with phase-shifting transformers on the other hand is also stated. Two types of phase-shifting transformers are considered: the first one – with bounded range of phase angle control between the voltage vectors' system at the output with respect to the other at the input; the second one – with circular rotation of one voltage vectors' system with respect to the other. The first type of devices is aimed to control the power flows within the system or through the intersystem tie-lines of synchronously operating systems. The second type of phase-shifting transformers is aimed to interconnect power systems that operate non-synchronously and to control the power flows between them through connecting OHTL. The first type of devices was introduced in calculation model in 330 kV Moldavskaya GRES – Chisinau OHTL and the second one – in the OHTL that are connecting the power systems of Moldova and Romania. The dependences of power flows through power system's and intersystems' OHTL are established on base of performed calculations, research and analysis.
Keywords: compact one-circuit and two-circuit controlled self-compensated overhead transmission lines, phase-shifting transformers.

Posibile regimurile de funcţionare în comun a sistemelor electroenergetice ale Moldovei, Ucrainei şi României

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Rezumat. În această lucrare se examinează soluţii de realizare a liniilor dirijate de interconexiune, care pot permite funcţionarea în comun a sistemelor electroenergetice din Moldova, Ucraina şi România. Pentru realizarea liniilor de interconexiune de curent alternativ (CA) în scopul asigurării schimbului de putere în regim dirijat se examinează utilizarea liniilor electrice compacte de tensiune înaltă cu un circuit şi a liniilor electrice dirijate cu autocompensare cu două circuite dotate cu regulatoare de unghi de fază la capetele lor. Se examinează două variante de utilizare a regulatoarelor de unghi de fază al vectorilor de tensiune de la începutul şi sfârşitul liniei. În prima variantă se prevede utilizarea regulatorului cu o bandă limitată de reglare a unghiului de fază, iar în altă variantă regulatorul are posibilitatea de a regla valoarea unghiului de fază în bandă largă ($0\text{-}360^0$). Primul tip de dispozitive este destinat pentru a controla fluxurile de putere în cadrul sistemului sau prin intermediul liniilor de interconexiune pentru fucnţionarea sincronă a sistemelor electroenergetice. Al doilea tip de regulatoare a unghiului de fază are ca scop interconectarea sistemelor electroenergetice care operează non-sincron și de a controla fluxurile de putere prin liniile electrice aeriene (LEA) de interconexiune a sistemelor electroenergetice. Primul tip de dispozitive s-a considerat a fi inclus în circuitul LEA 330 kV Moldavskaya GRES – Chişinău, iar al doilea tip de dispozitive a fost considerat ca element funcţional al LEA de interconexiune a sistemelor electroenergetice din Moldova şi România. În lucrare este prezentată informaţia privind modificarea circulaţiilor de putere prin liniile electrice de tensiune înaltă ale sistemelor electroenergetice examinate şi prin liniile de interconexiune ale lor în baza calculelor şi analizei efectuate.
***Cuvinte-cheie*:** linii electrice compacte cu un circuit, linii electrice dirijate cu autocompensare cu două circuite, regulator de unghi de fază.

Возможности совместной работы электроэнергетических систем Молдовы, Украины и Румынии

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***Аннотация*.** В статье предлагаются типы управляемых межсистемных электропередач, которые могут позволить совместную работу электроэнергетических систем Молдовы, Украины и Румынии. Применение межсистемных управляемых линий электропередачи переменного тока базируется на

компактных высоковольтных линиях электропередач (ВЛ) и двухцепных управляемых самокомпенсирующихся ВЛ (УСВЛ) с установкой фазоповоротных трансформаторов. Рассматривается два типа фазоповоротных трансформаторов: первый – с ограниченным диапазоном управления углового сдвига между системами векторов напряжений на выходе по отношению на входе; второй – с круговым вращением одной системы векторов напряжений относительно второй. Первый тип устройств предназначен для управления потоком мощности по электропередачам, которые соединяют синхронно работающие системы. Второй тип фазоповоротных трансформаторов предназначен для соединения работающих несинхронно электроэнергетических систем и управления потоками мощности сквозь соединяющие их ВЛ. Первый тип устройств включен в расчетную модель ВЛ 330 кВ Молдавская ГРЭС - Кишинев, а второй тип устройств -в модель линий, которые могли бы соединить энергосистемы Молдовы и Румынии. Установлена зависимость потоков мощности по внутрисистемным и межсистемным ВЛ на базе выполненных расчетов, исследований и анализа.
Ключевые слова: компактные одноцепные и управляемые двухцепные самокомпенсирующиеся линии электропередачи, фазоповоротные трансформаторы.

I. Introduction

Last years the electrical power systems of Moldova, Ukraine and Romania worked synchronously within an interconnected power system. Power systems of Romania and Bulgaria were disconnected from the power systems of Moldova and Ukraine, which kept working synchronously in parallel within the integrated power system of CIS countries, due to the changes that occurred in nineties. Power system of Ukraine still exports electrical energy from Burshtyn TES power plant for island mode operation by means of several generating units. Electrical energy was attempted to be exported from Moldavskaya GRES power station as well through 110 kV overhead transmission lines (OHTL) to supply the demand “island” from Romania. The existing 400 kV OHTL Moldavskaya GRES – Isaccea is disconnected on the portion Vulcaneshti – Isaccea and the 750 kV OHTL South Ukraine nuclear power plant – Isaccea – Varna was disassembled in the area of Moldova.

The work on “full synchronization” of CIS countries’ power systems and European interconnected system is ceased, but is still relevant. Great attention has been recently paid to solve the issues of Moldova’s and Ukraine’s power systems’ joint work, as in [1]. It is preferable to ensure the joint work of Moldova’s and Romania’s power systems connected in parallel with Ukraine’s.

A particular solution for these issues is presented by technical proposals to create 330-400 kV tie-lines between power systems of Moldova and Romania based on back-to-back (BtB) high-voltage direct-current converter station use. The following places to build B2B stations are considered:

- 330/400 kV B2B station at 330 kV Baltsi substation and the construction of 400 kV Baltsi – Suceava OHTL;
- BtB station at Iashi substation and the construction of 330 kV Strasheni – Iashi OHTL;
- BtB station at Vulcaneshti substation and switching on of the 400 kV Vulcaneshti – Isaccea OHTL portion.

The construction of second-circuit of 330 kV Baltsi – Dnestrovskaya GES (hydropower plant) OHTL is considered to be an additional solution. High capital costs for construction the BtB stations, operation complexity and their insufficient transient response to ensure power system’s transient stability when subjected to severe disturbances are the main difficulties to be considered.

An alternative solution to the problem is stated in the paper, that consists in: the use of intersystem controlled ac transmission lines based on compact one-circuit OHTL and two-circuit controlled self-compensated OHTL (CSCTL) with phase-shifting transformers on the other hand. Such transmission lines include “Smart Grid” elements.

The analysis of recent publications in this field has shown that CSCTL and phase-shifting transformers have a lot of technical, operation and economic advantages in comparison with traditional means of electrical energy transmission and control of power systems’ operation.

II. Purpose statement

The analysis of various types of controlled ac tie-lines between Moldova’s and Romania’s power systems subject to parallel work with power system of Ukraine and strengthening their intersystem transmission lines; the analysis of system-defined operation efficiency of controlled ac transmission lines’ use.

III. Main results of the research

The interconnected power system of Moldova, Romania and Ukraine is examined. The operation is modeled by taking into account the levels of electrical energy consumption and generation for 2015.

The principal existent transmission lines between power systems of Moldova, Ukraine and Romania are depicted in Fig. 1.

Power systems of Moldova and Ukraine work in parallel through seven 330 kV and fourteen 110 kV OHTL. The connection between power systems of Moldova and Romania is ensured by one 400 kV and three 110 kV OHTL. Only the island mode functioning is possible at the present time.

The second circuit of 330 kV Baltsi – Dnestrovskaya GES, 400 kV Baltsi – Suceava, 330 Baltsi – Strasheni – Chisinau are supposed to be built in future.

A 330 kV two-circuit CSCTL is proposed as an alternative to 400 kV Baltsi – Suceava OHTL.

Calculations of initial operation were performed in RASTRWin program on the assumption that the analysed power systems, interconnected by existing tie-lines, worked in parallel and for the case that new OHTL would have been brought into operation. Generation and consumption levels were considered for the period of 2015.

Phase-shifting transformers were chosen as power flow regulation means. They were installed at 330 kV Baltsi substation in 400 (330) kV Baltsi – Suceava OHTL, at 400 kV Vulcaneshti substation in Vulcaneshti – Isaccea OHTL and also at 330 kV substation of Moldavskaya GRES in 330 kV Moldavskaya GRES – Chisinau OHTL.

Two types of phase-shifting transformers are considered in the paper: the first one – with bounded range of phase angle control between the voltage vectors' system at the output with respect to the other at the input; the second one – with circular rotation of one voltage vectors' system with respect to the other.

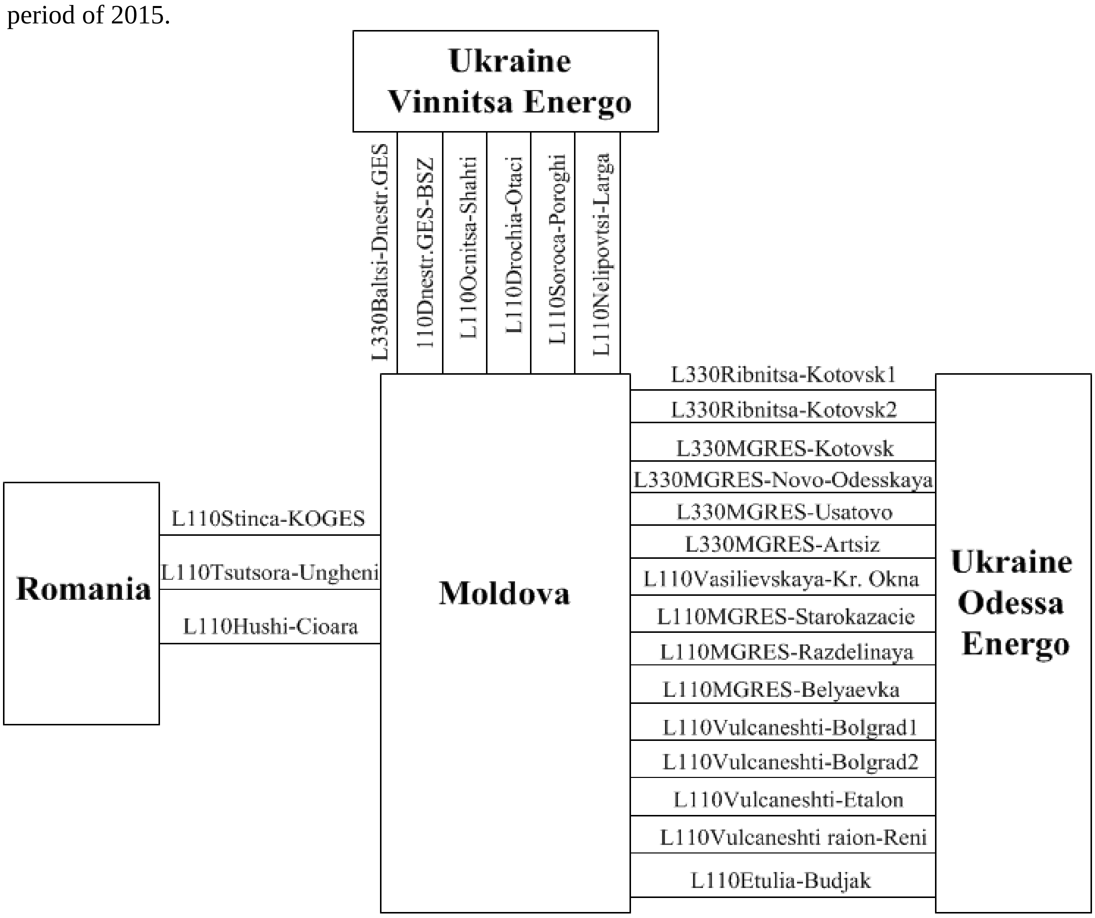

Fig. 1. The connections between Moldova, Ukraine and Romania through high-voltage transmission lines

The first type of devices is aimed to control the power flows within the system or through the intersystem tie-lines of synchronously operating systems. The second type of phase-shifting transformers is aimed to interconnect power systems that operate non-synchronously and to control the power flows between them through connecting OHTL.

The first type of devices introduced in calculation model in 330 kV Moldavskaya GRES – Chisinau OHTL and the second one – in the OHTL that are connecting the power systems of Moldova and Romania.

The second type of phase shifters has the characteristic property to ensure the frequency matching of interconnected power systems, as well as to ensure the conditions of their functioning in parallel. The power flow value and sign are controlled in the same manner as the first type of phase shifters do, by adding the phase-shifted component between vector systems of input and output voltages.

Phase-shifting transformers can change the equivalent parameters of two-circuit and polycircuit CSCTL. The circuits of these types of transmission lines are drawn together and an increased electromagnetic mutual influence is ensured between them. Its value depends on the transmission line's construction and phase angle between voltage vectors' systems of the circuits.

Phase-shifting transformers and CSCTL are described in [2]. The results presented in that publication are partially used in this paper. CSCTL, equipped with phase shifters, are related to controlled ac transmission lines that have "Smart Grid" elements.

The dependences of power flows through power system's and intersystems' OHTL are established on base of performed calculations, research and analysis. Some of them are illustrated in Fig. 2-4.

Phase angle ($\delta_{ph\text{-}sh}$) control between voltage vectors' systems in the range of (0° - 30°) by phase-shifting transformers (Fig. 2), if installed in two-circuit 330 kV

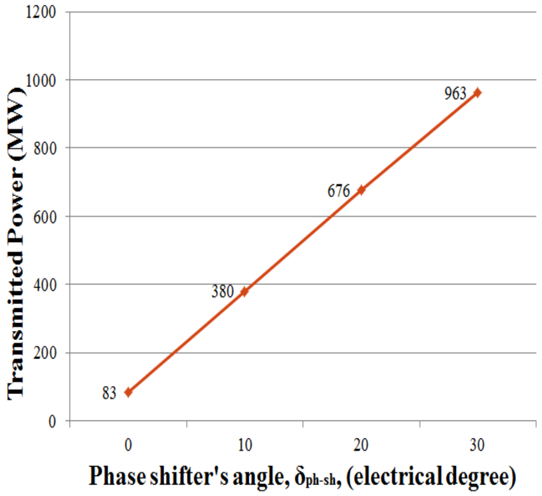

Fig. 2. The dependence of power flow through 330 kV Moldavskaya GRES – Chisinau on phase shifter's angle changes.

Moldavskaya GRES – HBK – Chisinau OHTL, will lead to power flow's value changing from 83 MW (phase angle is equal to 0°) to 963 MW (phase angle is equal to 30°) through this transmission line in the direction of 330 kV Chisinau substation. The power flow will change its direction with phase angle sign.

Phase-shifting transformers, allow to change the amount of power flows as well as their sign in a wide range being installed in intersystem tie-lines between Moldova and Romania, (Fig. 3-4). The operational control may be chosen from technical and commercial considerations.

Power flow control is interdependent regarding that interconnected power systems have mesh architecture.

Different variants of separated phase angle control by phase shifters between voltage vectors were considered:

First variant:

- at Baltsi substation (the phase shifter's angle was fixed at Vulcanehsti substation);

Second variant:

- at Vulcanehsti substation (the phase shifter's angle was fixed at Baltsi substation).

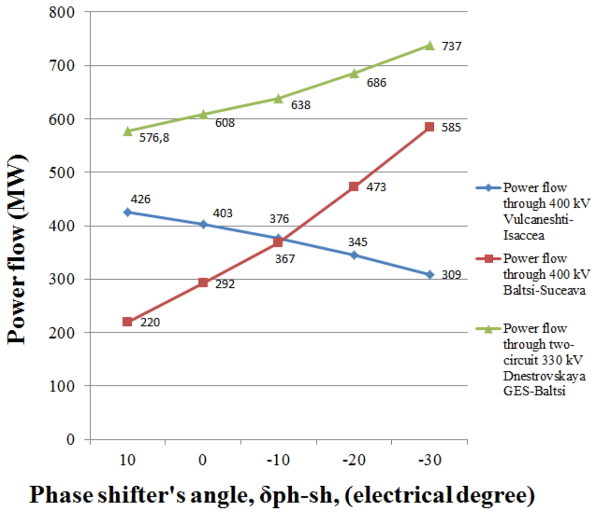

Fig. 3. Power flows through 400 kV Baltsi – Suceava and 400 kV Vulcaneshti – Isaccea OHTL for $\delta_{ph\text{-}shBaltsi}$ = var; $\delta_{ph\text{-}shVulcaneshti}$ = -30 el.deg. = const.

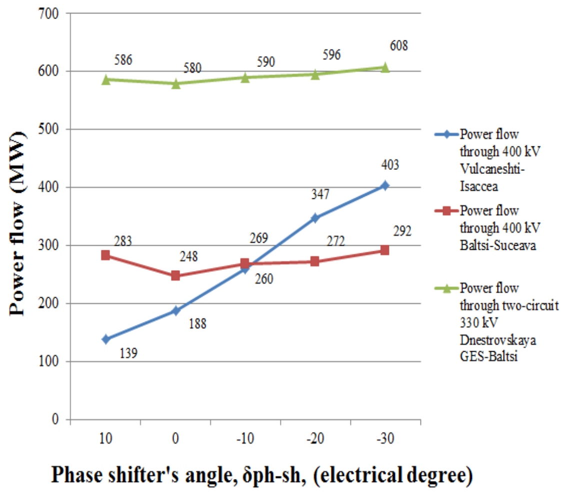

Fig. 4. Power flows through 400 kV Vulcanehti – Isaccea and 400 kV Baltsi – Suceava OHTL for $\delta_{ph\text{-}shVulcaneshti}$ = var; $\delta_{ph\text{-}shBaltsi}$ = 0 el.deg.

The phase shifter's voltage phase-angle control in the range of (+10°) ÷ (-30°) resulted in a larger amount of active power flowing through 400 kV Baltsi – Suceava OHTL, which increases from 220 MW to 580 MW in the first variant.

When the phase shifter's voltage phase-angle was controlled in the range of (+10°) ÷ (-30°) at Vulcaneshti substation, the power flow through 400 kV Vulcaneshti – Isaccea OHTL increased from 140 MW to 400 MW.

In the paper was stated that power flow control in one OHTL would lead to the power change in other OHTLs. Therefore, it is necessary to adjust phase-shifting transformer's phase-angle in the line it is installed to maintain constant the amount of power flowing through it, when changing the power flow in the other OHTL.

The illustrated diagrams show the obvious dependence of active power flowing through OHTL due to the installed phase-shifting transformers, and characterize the systemic efficiency of controlled ac transmission lines use. It is necessary to cooperate between interested power systems, scientific organizations and developers regarding the implementation in practice of the controlled transmission lines.

VI. CONCLUSIONS

1. Some problems of Moldova's, Ukraine's and Romania's power systems joint work could be solved by creating controlled ac transmission lines based on high-voltage transmission lines with increased power-carrying capacity and phase-shifting transformers use.

The value and the sign of the power that is flowing through intersystemic tie-lines and system's power lines could be changed by means of controlled transmission lines and phase shifters.

2. They also could solve the problem of power systems' interconnection that work non-synchronously.

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