EVALUATION OF POSSIBILITIES OF THE HVDC CONVERTER STATION UTILISATION FOR REACTIVE POWER COMPENSATION

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1. INTRODUCTION

Typical devices used for reactive power compensation in system nodes are static compensators in the form of capacitor and choke batteries and the state–of-the-art power electronics compensators of the following types: SVC (*Static Var Compensator*) and STATCOM (*Static Compensator*). For compensation purposes, synchronous machines are also used, e.g. water-power station generators.

The element operating for several years in the National Power System (KSE) and which can theoretically be used for reactive power regulation is the HVDC (High Voltage Direct Current) circuit. The main task of this system is the transmission of active power between Polish and Swedish power systems. The reactive power issue is also related to the above transmission. It relates directly to the circuit converters which, during operation, draw considerable amounts of reactive power from the systems.

Reactive power consumption depends on the active power transmitted through the circuit and the angle of control for the converter semiconducting elements. The authors have investigated the possibility of using HVDC circuit converter stations to regulate this power. The evaluation has been conducted on the basis of simulation tests. This article presents a part of the research conducted and described within the framework of [3].

2. POLAND – SWEDEN HVDC CIRCUIT

The Sweden-Poland HVDC transmission system started operating in 2000. The created connection between the Polish and Swedish power systems has greatly enhanced the National Power System operation safety, in particular its northern part which is characterised with a small number of generating systems [8].

The circuit connects the Karlshamn region in south-east Sweden with Wierzbięcin located near Słupsk in Poland. HVDC is connected to the Polish power system in the Słupsk station (voltage 400 kV) and to the Starno station on the Swedish side (voltage also 400 kV). The circuit length is 254 km.

The HVDC system diagram is presented in fig. 1. The technical data of the circuit and its individual elements has been obtained from sources [5, 6, 7, 8, 9].

Abstract

This paper presents the results of the research related to the evaluation of the possibility of using HVDC circuit converter stations to compensate reactive power in a power system. Proper control of the ignition angle in converters may influence the value of the reactive power drawn by this converter. By adding the control of the converter voltage transformation ratio, a system is created where the constant flow of active power with changeable reactive power may be maintained. Theoretically speaking, if the controls of reactive power compensation elements installed in the HVDC station are connected with the controls of the converter system operation (converter + transformer), a system may be obtained which can be successfully used for reactive power compensation in a power system.

The conducted research has shown that regulation of the reactive power drawn by the HVDC circuit converters can be obtained, which results in significant ranges of changes in this power with maintaining the constant set value of active power transmitted through this circuit.

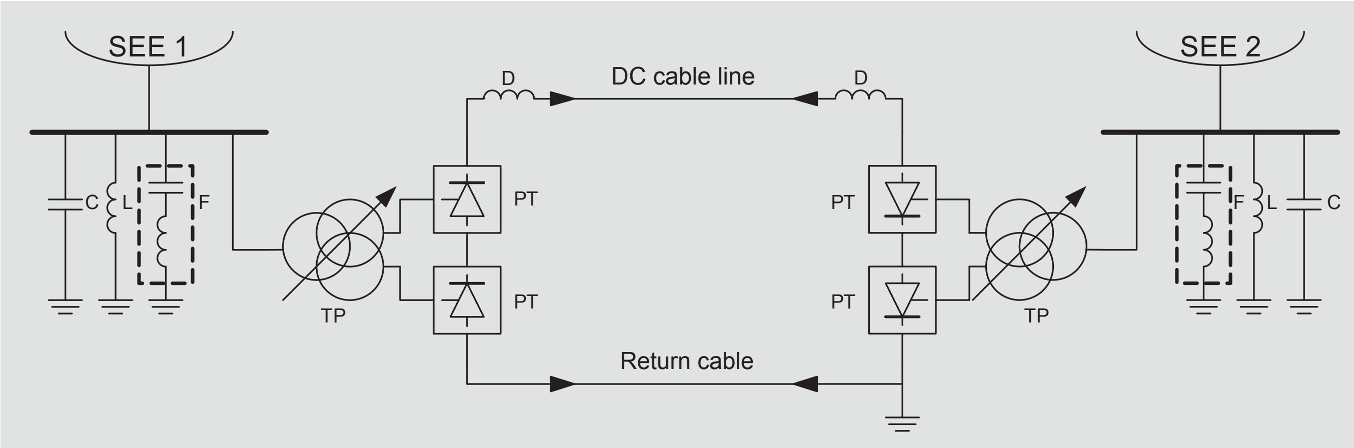

Fig. 1. HVDC transmission system diagram: PT – 6-pulse thyristor converter; TP – 3-winding converter transformer; D – choke; C – capacitor for reactive power compensation; L – choke for reactive power compensation; F - filters

The station located in Poland includes the following elements: a converter system, smoothing choke, higher harmonic filters, capacitor batteries and a choke for reactive power compensation. The converter system consists of two 6-pulse thyristor bridging systems connected in series on the DC side. The converter transformer consists of three 3-phase 3-winding units (power 236 MVA each) and the 405/181 kV/kV voltage transformation ratio. Thanks to proper connection of all converters and transformer windings, 12-pulse converter systems have been obtained.

The smoothing choke on the DC side (inductance 225 mH, nominal current 1381 A and nominal voltage 450 kV) operates as a rectified voltage filter and as a system reducing the surge values.

In order to limit the voltage and current disturbances caused by the converters during operation on the circuit AC side the higher harmonic filters have been installed. The reactive power generated by the filter systems is 95 Mvar with 400 kV voltage, which makes it an additional reactive power source. For the purposes of the HVDC station reactive power compensation, two capacitor batteries (nominal power 95 Mvar each) and a choke (nominal power 117 Mvar) are used. Capacitor batteries are activated as necessary and the choke is used to balance the reactive power of higher harmonic filters in the circuit low load states so as to avoid over--compensation.

Both circuit converter stations are similarly created units.

The control method for the HVDC circuit operation has been discussed in [2]. In the normal state, the thyristor control angles are within relatively narrow limits. During the rectifier operation, converters operate with the thyristor ignition angle α equal to $\alpha = 15° \pm 2.5°$. However, during the inverter operation, the extinguishing advance angle γ is equal to $\gamma = 18° \pm 1°$. The regulation of the set current value in the rectifier is effected through changing the voltage transformation ratio of the rectifier system and additionally regulating with the thyristor ignition angle from the given range. However, voltage regulation on the DC side is effected by the inverter and is achieved by changing the voltage transformation ratio of the inverter system and additionally regulating by means of the extinguishing advance angle from the given range.

3. REACTIVE POWER RELATED TO CONVERTERS

The change of the thyristor activation angle in converters results in the change of the phase shift angle of the basic current harmonic in the power system in relation to the sinusoidal supply voltage. The increase in the thyristor control angle is related to the increase in the phase angle of the current run delay in the line in relation to the converter input voltage (fig. 2), which clearly shows that the controlled power electronics converters are the receivers drawing reactive power from the line depending on the control angle [1, 10, 11].

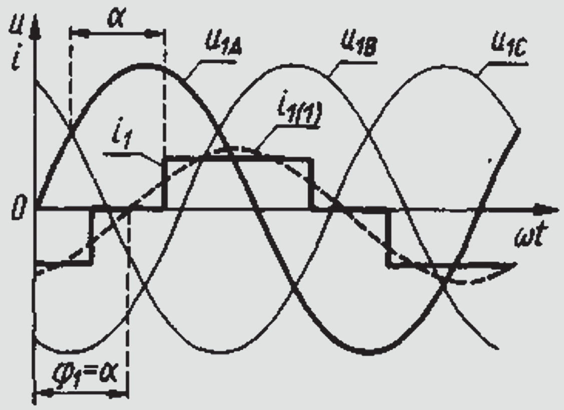

Fig. 2. Time runs of current and voltage supplying the rectifier controlled after omitting commutation processes

The elements for reactive power compensation located in the HVDC circuit converter station ensure only discontinuous control of this power. The simultaneous control of the voltage transformation ratio and the thyristor activation angle in the circuit theoretically makes it possible to control the reactive power in an incremental manner which, in connection with the incremental regulation of the capacitor battery and the choke, would make it possible to control the reactive power during the circuit operation in a substantially broader range.

4. EVALUATION OF THE HVDC CIRCUIT STATIONS CAPABILITY FOR REACTIVE POWER REGULATION

Model examinations of the circuit operation have been carried out using the DIgSILENT PowerFactory 13.2 program. The circuit static model has been designed for the purposes of the examinations. The model uses ready-made components built into the simulation program. Fig. 3 shows the structure of the designed HVDC circuit model.

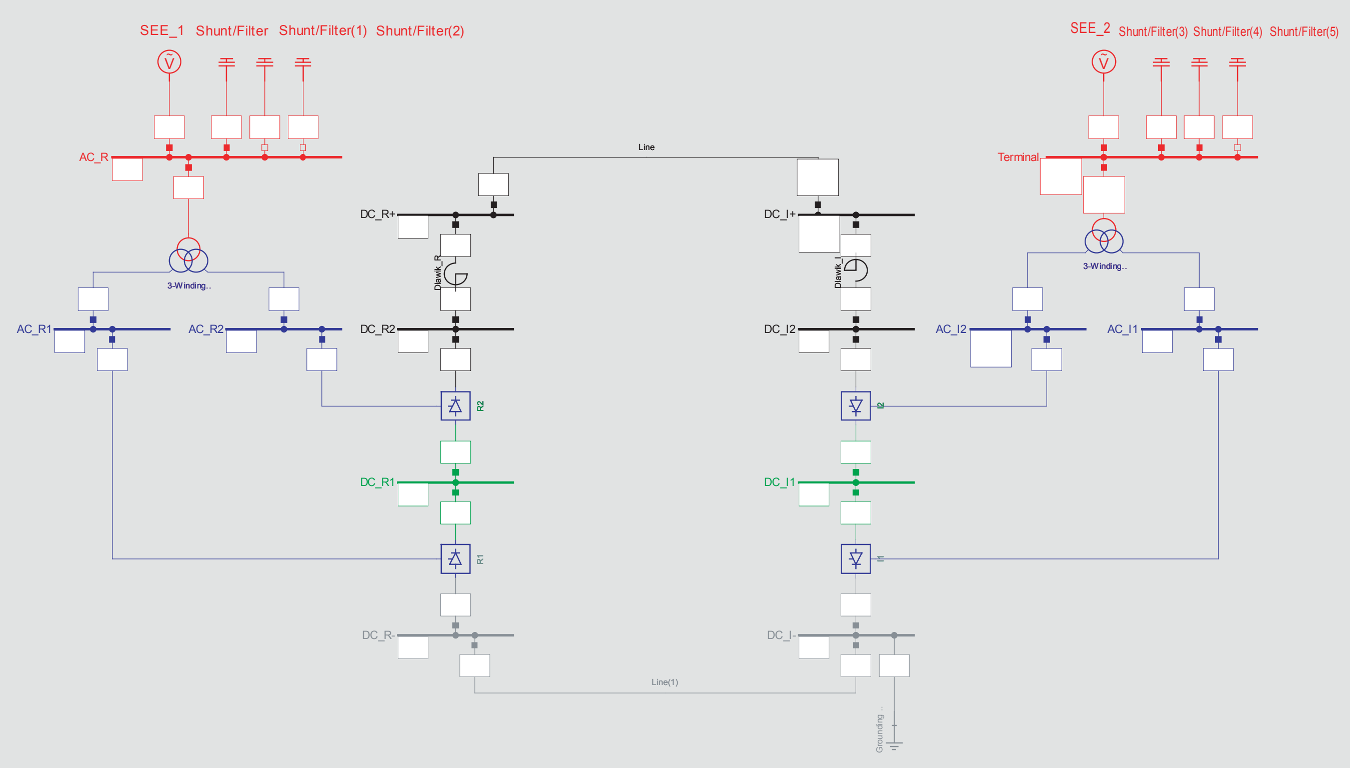

Fig. 3. Structure of the designed HVDC circuit model

In order to represent the power systems, voltage sources with introduced impedance corresponding to the systems short-circuit power have been used. The circuit AC buses have been fitted, on both sides, with three

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capacitor batteries for reactive power compensation (95 Mvar each), two of which model the actual batteries while the remaining one provides the same reactive power as a higher harmonic filter. Depending on the power transmitted through the circuit and voltage levels, the batteries were activated or deactivated during the simulation examinations. Deactivation of the last battery was to represent choke activation with operating higher harmonic filter.

While creating the converter system models, a ready-made 3-winding transformer model and bridging thyristor 6-pulse converter models were used. The parameters for these elements have been assumed as for the actual object. Smoothing chokes in a form of inductance itself have been modelled between the converters and the HVDC cable line. In order to represent the circuit cable, ready-made models of the DC cable line have been used and proper parameter values have been inputted to them.

As in the model designing stage complete data was not available, it was complemented on the basis of other similar objects. Verification was necessary to check if the designed model corresponds to the actual object. For comparison purposes, the characteristics of the circuit obtained from available sources have been used. For the purposes of the study, they have been represented on diagrams and the characteristics obtained from the designed model have been imposed on them.

Fig. 4 shows characteristics $Q = f(P_{DC})$ (of the model and the circuit) obtained during rectifier operation and fig. 5 shows these characteristics obtained during inverter operation.

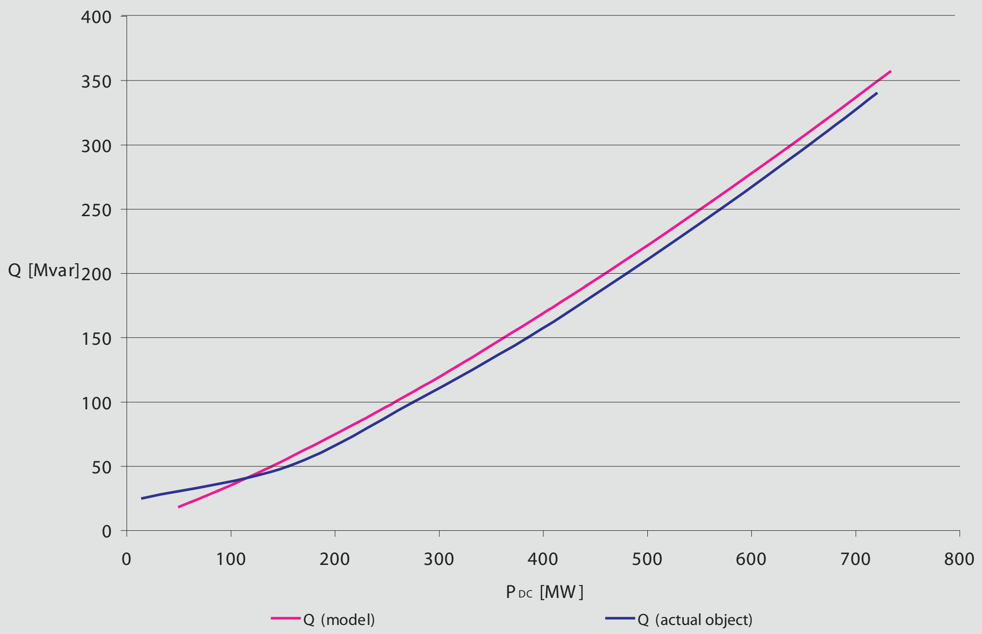

Fig. 4. Q = f (PDC) characteristics of the HVDC circuit converter system during rectifier operation

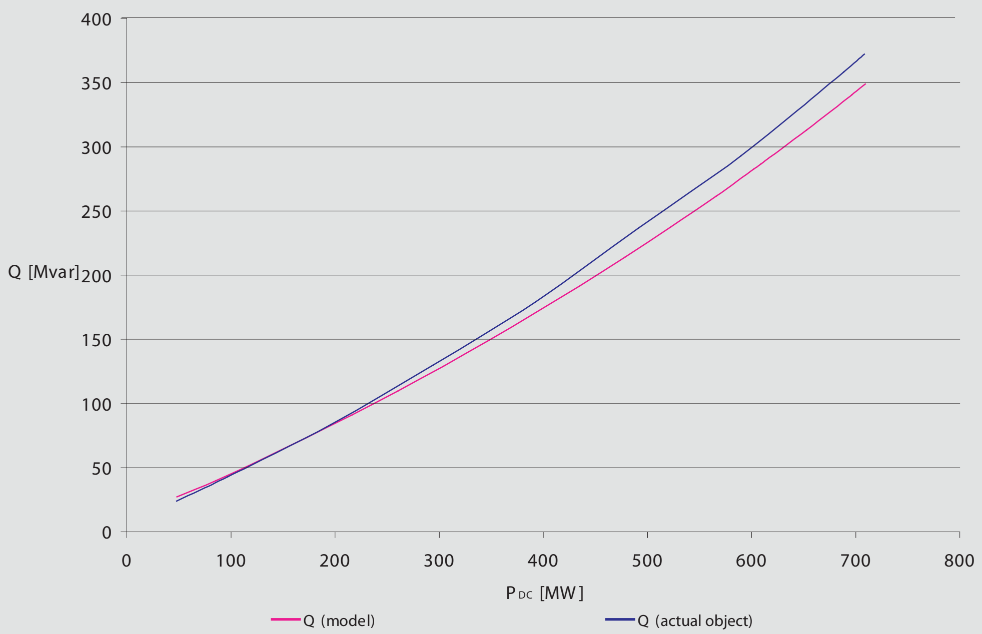

Fig. 5. Q = f (PDC) characteristics of the HVDC circuit converter system during inverter operation

As shown in the presented diagrams, model characteristics do not precisely correspond to the actual object characteristics. The reasons for the differences may be numerous, however, the most significant are the assumptions for given circuit parameters and the fact that several model elements are idealised. Taking the above into account, a conclusion has been drawn that the characteristics obtained in the model are precise enough and the model has been designed with the precision allowing conducting the planned examinations.

5. EXAMINATION RESULTS

The simulation examinations were conducted in two stages: the first stage consisted in checking the reactive power regulation range with the station rectifier operation and the second stage consisted in checking the regulation range with the station inverter operation.

During both examinations the constant set transmitted power in the circuit was maintained by maintaining the constant DC value in the rectifier and the constant voltage value on the DC side in the inverter. The examinations were carried out for the entire range of transmitted reactive powers set in the circuit assuming that the power change is to be incremental (by 50 MW). Only the extreme analysed power values were inconsistent with the assumed increment. This was related to the current limits in the converter: lower limit equal to 114 A, which corresponded to the transmitted power on the level of 50.46 MW; upper limit equal to 1664 A, which corresponded to the transmitted power equal to 736.54 MW.

The results obtained have been presented on diagrams in the form of points. In order to clearly show the change trends, the points have been connected with curves. The points have been coloured to highlight results obtained in slightly altered conditions of converter station operation and the following indications have been introduced in the diagrams:

◆ – all three reactive power compensation batteries activated in the station;

■ – two reactive power compensation batteries activated in the station;

▲ – one reactive power compensation battery activated in the station (equivalent of higher harmonic filters);

● – no compensation in the station (equivalent of the situation when the choke compensates reactive power of the higher harmonic filters).

Unfilled points show that the voltage on the converter AC side has reached values lower than the ones which are permissible in the long run.

Fig. 6-8 shows the results obtained during rectifier examinations and fig. 9-11 shows the results obtained in relation to the inverter.

The first figure (6) shows the consumption of reactive power by the rectifier in the function of the location of rectifier transformer taps. The obtained results show that the reactive power regulation range is not small. The figure shows that it was impossible, for any of the set power values in the circuit, to use the full regulation range of the voltage transformation ratio due to the limited possibility of controlling the rectifier. The present reactive power changes are incremental but their increment is much lower than the increment caused by activation of the capacitor battery or the choke. The most extensive changes of the rectifier reactive power have been detected with the highest power values transmitted in the HVDC circuit. The decrease in the power transmitted in the circuit has been accompanied by a decrease in the number of points obtained in the characteristic.

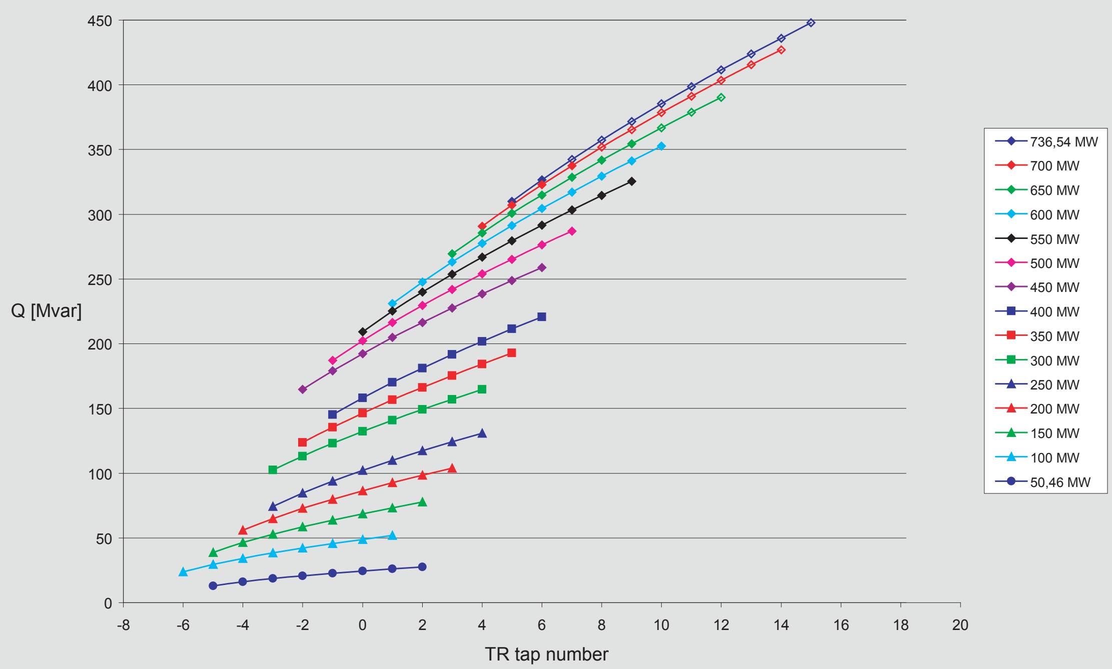

Fig. 6. Reactive power drawn by the rectifier in the function of power transmitted by the circuit and the location of the rectifier transformer tap

The next figure (7) shows the value of the converter reactive power in the function of the thyristor activation angle. Regardless of the set value of the transmitted reactive power, the range of the α angle regulation has remained practically constant. This resulted from the fact that, on the one hand, it was limited by the minimum permissible value (5°) and, on the other, the limit resulted from the constant voltage value maintained in the circuit. However, the available reactive power regulation range was significant and made it possible both to increase and decrease its draw in relation to the current value dependant on the ignition angles used. This was related to the fact that the currently used ignition angle is located in the middle of the available range of activation angles.

However, fig. 8 shows the dependence of the reactive power value in the function of voltage on the AC side of the rectifier. During transmission of a large amount of power in the circuit, the rectifier draws a large amount of reactive power, which, as a result, causes problems with maintaining the correct voltage on the AC side, which is undoubtedly one of the limits in using this type of reactive power regulation.

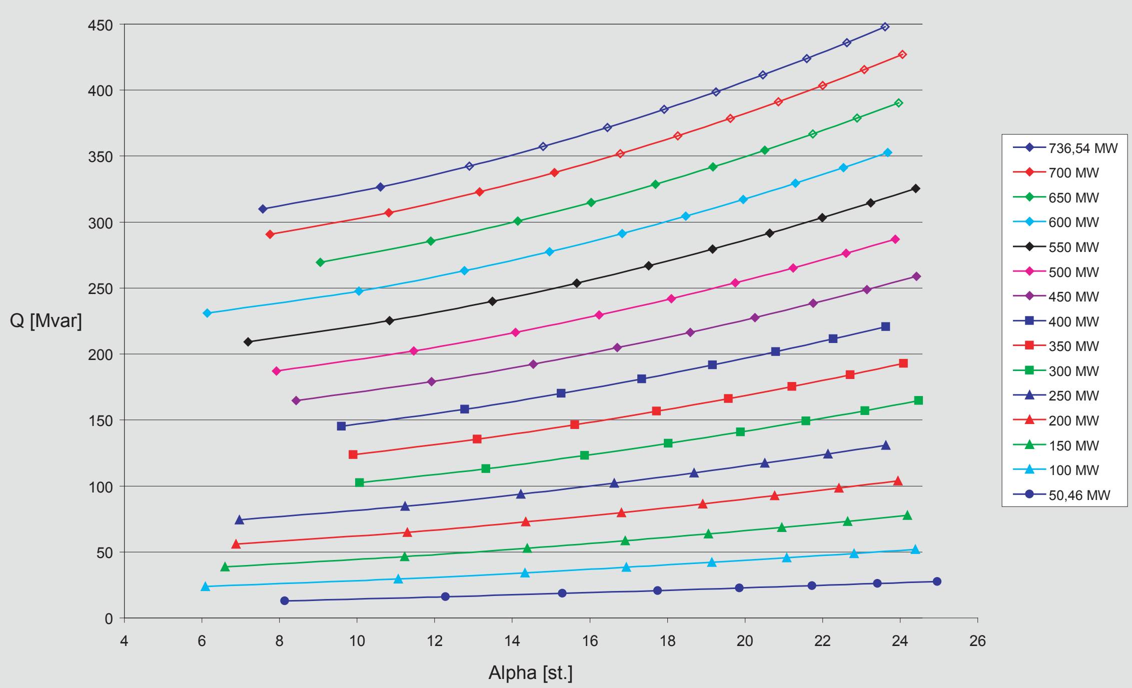

Fig. 7. Consumption of reactive power by the rectifier in the function of power transmitted in the circuit and the angle of activating thyristors in the rectifier

Analogously, the examination of the range of the reactive power regulation achieved by the rectifier system of the circuit with inverter operation was conducted.

Fig. 9 shows the value of the reactive power drawn by the inverter in the function of the location of the inverter transformer taps. The results obtained also confirmed that the regulation range of the reactive power drawn by the HVDC station converter is significant. Despite the fact that also here, in any analysed case of the circuit operation, it was not possible to use the full range of transformer regulation, the obtained range of reactive power changes was more extensive than for the rectifier operation. Similarly to the rectifier operation, the obtained changes of reactive power were incremental with an increment lower than might result from the activation of the circuit compensator system elements.

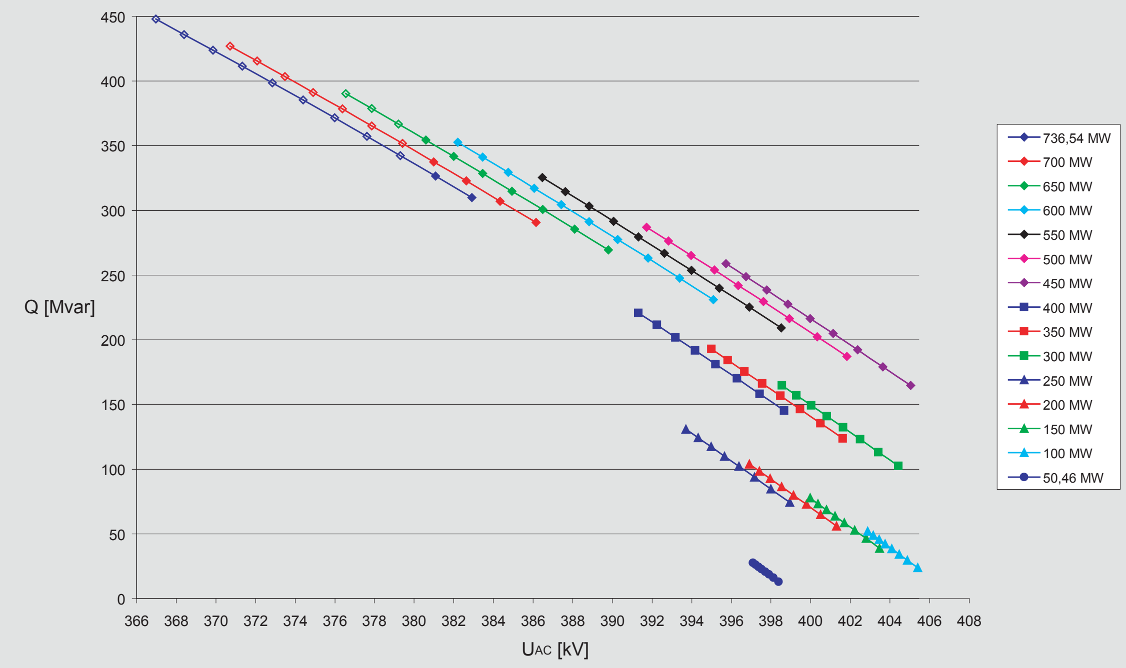

Fig. 8. Consumption of reactive power by the rectifier in the function of the power transmitted in the circuit and the voltage angle in the 400 kV buses of the rectifier station

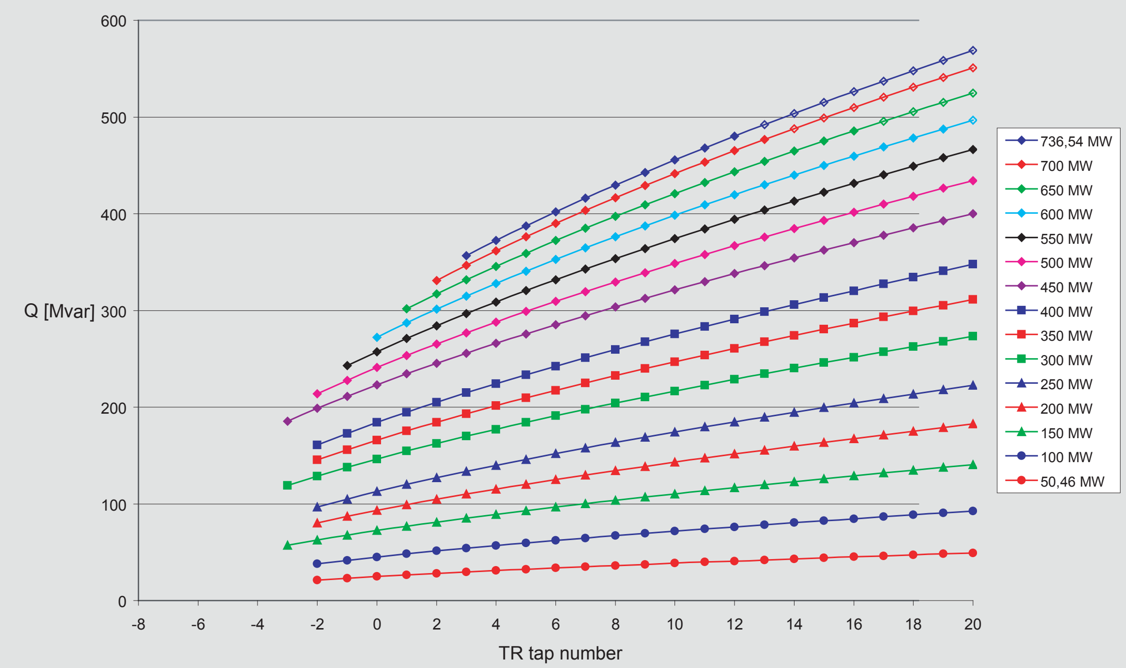

Fig. 9. Reactive power drawn by the inverter in the function of the power transmitted in the circuit and the location of the inverter transformer tap

Fig. 10 shows the converter reactive power in the function of the thyristor activation angle in the inverter. Depending on the value of the transmitted power set in the circuit, the available regulation angle α changed. This was related to the fact that with the maintained constant value of the γ angle in the inverter the commu-

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tation angle μ was significantly changed together with the changes in the transmitted active power which with the γ angle determined the moment of thyristors activation in the inverter. In this case, the regulation range is limited, on the one hand, by the minimum γ angle and, on the other hand, by the number of transformer taps. The range of control for the inverter thyristors in relation to the one currently utilised during normal operation makes it possible only to increase the reactive power drawn by the inverter as the present range of ignition angles is practically located at the end of the available range of inverter thyristors activation angles.

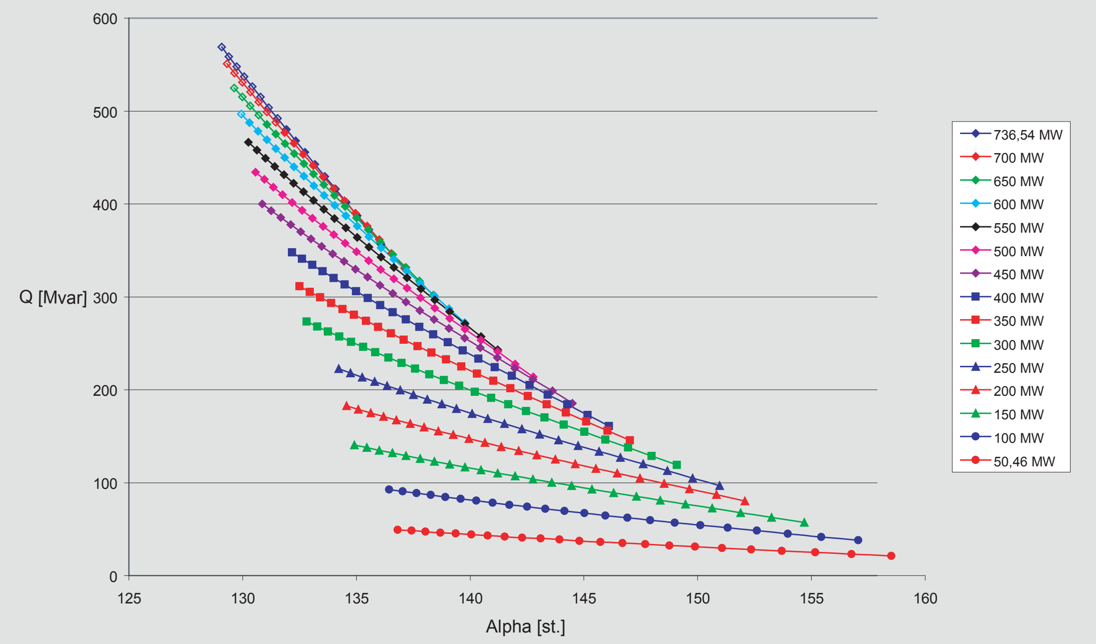

Fig. 10. Consumption of reactive power by the inverter in the function of power transmitted in the circuit and the angle of activating thyristors in the inverters

The last figure (11) shows the value of the inverter reactive power in the function of voltage on the AC side. Similarly to the rectifier operation, during the transmission of high power, the inverter operates with significant difficulties related to maintaining the correct voltage level on the AC buses. Points presenting obtained results in fig. 11 have been grouped according to the number of currently activated capacitor batteries. Deactivation of other batteries has resulted in shifting the voltage range on the AC buses towards the middle of the permissible voltage range and together with decreasing the power transmitted in the circuit the characteristics have systematically shifted towards increasingly higher AC voltage values. A similar tendency has also been observed in the rectifier.

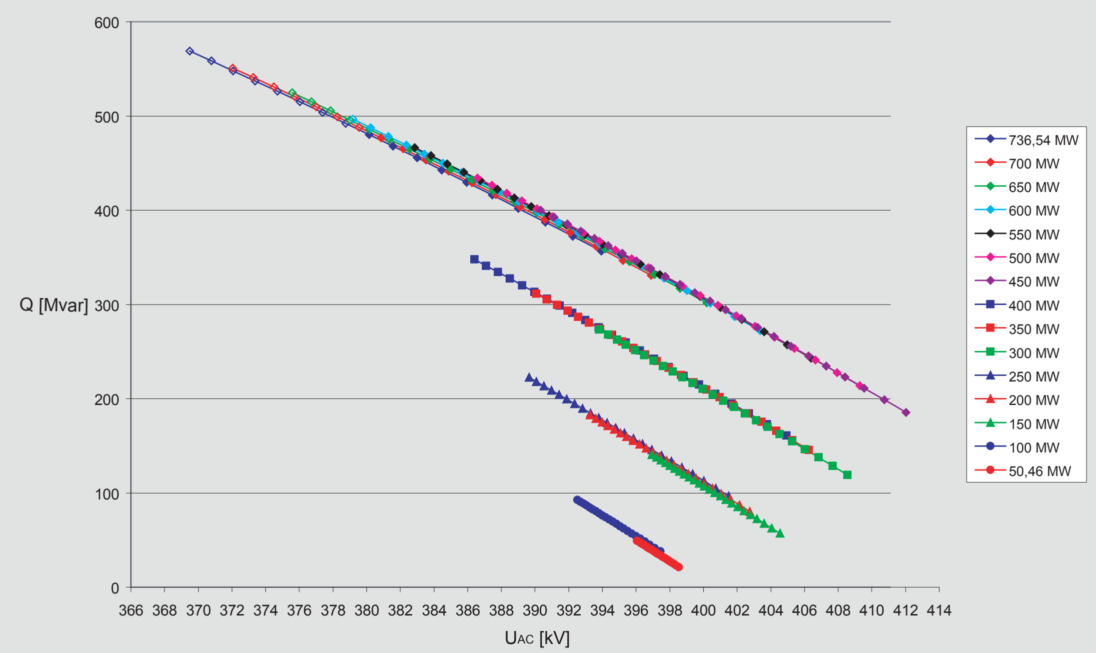

Fig. 11. Consumption of reactive power by the inverter in the function of the power transmitted in the circuit and the voltage value in the 400 kV buses of the inverter station

6. SUMMARY

The conducted research has shown that the regulation of the reactive power drawn by the HVDC circuit converters can be obtained while maintaining the constant set value of the active power transmitted through this circuit. The utilisation of the theoretically available range of converter control angles and the range of changes in the converter transformers voltage transmission ratio has made it possible, in relation to the present state, to increase and decrease the reactive power draw with rectifier operation and mainly to increase the draw of this power with inverter operation. The obtained reactive power regulation is incremental, which results from the character of the transformer taps switching. Nevertheless, the change in the converter station reactive power obtained in this manner is achieved with smaller increments than if the currently utilised method is used. The determined range of the rectifier reactive power changes is much broader than the one currently used and has reached the maximum value approaching 140 Mvar, but, taking into account the voltage limit, the maximum available range amounts to approximately 120 Mvar (while maintaining the constant power in the circuit) and has gradually decreased together with the decrease in the value of the power transmitted in the circuit. However, the range of the inverter reactive power changes has also been extended and has reached the maximum value approaching 220 Mvar (while maintaining the constant power in the circuit) and has also gradually decreased together with the decrease in the value of the power transmitted in the circuit.

The aim of the research conducted has only been to show that reactive power regulation by means of HVDC circuit converters is possible (which has been demonstrated) and, due to this, it has not included a very precise determination of the available reactive power ranges.

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