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Series compensator 's influence on the distance protection operation

Abstract *In the paper, the rules for finding formulas which describe the value of impedance measured by a distance protection due to the series compensator's influence are presented. The graphical interpretation of the formulas has been shown and the digital simulation-based verification of the formulas has been carried out. The modifications required in the protection settings under the standard operation of the series compensator as well as with the fault current limitation available have been defined. Influence of the shunt network failure on the operation of protections has been considered.*

Streszczenie. *W artykule podano zasady wyznaczania wzorów opisujących wartość pomierzonej impedancji przez zabezpieczenie odległościowe na skutek oddziaływania kompensatora szeregowego. Podano interpretację graficzną tych wzorów oraz dokonano ich weryfikacji poprzez symulację cyfrową. Określono wymagane zmiany w nastawach zabezpieczeń w przypadku standardowej pracy kompensatora szeregowego jak i z możliwością ograniczania prądów zwarciowych. Rozważono wpływ awarii układu bocznikującego na pracę zabezpieczeń. (Tytuł :* ***Wpływ kompensatora szeregowego na pracę zabezpieczenia odległościowego****)*

Keywords: FACTS, TCSC, distance protection
Słowa kluczowe: system FACTS, sterownik TCSC, zabezpieczenia odległościowe

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Introduction

Operation of the Thyristor Controlled Series Compensator (TCSC) relies on implementation of the variable value reactance (both the capacitive or the inductive one) of the controller in series with the line reactance. Thus, the active and reactive power flow can be controlled [2], the voltage fluctuations resulting from the fast-variable reactive power can be limited [4] and the fault current value can also be limited [1].

The distance protection is one of the protections mostly applied in the 220kV and 400kV transmission lines. It founds the fault location referring to the impedance measurement. The TCSC controller connected in series with a line changes the apparent line reactance and, finally, makes the measurements made by the distance protection are false [4].

Worldwide, the Flexible Alternating Current Transmission Systems (FACTS) and, in effect, the TCSC controllers, are mounted in the middle of the long-distance transmission line. Therefore, the papers concerning the troubles in the protection operation (including the Poland-born papers) discuss the controllers located in such a location [3,5].

In Europe, there is a high density of interconnected lines; therefore, regarding the urbanization degree, the construction of the FACTS nearby the existing transmission stations is recommended (road infrastructure, easy ground purchase, lower maintenance costs). In addition, opposite to the parallel compensators, the location of the TCSC controller in the line does not affect its regulation properties; thus, it is additionally suitable to be installed adjacent to the existing substations. In such a case, the impedance measurement carried out by the protection is also affected by other lines co-feeding the fault, and the controller as such will affect the protections in some adjacent lines. Such a case is the subject of the presented paper.

System model and its mathematical description

Like in [6], the point of issue for the formulas was the system model in form of the star-type connection of three subsystems in which not but the longitudinal (Fig.1) have been considered with a TCSC controller installed in the common substation.

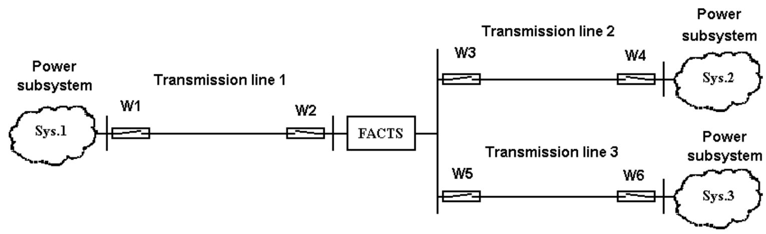

Fig.1 System for investigation of influence of any FACTS controller on the protections' operation

The assumption was that, depending on the operation mode, the TCSC introduces impedances (in principle, the reactances):

a) capacitive: $-jX_{TCSC}^{C\ min} \geq \underline{Z}_{TCSC} \geq -jX_{TCSC}^{C\ max}$
b) inductive: $jX_{TCSC}^{L\ min} \geq \underline{Z}_{TCSC} \geq jX_{TCSC}^{L\ max}$
c) during shunting $\underline{Z}_{TCSC} = 0$.

The formulas are derived in the way like that described in [7]. We can see that, referring to the origin, $\underline{Z}_{L1}$ (impedance of line 1) was replaced by $\underline{Z}_{L1} + \underline{Z}_{TCSC}$. Therefore, the protection at the circuit-breaker W1 under metallic short-circuit conditions in line 2 will measure the impedance given by the formula (1)

$$\underline{Z}_P = \frac{\underline{Z}_{L1} + \underline{Z}_{TCSC} + \alpha \underline{Z}_{L2}\left(1 + \frac{\underline{Z}_{S1}e^{-j\delta_{13}} + \underline{Z}_{L1} + \underline{Z}_{TCSC}}{\underline{Z}_{S3} + \underline{Z}_{L3}}\right)}{1 - \frac{\alpha \underline{Z}_{L2}}{\underline{Z}_{S3} + \underline{Z}_{L3}}\left(e^{-j\delta_{13}} - 1\right)} \quad (1)$$

The by-passed controller does not affect the protection. If it works in the inductive mode, a significant increase only in the distance protection's setting in the III zone is forced. However, the conditions become worse when it would work in the capacitive mode. Then, at the negative angle δ_{13} – angle between voltage phasor of sys.1 and sys.3 - (Fig.2) as well as at the positive angle δ_{13} (Fig.3) the value of impedance $\underline{Z}_P$ during the short-circuit in the line 2 measured by the protection in the line 1 will try to enter the zone I of protection leading to the non-selective operation of protections that brings the risk of islanding. Moreover, at the negative angle δ_{13} (Fig.2) and specific parameters of both the grid and the controller, it can be that the II protection zone in line 1 will cover the entire line 2 (including arc faults) and the II protection zone in line 2 will not cover the entire line 2 ($Z_{TCSC}^{C\,max}$). Finally, to avoid the non-selectivity for II protection zone, a diversification of their operation times is forced.

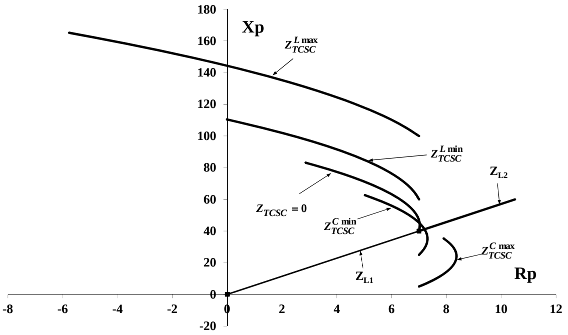

Fig.2 Measurement of impedance by distance protection at the circuit-breaker W1 under metallic short-circuit conditions in transmission line 2 for significant negative angle δ_{13}

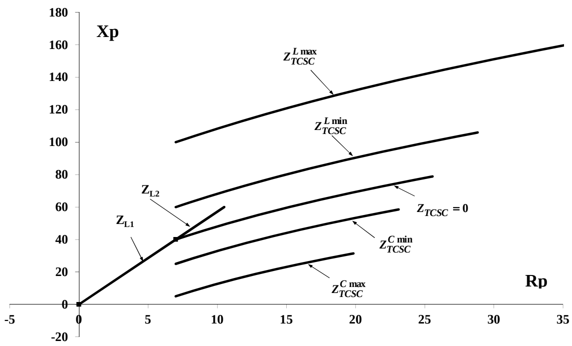

Fig.3 Measurement of impedance by distance protection at the circuit-breaker W1 under metallic short-circuit conditions in transmission line 2 for significant positive angle δ_{13}

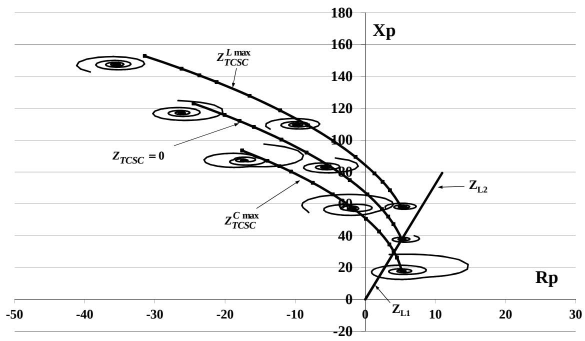

Fig.4 Influence of TCSC controller on measured impedance found in analytical and digital ways, for metallic fault and negative angle δ under short-circuit on line 2

Digital-based verification of analytically derived formulas

Like in [6], the platform proposed by Jiang to study the FACTS models [8] has been used to verify the formulas. The studies have been carried out in PS CAD environment. The goal of studies was to state if a series of assumpions introduced to simplify the work (cross elements neglected, rated source voltages, etc) does not significantly affect the measurement result. Like in [6], no simplifications were introduced into the digital model (identical model) and, referring to the preliminary digital simulations, the parameters of the network presented in Fig.1 have been found. Thus, the opportunity to develop a model of the grid section referring to the power transmitted before the fault and the short-circuit capacities of substations, sufficient to study the operation of protections, has also been verified.

Plots for impedances obtained from formula (1) (Fig.4) are similar to those in Fig.2; the differences result from different parameters of lines, systems etc. The fragments just before reaching the steady state (spiral lines) have been cut out from the time plots of measured impedances obtained by digital simulations. One can see that an ideal match between the results obtained in simulations and those found analytically using formulas does not exist. Differences come from simplifications assumed for computation purposes. However, regarding the safety and sensitivity coefficients taken into account when choosing the protections, the accuracy of results obtained using formulas is sufficient for the protection choice's purposes. Therefore, is can be stated that the verification of results was successful.

In preceding section, neither the formula for impedance measured under the arc fault nor that for the arc resistance was given. From one hand, these formulas are complex; from other hand, they are similar in the same way as formula (1) to those presented in [7]. Therefore, the related graphical interpretation was not presented in preceding section. However, very wide section of the line 1 must not be covered by the first protection zone of the distance protection under the arc fault conditions due to the false measurement under the metallic fault conditions (Fig.4). To realize that, the grapical interpretation of the formula along with the digital verification is presented in this section (Fig.5).

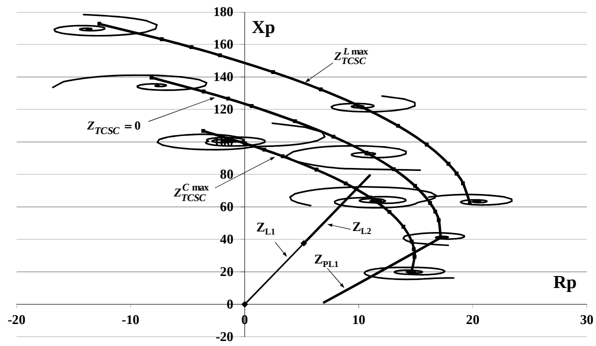

Fig.5 Influence of TCSC controller on measured impedance found in analytical and digital ways, for arc fault and negative angle δ under short-circuit on line 2

The region covered by the first zone of the distance protection should include majority of the field (extended as to the resistance by the sensitivity coefficient) between lines Z_{L1} i Z_{PL1} (Fig.5) where: Z_{L1} – true value of the line 1 impedance that is also the measured value of the impedance during metallic fault; Z_{PL1} – measured value of the impedance during arc fault.

Otherwise, if TCSC would stay in the capacitive operation mode during the fault, the measured values of impedance $Z_{TCSC}^{C\,max}$ representing impedances during a fault in line 2 could not enter this region neither for metallic fault (Fig.4) not for arc fault (Fig.5) because of the selectivity of protections' operation.

The reach of the I zone for reactances the standard value of which is 85% of the line length (for data for grid section and TCSC controller as in figures 4 and 5) should be limited down to 50%, and, in some cases (for data from figures 2 and 3), even to 10%. It means that this zone is excluded from the protection operation, and the protection as such could only play role of the reserve one.

Final remarks

The regulation properties of TCSC are identical regardless location of the latter in the line. Its installation adjacent to the existing substation is decided referring to the technical and economical aspects: local infrastructure simplifies the construction, adjacent substation simplifies supervision and maintenance, etc.

Under normal operation conditions the task of the TCSC controller is mostly to adjust (mainly increasing) the power flow by the line it is installed on. Thus, TCSC controller operates in the capacitive mode and influences the power flow in the adjacent grid section. As the short-circuit current is much higher than the operational current, the TCSC controller should be by-passed during the fault (unless it is provided for operation under fault conditions). It is carried out by the overvoltage protections (response to the instantaneous value) mounted on the controller. The response takes place in the first quarter of the short-circuit period whilst the distance protections (regarding the unsteady states of current transformers for the first zone (theoretically instantaneously-operating) carry out the measurement not but in the second half of the second period; thus, their operation is not affected here by the TCSC controller.

There is an opportunity to use the TCSC controller, additionally, to limit the short-circuit currents (the controllers are too slow for surge current i_p, but fast enough for thermal current I_{th}). In such a case, in the controller, there are two extents of overvoltage protection reacting to the instantaneous value: first one switches it over from the capacitive mode to the inductive mode; second stage by-passes for the too high short-circuit current. Properly, both switching operations proceed very quickly (in first half of the fault period). Duration of transients in the grid resulting from the change in charge of such significant capacity can be from two to three successive periods. In effect, the change from the capacitive to inductive response of the TCSC controller under standard time settings can be observed (transients) during the operation of the distance protection's first zone. In the second zone, the affect of transients due to the change in the TCSC character (from capacitive to inductive) should decay. In the impedance range, the TCSC controller operating in inductive mode will only force an increase in the III zone of distance protection; however, regarding intensive transients, the operation of the first zone should also be modified, i.e. delayed.

As devices are unreliable, a failure of the system that switches over the TCSC controller from capacitive to inductive operation mode or provides its by-pass has to be taken into account. If the controller is not designed to work during the short-circuit, too high voltage will cause the capacitor's insulation break down and the failure of controller that will no more affect the operation of the line protections. If the controller is designed to work during the short-circuit, its admissible voltage is adequate and the capacitive operation mode will continue. In such a case, there is a risk of unnecessary actions of distance protection (unselective operation).

Thus, the most safe solution is :

- to apply differential protection as a basic one on the line in which the TCSC controller is mounted,
- to apply distance protection with significantly limited first zone and extended third zone as a local reserve; it will simultaneously provide functions of the remote reserve which is not only protection-type but also circuit-breaker-type.

To obtain the first zone's limitation for arc-type faults only and to generate no problem in the second zone's choice, and the constant direction of the power flow can be defined (power take-off from the power station, international interconnection lines, etc.), the TCSC controller should be mounted in the take-off substation (positive angle $\delta_{13,}$ in Fig.3).

Sometimes, constant direction of the power flow can not be defined due to the changes in the multi-meshed transmission network configuration and the station in which the TCSC controller is mounted is able to deliver the power (angle δ_{13} can be negative). In such a case, the protection chosen in a standard way is not able to distinct, under extreme conditions shown in Fig.2, if there is an arc-type fault in the line1 or a metallic-type fault in the line 2. Thus, , not but the metallic-type faults in line 1 are being switched off in the zone I whilst the arc-type faults - not but in the zone II (the resistance of zone I is shorted).

If the TCSC controller works in the line that co-feeds the fault referring to the protection (see Fig.1 – short-circuit in line 2, protection adjacent to the W6 circuit-breaker), its influence can be seen; however, regarding the changes in settings of protections it is very small, i.e. negligible.

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