The influence of unified power flow controller on work of distance protection

Krzysztof Szubert
Poznan University of Technology, Institute of Electrical Power Engineering
Piotrowo 3A. 61-138 Poznań,
E-mail: krzysztof.szubert@put.poznan.pl

Summary**: The short-circuit current in transmission nets (220kV) is from a dozen or so to over 20 times greater that duty current. Therefore when short-circuit occur on the same line there the UPFC exist, this controller has to be by-passed. So it does not influence on first and second zones of distance protection. Short-circuit in nearby power line, when in this side co-supply from other line additionally occur, it can cause, that current in considered line will grow up less than 2 times. Then the UPFC can stay in work. Introduced add voltage and the change of current phase in consider line in relation to predominant current of short-circuit could cause considerable measurement mistakes of short-circuit impedance. This phenomenon will be observed in III zone of distance protection. The example characteristics of measured impedance by distance protection on base derivate equation are presented in this article. The principle of III zone set value selection of this protection is talked over on basis of these characteristics.**

Keyword: FACTS, UPFC, automatic protection

I. INTRODUCTION

The influence of the FACTS controllers on work of power system is wide described and it works over improvement their regulating proprieties all the time [1], [6], [7]. The FACTS with regard on their price will be applied in neuralgic points of power network only. To this time they were used to improvement the conditions of energy transmission on considerable distances and assembled mainly in central part of power line (the USA, Canada, Brazil, RPA) [2], [3], [11]. European power nets are strongly joined and their power line length is since tens to a few hundred kilometres. Substation with FACTS will be therefore assembled rather near existing power stations. So it will radically change influence of these controllers on work of protections [5]. So far they mainly influence on work of protections of line in which they are installed, in Europe they will influence on work of protections of majority power line in nearby stations. The incorrect working of automatic protection in neuralgic points of power system can bring to his break-up. So with European point of view the question of influence of the FACTS on work of automatic protection is very important.

In this study, the UPFC from among FACTS controllers and, the most popularly applied in power networks, the distance protection from among automatic protection was chosen. This range papers are well known also [4], [9], [10]. However they mark the foundation about unrestricted possibility of overload the current of serial converter. With the UPFC point of view it is the element, which is the most menaced during short-circuit. In this article was accepted, that serial connected converter can work with 15% rated voltage and with 200% average duty current of line – so converter can processing since 0 to about 15% of transmitted power in normal state as well as to 30% of this power in disturbance states.

II. THE INFLUENCE OF SHORT-CIRCUIT IN POWER SYSTEM ON WORK OF THE UPFC CONTROLLER

The current in short-circuit place in power nets (220kV) is from a dozen or so to over 20 times greater that duty current. In line on which short-circuit occur, the value of current has to exceed 5 times of duty current. At standard way of control the regulators of converters limit possible to introduce value of current to rated value (the two times of average duty current), they can make possible short-lived small overload, but they do not do it with regard on scarce influence on short circuit current and complicated thermal models of converter elements. In the effect, during nearby short-circuits, magnetically flux come from winding connected to power network does not be compensate by magnetically flux come from winding connected to converter, in serial transformer. This causes growth of voltage on serial transformer. After exceeding specific value of voltage, the controller not only loses the regulating proprieties, but also his elements can undergo damage. Therefore these controllers are protected by thyristors, that by-passing primary or secondary side of transformer when voltage exceeding specific value [8].

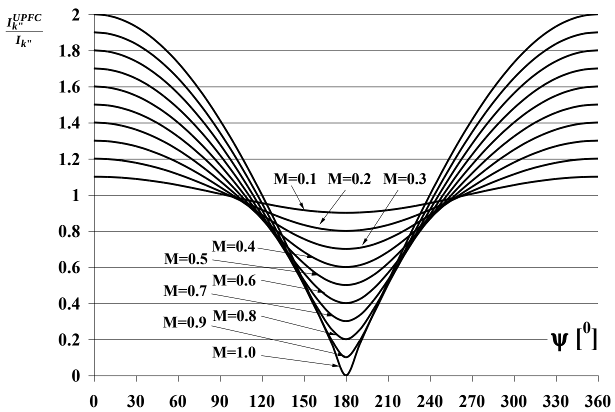

Fig.1 The influence of UPFC on short circuit current value

Theoretically maintenance in work the UPFC for all short circuits is possible. It would limit short circuit current by this controller (1) (Fig. 1).

$$\frac{I_{k"}^{UPFC}}{I_{k"}} = \sqrt{1 + M^2 + 2M\cos(\psi)} \qquad (1)$$

where $I_{k"}$ – short circuit current

M - the relation of amplitudes of introduced by UPFC voltage to phase voltage of system

Ψ - the angle of shift between introduced by UPFC voltage and the phase voltage of system

But in real, short circuit current would be limited in insufficient way (Fig. 1) by received add voltage as 15% rated voltage (M=0,15). Therefore the tap changer would be required for serial transformer during short-circuits. The possibility of not enlarging power would exist for series converter (2) for value M > 0,97 (Fig. 2).

$$\frac{S^{P2}}{S_N^{P2}} = K\,M\sqrt{1 + M^2 + 2M\cos(\psi)} \qquad (2)$$

where S^{P2} – power of series converter

S^{P2}_N – rated power of series converter

K – constant coefficient which is depend on system parameters

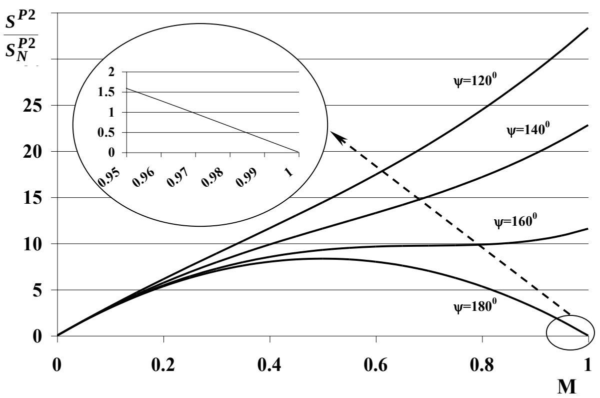

Fig.2 The relative serial converter power load durming short circuit as a function of his introsusception voltage (relative absolute value M and phase Ψ)

With regard for short fit time (the voltage of secondary side of transformer grows up to dangerous level in 1/6 network period) the switch of tap changer of series transformer would be very difficult. It appear possible solution, the keeping the converter in work with rated current till moment of considerable increase of the secondary side of series transformer voltage, at this moment (as reaction on temporary value of voltage), the part of transformer winding should be shunt by thyristors connected in inversely parallel arrangement. It change transformation ratio in this way. The controller could interpret current in thyristors circuit as a signal, that short circuit occur in power network nearly him and it should start to restrictive current work. The short-lived bypassing of part of secondary winding of serial transformer should not be dangerous for transformer, because his work is approximate to work of current transformer. In time smaller then 1/2 period, this by-pass is turned off by system similar to classic thyristor tap changer. At time of by-pass work, the magnetically fluxes come from both primary winding current and current in remaining part of secondary winding are compensated by magnetically flux come from current in shunt part of secondary winding. In effect, the growth of voltage will not happen in secondary side of serial transformer, but the converter can not control voltage and current of primary side of transformer also - his activity influence on current in shunt circuit only. So converter will lose the possibility of controlling short circuit current before this current will reach his maximum value. Therefore to tap changer switching moment and opening the shunt part of windings of secondary side transformer, the converter should not forcing current (the current above rated value would make up the unnecessary overload). The thyristors of by-pass turn off happens when the current of short-circuit achieves the zero value, which gives good perspectives of limitation of this current by the UPFC.

However different problems appear - this solution requires the exchange of information between the UPFC and protections. To the UPFC could limit the current of short-circuit, it has to be connected only to part of winding of transformer secondary side, independently from voltage value on secondary side of transformer. As the signal to normal work of controller, by thyristors regulate of top changer, could be only switch off short circuit. The information about this, it is possible to obtain on basis of data from protections that are installed in line with UPFC. The controller, by limiting short circuit current below load current value, makes the correct work of protections difficult. In power line with UPFC, which working as upper described, the distance protection next to UPFC has to working with impedance start-up characteristic, or it has to communicate with protection on opposite side of power line. The remote mutual reserve of distance protection on opposite sides of UPFC would be impossible.

The advantage of this way of control is decrease the influence of thermal component of shorting current, and the same the shorting power reduce in power net in comparison to standard way of control. But the method of control has a few of defects also:

- Bigger than standard cost of protection system – the serial transformer has to have secondary windings with tap, and it is required twice larger number of thyristors (the bypass – tap changer system),
- The information with network protections have to be delivered to the UPFC,
- The UPFC makes impossible remote mutual reserve of distance protection on opposite sides of this controller, so it influences on co-ordination of protection and it extorts duplication of protection in several places.

We should turn attention on the limitation of surge current does not occur in comparison to standard system of control (the driver starts to limit the shorting current from 1/6 to 4/6 of network period after short-circuit moment). So, the elements of power net have to keep the same value of surge current, only thermal shorting current is decreased. **Therefore for technical and economic point of view this type of steering seems unprofitable.**

So, after exceeding limit of voltage in secondary side of transformer, the transformer should be bypassed directly, by resistance or by reactance. It is recommended for standard serial transformer bypassing secondary winding by resistance switched by thyristors. It enlarges suppression of dynamic phenomena in shorting current. The application of transformer with hi speed core magnetic saturation makes possible use directly key of converter to shunt the transformer.

Sometimes, independent on manner of converter (transformer) protection, the shorting current in line with UPFC will grow up less than 2 times. It is possible, when short circuit occur in next to considerable line, these lines are long and third line co-supplies this shorting. At that time the UPFC can stay in work. Introduced add voltage and phase shift of measure current in relation to predominant short-circuit current will cause considerable mistakes of measurement impedance.

III. Object of investigations

The investigation was made for possibly small part of power network (Fig. 3). However, for given protection, one separates line where this protection is basic, line where it is redundant and line which co-supplies short circuit.

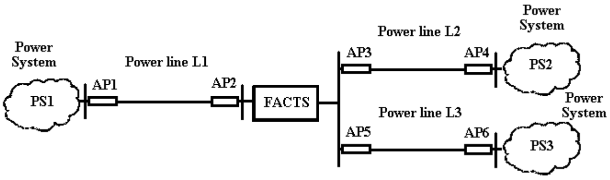

Fig.3 Schema of investigated system

The models of individual elements were maximally simplified also. Serial connected the source of voltage, resistance and the inductive reactance was accepted as a system. Only longitudinal elements were considered in power lines - serial connected resistance and the inductive reactance. One accepted the source of voltage is serial connected with resistance and reactance as the FACTS (UPFC). Ideal profiles were accepted for switches. The phenomenon of magnetic saturation of current transformers was skipped for marking impedance. The phase shifts of voltage vectors between models of systems were marked (3) on base of powers which were transmitted before short-circuit time, accepting the station next to the FACTS (Fig. 3) as reference station ($\delta = 0$) and the sign plus for power output from station and minus for power input to station

$$\delta_1 = \arcsin\left(\frac{P_{S1}(X_{S1}+X_{L1})}{E^2}\right)$$
$$\delta_2 = \arcsin\left(\frac{P_{S2}(X_{S2}+X_{L2})}{E^2}\right) \qquad (3)$$
$$\delta_3 = \arcsin\left(\frac{P_{S3}(X_{S3}+X_{L3})}{E^2}\right)$$

where P_S - power which was transmitted before short-circuit time
X_S , X_L – reactance of system and line
E – rms voltage of line voltage of system

The model of arc was accepted as a resistance with well-kept constant rms voltage value on him (nonlinearity was skipped). Researchers described voltage drop on freely burnt arc from 15V/cm (Majkopar) by 25 V/cm (Neugebauer) to 50V/cm (Królikowski). The length of arc increases in shorting time, so this length is not equal distance between ignition electrodes. Laboratory temporary voltage courses on electrodes show, that voltage drop on freely burning arc is equal approximately in time about ¾ his renewed ignition spontaneous voltage. It gives voltage drops on arc about 50V/cm in reference to distance between electrodes. Such value was accepted (one found, that Majkopar estimated the average triple growth of arc length, Neugebauer estimated twofold and Królikowski did not to take into account him.

The distance between distance protection and place of short-circuit is estimated on basis of measurement of impedance. For three-phase or two-phase short-circuit according with formula (4) - founding, that phase A and B take part in shorting, and for two-phase or single-phase earth according with formula (5) - founding, that phase A takes part in earth fault.

$$\underline{Z}_P = \frac{\underline{U}_P}{\underline{I}_P} = \frac{\underline{U}_{AB}}{\underline{I}_A - \underline{I}_B} \qquad (4)$$

$$\underline{Z}_P = \frac{\underline{U}_P}{\underline{I}_P} = \frac{\underline{U}_A}{\underline{I}_A + \dfrac{\underline{Z}_0 - \underline{Z}_1}{3\,\underline{Z}_1}(\underline{I}_A + \underline{I}_B + \underline{I}_C)} \qquad (5)$$

where $\underline{U}_P$, $\underline{I}_P$ – measured voltage and current
$\underline{I}_A$, $\underline{I}_B$, $\underline{I}_C$ – phase currents in automatic protection place
$\underline{Z}_0$ – zero-sequence impedance
$\underline{Z}_1$ – positive- sequence impedance

IV. Mathematical description

The dependence among measured by protection values of currents and the voltages were marked on basis of equations describing the schema (Fig.3). The parameters of power network and the UPFC occur in this dependence. For protection AP1 and short-circuit in line L2 this dependence is presented (6).

$$\left(\underline{U}_A^{AP1} - \underline{U}_B^{AP1}\right)\left\{1+\frac{\alpha \underline{Z}_{L2}}{\underline{Z}_{S3}+\underline{Z}_{L3}}\left(1-e^{-j\delta_{13}}\right) + \frac{R_A}{K_A}\left(\frac{\underline{K}_1}{\underline{K}_2}\right)\right\} =$$
$$= \left(\underline{I}_A^{S1} - \underline{I}_B^{S1}\right)\left\{\begin{matrix}\underline{Z}_{L1}+\underline{Z}_{UPFC}+\alpha\underline{Z}_{L2}\left(1+\underline{K}_5\right) + \\ \dfrac{R_A}{K_A}\left(\dfrac{\left(\underline{Z}_{S1}+\underline{Z}_{L1}+\underline{Z}_{UPFC}\right)\underline{K}_3+\underline{K}_4-\underline{Z}_{S1}\underline{K}_1}{\underline{K}_2}\right)\end{matrix}\right\}+$$
$$+\left(\underline{E}_A^{UPFC}-\underline{E}_B^{UPFC}\right)\left\{1+\frac{\alpha \underline{Z}_{L2}}{\underline{Z}_{S3}+\underline{Z}_{L3}}+\frac{R_A}{K_A}\left(\frac{\underline{K}_3}{\underline{K}_2}\right)\right\} \qquad (6)$$
$$\underline{K}_1 = \left(\underline{Z}_{S3}+\underline{Z}_{L3}\right)\left(1-e^{-j\delta_{12}}\right)+\left(\underline{Z}_{S2}+\underline{Z}_{L2}\right)\left(1-e^{-j\delta_{13}}\right)$$
$$\underline{K}_2 = \left(\underline{Z}_{S2}+(1-\alpha)\underline{Z}_{L2}\right)\left(\underline{Z}_{S3}+\underline{Z}_{L3}\right)$$
$$\underline{K}_3 = \underline{Z}_{S2}+\underline{Z}_{L2}+\underline{Z}_{S3}+\underline{Z}_{L3}$$
$$\underline{K}_4 = \left(\underline{Z}_{S2}+\underline{Z}_{L2}\right)\left(\underline{Z}_{S3}+\underline{Z}_{L3}\right)$$
$$\underline{K}_5 = \frac{\underline{Z}_{S1}e^{-j\delta_{13}}+\underline{Z}_{L1}+\underline{Z}_{UPFC}}{\underline{Z}_{S3}+\underline{Z}_{L3}}$$

where ($\underline{U}_A^{AP1}$-$\underline{U}_B^{AP1}$) – voltage which is measured by automatic protection

($\underline{I}_A^{S1}$-$\underline{I}_B^{S1}$) – current which is measured by automatic protection

($\underline{E}_A^{UPFC}$-$\underline{E}_B^{UPFC}$) – voltage which is introduced by UPFC

$\underline{Z}_S$, $\underline{Z}_L$, $\underline{Z}_{UPFC}$ – impedances of system, line and UPFC (additional index 1, 2, 3 marks number of system or line)

R_A/K_A – arc resistance comes to one phase

δ_{13} , δ_{12} – phase shift between voltages of systems PS1 and PS3 or PS1 and PS2

α – coefficient (from 0 at begin to 1 at the end of line) decreases place of the short circuit

The arc resistance depends from current in place of short-circuit; next to power station it is smaller, in centre of line greater. Phase shift among systems influences on this resistance imperceptibly. The supply voltage module or the shorting circle impedance modification influence on value of arc resistance considerably. The coefficient K_A was introduced to description of arc resistance, because it was noticed, that for two phase short-circuit 1/2 of arc resistance belong to one phase and for three phase fault 1/3 of arc resistance belong to one phase. Moreover, at deduce formula time, it was received, that 1/2 of arc resistance for two phase shorting equals 1/3 of arc resistance for three phase shorting. So value R_A/K_A independent on kind of short-circuits (two or three phase fault).

After delimitation the parameters of controller UPFC and the value of effective resistance of arc, one could substitute this dependence to (4) and getting the impedance measured by distance protection.

In case of bypassing the UPFC at primary side (E^{UPFC}=0 and Z^{UPFC}=0) and the metallic short-circuit (R_A/K_A=0), the equations (4) and (6) changes to (7).

$$\underline{Z}_p = \frac{\underline{Z}_{L1} + \alpha \underline{Z}_{L2}\left(1 + \frac{\underline{Z}_{S1} e^{-j\delta_{13}} + \underline{Z}_{L1}}{\underline{Z}_{S3} + \underline{Z}_{L3}}\right)}{1 + \frac{\alpha \underline{Z}_{L2}}{\underline{Z}_{S3} + \underline{Z}_{L3}}\left(1 - e^{-j\delta_{13}}\right)} \tag{7}$$

The well-known equation (8), which is the most often used to selection preset value of protections was received by substituting δ_{13}=0

$$\underline{Z}_p = \underline{Z}_{L1} + \alpha \underline{Z}_{L2}\left(1 + \frac{\underline{Z}_{S1} + \underline{Z}_{L1}}{\underline{Z}_{S3} + \underline{Z}_{L3}}\right) \tag{8}$$

The value of angle δ_{13} can not be zero to assure transmission energy. The changeability of δ_{13} in range $\pm 10^0$ influences on measurement of reactance imperceptibly, but it influences on measurement of resistance significantly. So it is not surprise the opinion that reactance matches on basis (8) but resistance matches on basis of “engineering practice”. It is recommended for people with out “this practice” to application (7)

When the UPFC works, it introduces voltage $\underline{E}^{UPFC}$ (9) and at this time it is founded, that $\underline{Z}_{UPFC}$ = 0.

$$\left(\underline{E}_A^{UPFC} - \underline{E}_B^{UPFC}\right) = M\left(\underline{E}_A^{S1} - \underline{E}_B^{S1}\right)e^{j\Psi}$$
$$\text{where} \quad 0 \le M \le 0{,}15 \tag{9}$$
$$0^0 \le \Psi \le 360^0$$

In case of shunting of serial transformer, it is founded, that the voltage which is introduced through controller $\underline{E}^{UPFC}$=0, and that the value of impedance $\underline{Z}_{UPFC}$ equals the resultant product of transformer and the by-pass impedance. For standard of transformers, which secondary windings are shunted by resistance, the impedance value $\underline{Z}_{UPFC}$ is permanent. For transformer with hi speed magnetic saturation of core which secondary windings are shunted directly, the impedance $\underline{Z}_{UPFC}$ depends on transformer current, so it depends on place and kind of short-circuit.

The formulas described $\underline{Z}^{UPFC}$ for transformer with hi speed magnetic saturation of core as well as the R_A/K_A in function of currents and voltages measured by protection are complicate and it occupy many place. So it was decided does not present them in article. By replacement these formula to (6), then result to (4), the impedance measured by distance protection was received. This formula writes with regard on its complex structure was skipped in article too. The graphic interpretation of this formula was used, in next chapter, for discussion of UPFC influence on measure impedance by distance protection.

V. Graphic interpretation of measured impedance by distance protection

How it was described earlier, the angle between subsystem voltages (with line on which is installed protection and with line which co-supplying shorting) strongly influences on measured impedance by distance protection, independently on influence of UPFC. So investigation was made for different powers transmitted among subsystems before fault. It was observed strong influence of arc resistance on measured resistance and reactance also, so investigation was made for metallic as son as for arc shorting. For short-circuits in line L1 (Fig. 3) the UPFC was shunted always. From regard on insignificant value of by-pass impedance, by-pass influence on measured impedance by protection was small and application him did not require the changes set value of distance protection zones. Short-circuit in line L2 and L3 have similar mathematical describing model for measured impedance by distance protections. So presented results of investigations was limited to short-circuit in line L2. On measurement of impedance by protection AP3 during short-circuit in line L2, the UPFC does not influence, this part of investigations is not present in article too. Take into consideration the direction blockade of protections, it was considered the influence of the UPFC on work of protection AP1 (the UPFC in including the protection line) as well as on protection AP6 (the UPFC on line co-supplying short-circuit). The parameters of power network (Fig. 3) were chosen so, to the UPFC for some short-circuits in line L2 could stay in work (E=220kV, S_K=2,6GVA, X_S/R_S=10, $X_{1\,0\,L}$=0.4Ω/km, $R_{1\,0\,L}$=0.07Ω/km, l_{L1}=l_{L2}=100km, l_{L3}=50km), the angle between subsystems (the transmitted energy before fault) was changed.

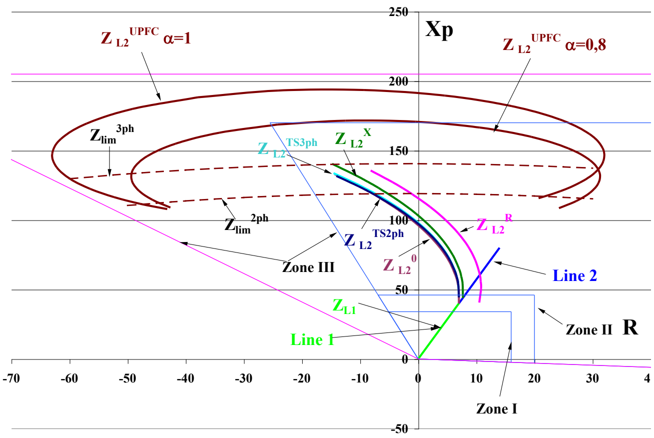

Fig.4 The measured impedance by protection AP1 at metalic shor-circuit in line L2 for negative angle δ_{13}

For metallic short-circuit in line L1 distance protection AP1 measures impedance Z_{L1} equal of line impedance (Fig. 4). For short-circuit it in line L2 the protection AP1 even for metallic by-passing of serial transformer (Z_{L2}^{0}), as result co-supplying of shorting by the power supply PS3, measures the different impedance from the sum of impedance line L1 and L2. Moreover the resistance of line L2 could be measured as negative for negative angle δ_{13}. Therefore protections zones have to penetrate to second quarter of co-ordinate system. The different types of by-passes (Z_{L2}^{R} - the resistance character used to suppression of fault current dynamics, Z_{L2}^{X} - inductive character used to limiting the maximum value of fault current, Z_{L2}^{TS2ph} – the shunted transformer with hi speed magnetic saturation of core for two phase shorting, Z_{L2}^{TS3ph} - the shunted transformer with hi speed magnetic saturation of core for three phase shorting) imperceptibly influence on impedance measurement by protection with regard on their small own impedance.

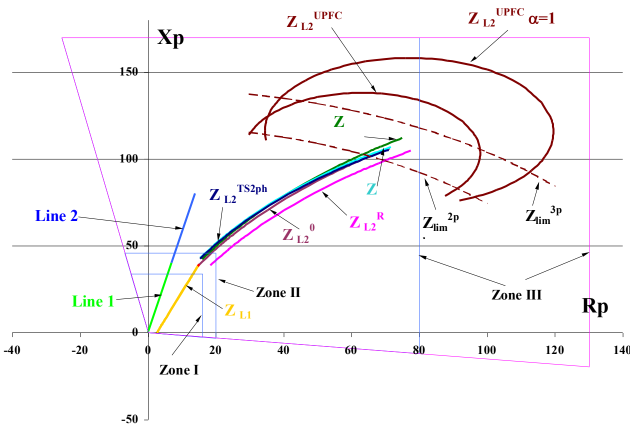

Fig.5 The measured impedance by protection AP1 at arc shor-circuit in line L2 for positive angle δ_{13}

For current which causing shunting serial transformer was marked impedance, which measure protection Z_{lim}. The value of limitary impedance do not depend on place of short-circuit, it depend only on type of short-circuit (three phase Z_{lim}^{3ph} or two-phase Z_{lim}^{2ph}) for protection installed on the same power line that the UPFC (Fig. 4, Fig.5). When driver UPFC can stay in work, the voltage introduced by him changes impedance measured by protection Z_{L2}^{UPFC} considerably. For metallic short-circuits and negative angle δ_{13} it was observed principal influence in range of negative resistances (Fig.4). During arc short-circuit and positive angle δ_{13}, it can influence on enlargement of measured value of resistance (Fig.5).

In every case (Fig. 4 and Fig.5), the measured value of reactance in III zone can have larger value than without UPFC. For regard on limitary value of measured impedance of shunting the UPFC, this controller do not influence on set value of first and second zones of considered protection.

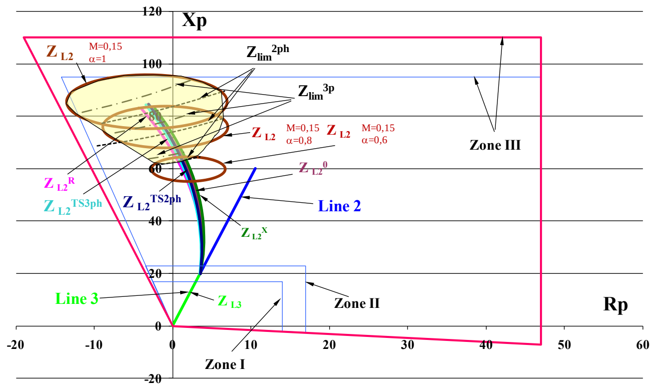

Fig.6 The measured impedance by protection AP6 at metalic shor-circuit in line L2 for negative angle δ_{31}

When, in relation to distance protection, the UPFC occur in line which co-supply shorting, the limitary value of impedance Z_{lim} appointed by protection depends not only on kind of shorting (two phase, or three phase), but also on place of shorting α. In effect for given place of short-circuit one should consider mistakes of impedance measurement by protection on result of introduced voltage Z_{L2}^{UPFC} as well as the limitary value of impedance Z_{lim} which causes shunting controller (Fig.6 and Fig.7). On this basis one should mark the area of possible measurements really.

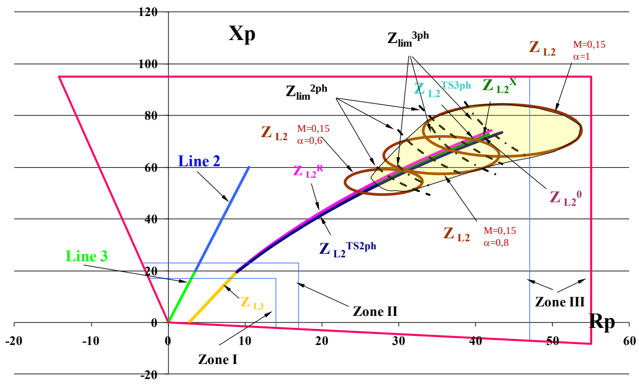

Fig.7 Impedancja pomierzona przez zabezpieczenie AP6 podczas zwarcia łukowego w linii 2 i dodatnim kącie δ_{31}

When the UPFC is in line which co-supply short-circuit (Fig.6 and Fig.7) his influence on measurement of impedance is considerably smaller than, when it occurs in the same line that protection (Fig.4 and Fig.5). The changes of measured impedance occur also for smaller value, because the limitary value of impedance Z_{lim} appointed by protection depends on place of short-circuit α (Fig.6 and Fig.7). In this case changes occur also only in III zone, it is still far from II zone. Therefore changes are required only for III zone and here are in smaller range. I zone and II zone can stay without changes.

VI. Recapitulation

The standard chosen UPFC during short-line fault will be always shunted. This is caused by shorting current considerably larger then load current of serial transformer, it gives too large voltage at secondary side of this transformer during short-circuits and that is threat for elements of converter. For technical and economic point of view the building of the UPFC that can always working at short-circuit time seems unprofitable.

The UPFC can work during short-circuit, when power line with him takes small part in short-circuit current. This phenomenon occur, when controller is installed in long power line, or when this line is connected to subsystem with small shorting power, moreover short-circuit occur in final part other long line as well as the third power line is connected on common (for these lines) power station and co-supplying shorting – the third power line should be little and connected to subsystem with big shorting power.

The UPFC never influences on selection of I and II zones of distance protection. But the UPFC could cause necessity of increase of III zone of this protection it happens so, when controller is not shunted and it can stay in work during short-circuit. So one should always estimate possibility of appearing such situation by marking possible to receipt value of impedance measured by distance protection during short-circuit on end of next line and marking for this place the limitary value of impedance of working UPFC.

When driver UPFC stays in work, about enlargement of III zone in range of resistance, the arc shorting with positive value of angle δ between voltages of subsystem with protection and subsystem co-supplying shorting will decide. The metallic shorting with negative value of angle δ will decide about increasing III zone in second quarter of co-ordinates system. For enlargement III zone in reactance range, the metallic shorting with value of angle δ nearly zero or the arc shorting with negative value of angle δ will decide.

Impedance of by-pass of UPFC from rule is so small, that it influences only on measurement of impedance by protection, but this influence is not significant, so it is not required changes of zones set.

References

[1] Collins Ch., Watson N., Wood A.: UPFC Modeling in the Harmonic Domain, IEEE Transactions On Power Delivery, Vol. 21, No. 2, April 2006 pp. 933-938

[2] Jamali S., Kazemi A., Shateri H.:"Distance Relay Tripping Characteristic in Presence of UPFC" Power Electronic, Drives and Energy Systems, 2006 12-15 Dec.2006 New Delhi

[3] Khederzadeh M.: "UPFC Operating Characteristics Impact on Transmission Line Distance Protection", Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 20-24 July 2008, Pittsburgh, PA

[4] Plenzler G. „*Wpływ układów FACTS na pracę zabezpieczeń elektroenegetycznych"(The influence of FACTS on automatic protection work)*, VIII Sympozjum Podstawowe Problemy Energoelektroniki i Elektromechaniki PPEE'99, Wisła 22-25 marca 1999, pp.277-282

[5] Seethalekshmi K., Singh S. N., Srivastava S. C.:" Adaptive Distance Relaying Scheme in Presence of UPFC using WAMS", Power Systems Conference and Exposition, 2009, 15-18 March 2009, Seattle, WA

[6] Sen K. K., Keri A. J. F.: *Comparison of Field Results and Digital Simulation Results of Voltage*-Sourced *Converter-Based FACTS Controllers*, IEEE Transactions On Power Delivery, Vol. 18, No. 1, January 2003, pp. 300 – 306

[7] Son K. M., Lasseter R. H.: *A Newton-Type Current Injection Model of UPFC for Studying Low-Frequency Oscillations*, IEEE Transactions On Power Delivery, Vol. 19, No. 2, April 2004, pp. 694 – 701

[8] Szubert K.: *The Influence Of Facts Controllers On Work Of Automatics Protection*, International Symposium Modern Electronic Power System MEPS'06, 06-08 Sep. 2006 Wrocław, Poland ; pp. 205-209

[9] Witek B.: „*Działanie zabezpieczeń elektroenergetycznych podczas zwarć w linii z regulatorem UPFC" (Automatic protection work in power line with UPFC at short circuit time).* Automatyka Elektroenergetyczna No 4/2003 pp. 10 – 16

[10] Witek B.: *Selected Aspects of Protection and Control in Flexible Electrical Power Transmission and Distribution Systems*, International Symposium Modern Electronic Power System MEPS'06 ; 06-08 September 2006 Wrocław, Poland ; pp. 216-227

[11] Zhou X., Wang H., Aggarwal R. K., Beaumont P.:" Performance Evaluation of a Distance Relay as Applied to a Transmission System With UPFC", IEEE Transactions On Power Delivery, Vol. 21, No. 3, July 2006 pp.1137-1147