# NEW METHOD FOR PHASE SELECTION IN EFFECTIVELY EARTHED NETWORK

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### Abstract

The question of phase selection in effectively earthed network is a complex and difficult problem. The author surveys the methods applied till now and, based on them, he introduces a new way which has high reliability even if the value of the sound phase current or the fault impedance is big, and which exceeds the previous methods in elasticity and reliability.

## The purpose of phase selection

The main tasks of a distance protection are as follows.

— The "fault detection" is the distinction of the faulty condition from the loaded or overloaded conditions or the power swinging one. This function can be called "starting" action, as well.

— The "fault classification" or "identification" involves the determination of the number of the faulty phases and to identify them. It can be called also "phase selection".

— The "fault zone determination" implies the decision whether the fault occurs inside or outside of the section protected by the distance protection, hence it should trip the relevant circuit breaker (C.B.) or block it. This task contains also the preparing of the protection to trip as a back up protection. The fault zone determination can be called "measurement", too.

These parts of the protection which perform the basic tasks mentioned above can be found either in a classical protection which is built of electromechanical elements also which has rectifying or static measuring circuits, or in a protection of master technics, which has digital elements or microprocessors. These parts or tasks can generally be distinguished easily. It can happen of course that the tasks are separated much more, e.g. the third task is fulfilled with more measuring elements and timers, or the tasks can be drawn together, e.g. the first two tasks are realized only in one "starting" function.

Just the fact that the classical distance protection has independent starting units, e.g. impedance relays in European practice [1], or third zone which can be considered as a starting unit, e.g. mho or offset mho relay in English practice [2], disturbs the attention of many protection engineers and hence it is understandable that they can loose the sight of the division of the tasks, that is, the division into "fault detection" and "fault classification". In this paper, the author first of all deals with the classification, i.e. the phase identification only, although, of course, the two tasks are in some cases interwoven — considering e.g. the three-phase fault.

The question can be put why the phase selection is needed at all. This theme is discussed in detail in the technical literature, hence the purpose and necessity of the phase selection will be reviewed here only shortly.

The phase selection, or in other words, the classification and identification of the fault, is necessary for the following reasons:

— in case of a distance protection with one "switch-over" central measuring unit only, the phase selector selects the voltage and current values of the faulty phase and switches on the central measuring unit or in other words in case of most advanced technics, the protection calculates the zone perception with the selected voltage and current values only due to the effect of the phase selector,

— in case of a distance protection with more measuring units or in other words in case of a protection of microprocessor whose algorithm calculates all types of faults, the phase selector averts a defective trip. Namely, as it is known in the literature, if there is no right phase selection, a defective trip can take place [3], [4],

— the correct operation of the phase selection together with the measuring units often increases the protection security, i.e. not to trip to outside fault,

— in case of single phase automatic reclosing, the phase selector guides the trip command to the relevant phase of the C.B. and controls (initiates or blocks) the automatic recloser for single or three phase reclosing,

— the phase selector gives right local annunciation and remote signal to the control personnel for fault investigations and statistics.

As it is perceptible, even one of the tasks mentioned above would already be enough reason to accept the necessity of the right and secure phase selection. Hence, such a shallow conception that only the application of the single phase automatic recloser needs phase selection is incorrect.

## Review of the employed methods for phase selection
## Disturbing factors

First, the disturbing factors of the phase selection should be looked over.

If a fault occurs on a high voltage network, the current in the faulty phases will suddenly increase, the voltage will drop and the quotient of them, the impedance of the faulty loop will also decrease. Hence, the identification of the faulty phase seems trivial and free from problems for a shallow investigator.

Many factors disturb this clear picture on the real network. The most important ones are as follows.

— The presence of the load current. This can increase or decrease or turn the faulty current and it flows in the sound phase as well.

— The appearance of the equalizing current. This appears at ground faults, mainly at single phase to ground faults, and it can cause considerable faulty current in the sound phases. The reason of its appearance is the different distribution of the positive and zero sequence current, see [5] and [6]. The equalizing current added to the load current can cause trouble in phase selection.

— Current due to power swinging [7]. This trouble generally induces symmetrical overcurrent and voltage drop, hence it can cause incorrect three-phase fault detection only, therefore we will not deal with it here.

— Sound phase currents. They can occur during the dead time of the single phase reclosing.

The disturbing factors mentioned above can cause severe conditions on the real network in such a high degree that in these cases the current, the voltage or the impedance of the faulty phase and of the sound phases can not be distinguished by usual simple means.

For overcoming the disturbing factors, several methods are known in the literature and practice. They will be reviewed below in order of complication, and the limit of their application will also be shown or referred to the exposition of the technical literature.

## *Phase overcurrent relay*

The overcurrent relay applied in all phases is the simplest phase selection unit. It can be applied on a relatively short line with great & constant short circuit power, i.e. the ratio of the protected line impedance and the source one is always high and the load current and the sound phase current (i.e. equalizing current) is limited, they are not more than 2/3 of the minimum short circuit current. The practical cases are few for application. There are problems with it on the EHV and UHV networks generally. The main reasons are often nearly the same order of the minimum short circuit current and the maximum (emergency) load current [8] or the maximum sound phase current which involve load and equalizing current components together (see Appendix F1).

## *Impedance relay*

On occurring short circuit, the current in the faulty phases increases, the voltage drops, hence the ratio of them, the impedance decreases substantially. Sufficient phase selection can be generally got with such a method on a high voltage network.

The right phase selection of a simple impedance relay which has central circle characteristic is, however, limited as follows.

*A*. In some cases, the relay due to the sound phase current caused by the load current and the equalizing one can see nearly the same impedance in the sound phases and the faulty phase ([5] and Appendix F3), hence there is no right phase selection.

*B*. The impedances seen by the relay are nearly the same at a short circuit on the end of the protected line and at rush hours in normal operation due to a heavy load current, if a long line and rigid source (of great short circuit power) are in question.

In both cases it is characteristical that although the seen impedances of the faulty phase and the sound phase are nearly the same, they are generally distinguished in phase angle. The angle in the faulty phase is about the protected line impedance angle, i.e. nearly 90°, whilst that in the sound phases is generally different. Hence, there is a chance to apply phase sensitive impedance relays which have typical types as follows.

— *offset mho relay* which has a circle characteristic, the centre is shifted to the direction of the line impedance till about the half of the line and in the same time the radius of the circle is decreased to about the 75 per cent of the line (see [5] and Figure 7) or mho relay which has the same centre shifting as radius.

— *elliptical or lens characteristic relay* whose long axis is placed in the direction of the protected line impedance.

— *double circle characteristic relay* which has a central circle relay and another circle relay, very much shifted to the line impedance.

— *other directional impedance relay* as e.g. of polygon characteristic, or seen by the equation of $U_{\text{phase}} \times (U_{\text{phase}} - I_{\text{phase}} Z_a)$ [12], e.t.c. (see Figure 2).

The directional impedance relays mentioned above in four points can be applied in a wide scale and only in a very few cases they can not give right phase selection.

## *Voltage restrained overcurrent relay*

It can often be applied for phase selection but it should be mentioned it is essentially a current depending impedance relay (Fig. 1). Its "beginning" impedance is the quotient of the setting value of the voltage and current relays, whilst the competent impedance ($Z_c$) can be got from the maximal short circuit

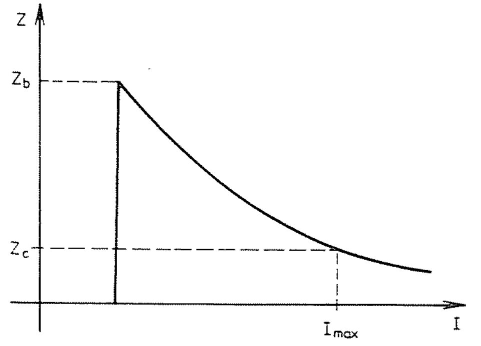



*Fig. 1*

current. If phase current and phase voltage is connected to the relay, its limit for application is determined by similar motives as mentioned with the impedance relays (*A* & *B*).

There is special application of this relay type, when zero sequence current is applied as starting current, and phase voltages are connected to the undervoltage relays. This scheme can be used in wide scale for phase selection in such a case, when single phase-to-ground fault occurs supplied by a weak source. Its most practical application field is at a line end and at a *T* tap in a line, both with transformer earthed in the star point.

## *Sudden change sensing*

Either for phase selection or for fault detection, there is an applicable solution to sense a sudden change in the voltage, in the current or in the quotient of both, i.e. in the impedance. These can be realized to form differential quotient (e.g. current excites iron core with air gap and the voltage induced in the secondary winding put on the iron core is sensed), quotient of differences (e.g. time sensing which elapses between the operation of two impedance relays set in two different values), and it is also possible to sense an irregular value in a system following the sinusoidal curve with sampling method. The form of sensation mentioned later is a frequent sensing method in a microprocessor based protection. The method needs always detailed fault analysis, since each switching action can cause also jumping in values not only the fault does that. Therefore its application field depends on the whole scheme of the protection.

### *Comparison sensing*

Typical static phase selection method is to compare each phase current or each phase impedance to another. The principle is the following. If it is impossible to give a certain threshold above which (or under which) the relevant phase is certainly faulty, then the phase values can be compared each to another. The *highest current* (the *lowest impedance*) belongs to the faulty phase.

E.g. after detecting fault, the highest phase current is selected and the other currents will be compared to that. If one of the other currents is about 70 p.c. or more than the preselected highest one, this is also faulty. If it is less, the latter is not faulty ([10]).

Similar method can be obtained with comparison of each phase impedance to the others. An example of such a phase selection is a device ([11], [20]) in which the phase impedances are compared one to another on occurring single phase-to-earth fault, i.e. there is high zero sequence current (impedance balance relay).

More proper and more exact phase selection can be got, if the load current is eliminated at comparison. E.g. a protection based on sampling method subtracts the prefault current from the faulty one and it compares the "clean" fault phase currents together ([10]). Of course, this method helps to realize the right phase selection, but the faulty component in the sound phases, namely the equalizing current, can not be eliminated. There is also a problem, if the fault was caused by a switching operation, by switching to fault or by false tripping, because in these cases the load current distribution is changed and it deceives the relay unit carrying out subtraction.

The comparison sensing methods described above extend the application scope of the reliable phase selection. But it should be noted that those methods need, on the one hand, the application of a special very advanced therefore expensive static technology and, on the other hand, false relay operation can theoretically also take place on occurring of a combined shutdown, a fault which follows a switching operation, or other extreme cases.

## Phase angle relays applied for phase selection

In addition to the relays which are described in the previous chapter and applied in the majority of cases in the practice, phase angle relays can also be found as phase selectors although they are known less and have been applied very seldom.

The principle and the practice of the phase selector application of the phase angle relays will be shown below, and afterwards a perfect, high speed and reliable new variation of them will be introduced in the last chapter.

*Angle limiting with relays connected to phase values*

If the impedance phase selector units mentioned above have been studied with attention it can be observed that we should advance from the simplest impedance relay with center in the origin to the relay characteristics with more and more restricted area, to be able to serve also the more complicated and more difficult network conditions. The essence of the restriction was the idea that, more and more, only surrounding of the impedance vector of the protected line be the tripping area of the characteristic, and its other parts of the

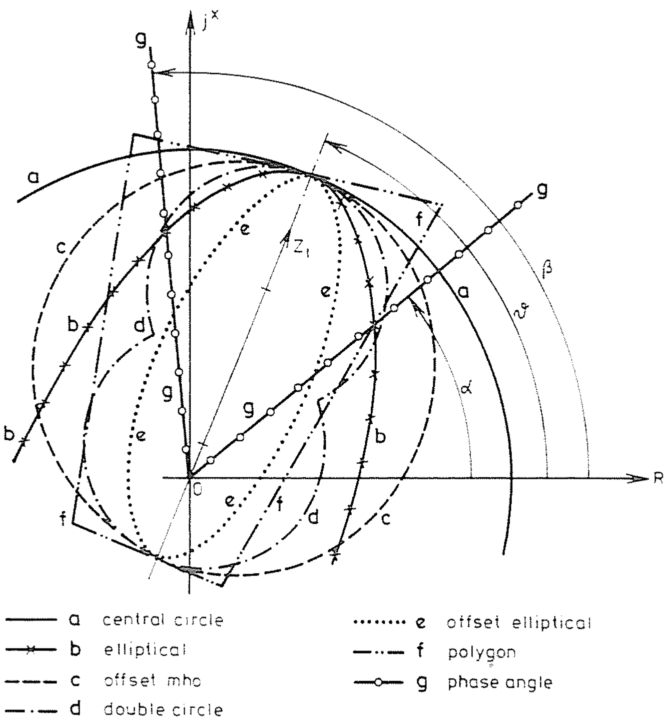



*Fig. 2*

impedance plane be blocking area. The approaching series of the characteristics can be followed in the Fig. 2. It is easy to see there, that *the smaller* (more restricted) *is the area, the more probable is the right phase selection.*

The sequence of ideas above logically leads to the application of the phase angle relay as a phase selector (Fig. 2, characteristic g.) where the relay is connected to the phase values. The tripping equation of the relay in all three phases is as follows.

$$\alpha < \mathrm{arc}\,\frac{U_{\text{phase}}}{I_{\text{phase}}} < \beta$$

where

$$\alpha < \vartheta < \beta$$

here

$U_{phase}$ & $I_{phase}$ are phase values on the place of the relay,

$\vartheta$ is the impedance angle of the protected line,

$\alpha$ and $\beta$ are characteristic angles of the relay.

This relay can give the most restricted but even proper characteristic.

It can be seen at once that this characteristic is not limited, i.e. it has infinite extension to the direction of $\vartheta$. Although it is even suitable for phase selection, it will be limited by the fault detector relay which can be impedance relay, offset mho relay, reactance relay, etc.

The phase angle relay presented here, connected to the phase voltage and current is applied as a phase selector, although very seldom ([13], [14], [19]).

The difficulties of its right sensing are caused by the disturbing factors. The sound phase impedances seen by the phase angle relays can come close to the tripping area due to the common effect of the load current and the equalizing current. If, in turn, the angle of the characteristic will be restricted, i.e. $\alpha$ and $\beta$ will be close to $\vartheta$ to avoid the effect mentioned above, the faulty phase impedance can be out of the tripping zone due to the fault impedance.

One can get also the application limit of the method from above. And you can get a final result from the ideas above: instead of phase angle relays, its "predecessors", namely the impedance relays of the "a – f" restricted characteristics in Figure 2 are generally to be applied for phase selection because, in this case it is not necessary to apply other relays for fault detection.

## *Symmetrical component phase angle relays*

The symmetrical component phase angle relays have been used for protection aim since the principle and practice of the symmetrical components were created.

The first field of their application was the sensing of the power direction. In consequence of the principle, these relays were not suitable for phase selection because they see the phases in a complex way.

However, we can get an interesting result if we study the angle between the symmetrical components of voltages on occurring ground faults. The [15] gives a useful picture to be followed in the Table 1.

It should be noted that the result in the Table 1 is valid only in certain conditions for simplification as follows. The angles of impedances of all the network elements and all the symmetrical components are about the same and there is no fault impedance. The index "*A*" means the reference phase.

The paper cited above characterizes the angle of the ratio $U_{2A}/U_0$ as the "basic direction of the fault" or the "axis of the fault". If we determine the basic

**Table 1**

| Angle \ Fault | AO | BCO | BO | CAO | CO | ABO |
|---|---|---|---|---|---|---|
| $\text{arc}\,\frac{U_0}{U_{1A}} =$ | $-1$ | $1$ | $-a^2$ | $a^2$ | $-a$ | $a$ |
| $\text{arc}\,\frac{U_{2A}}{U_{1A}} =$ | $-1$ | $1$ | $-a$ | $a$ | $-a^2$ | $a^2$ |
| $\text{arc}\,\frac{U_{2A}}{U_0} =$ | $1$ | $1$ | $a^2$ | $a^2$ | $a$ | $a$ |

direction, then we can state, the angle of the ratio $U_0/U_{1A}$ is always contrary to the basic direction on occurring single phase-to-earth fault and coinciding with the basic direction at double phase-to-earth fault.

It is interesting to observe which faults have got the same basic direction.

*A*— the fault AO is with the fault BCO,
*B*— the fault BO is with the fault CAO, and
*C*— the fault CO is with the fault ABO.

Hence, the possibility of the phase selection can be got as follows. Each basic direction should be sensed with phase angle relay of $\pm 60°$. Since the field is 120°, the whole angle is divided into three parts and therefore three relays should be applied. The relays give the pairs of the single and double earth faults (e.g. BO & CAO). Then $U_0/U_{1A}$ is measured by other angle relays. The aim of application of these relays is to sense whether the angle of $U_0/U_{1A}$ is in the basic direction $\pm 30°$ or in the opposite one, therefore there is double phase to earth fault (e.g. CAO) or single one (e.g. BO).

It is worth remarking to make the above solution complete that the symmetrical component voltages are to be got from voltage drops across artificial impedances in which symmetrical component currents at the protection flow. It is not a variation only but it has important reasons. On the one hand, even negative and zero sequence values can also be got in this way, if the voltages at the protection are symmetrical due to a very long line and, on the other hand, it can be used as a fault detector, too.

Phase selection of a phase to phase fault without earth can also be made with similar measurement as mentioned above. In this case there is no zero sequence current — it is the first condition — and the angle of the $U_{2A}/U_{1A}$ on BC fault is 1, on CA fault is $a$ and on AB fault is $a^2$. These are the same as it was got on double phase to ground fault having the same phase variation.

An effort was made to use the above principle directly or with few modifications ([13], [14], [16], [17]), but it has not spread in general use. It is so much more surprising because it is not so difficult to realize. Although the author could not find any references to the rare application in the technical literature, the reasons below become probable, however, from certain papers or from reasonable difficulty.

*a)* The angle values written above are true if the fault occurs before a protection i.e. on the protected section. If the fault occurs behind the protection, all the sequence currents at the protection are changed in direction hence also all the voltage drops are changed. While the direction of the positive sequence voltage remains unchanged due to the generator voltage present, the negative and zero sequence voltages change their polarity, because they are voltage drops completely. Hence the angle values will change their sign in the first and the second lines in Table 1 and that for the phase to phase fault written in the text but the "fault direction" angle values in the third line in Table 1 will not.

The above question can be solved by applying certain types of directional relays but it would complicate the scheme.

*b)* Although the symmetrical component filters are widely known and many papers in the literature and many descriptions of their real practical application deal with them, the necessary high speed of the phase selection is impeded by the energy store elements in the filters (time delaying or avoidance of transient faulty formation or overharmonic problems).

*c)* The scheme is pushed into the background because its solutions is not well known, the possibility of its realization is more complicate, and the impedance relays mentioned in the previous chapter are completely suitable in the most part of the cases.

The above described troubles and disadvantages which are partly supposed only can be eliminated by the phase selector with complex phase angle relays shown in the following chapter.

## Combined phase-symmetrical component angle relays

### *The principle of their sensing*

Both in the relaying and at other fields at which voltages and currents are used, it is frequent to apply only phase quantities or only symmetrical component values. Applying both phase and sequence values mixed in a complex way is very seldom.

The same situation can be found at the phase angle relays used for phase selection. The author has found only one reference ([14]) and it was also secondary and without recommendation for use (and only with line voltages).

For that reason, the method presented below can be called a novelty and therefore the author has named the basic figure of the principle with his own name (see Fig. 3).

If we choose the phase A as the reference one, the vector diagram of the single phase to earth faults in the phase A, B and C can be seen in the Fig. 3a, b and c, and of the double phase to earth faults in the d, e, and f. When drawing the diagrams we use the same approach as it was used earlier, i.e. the angles of

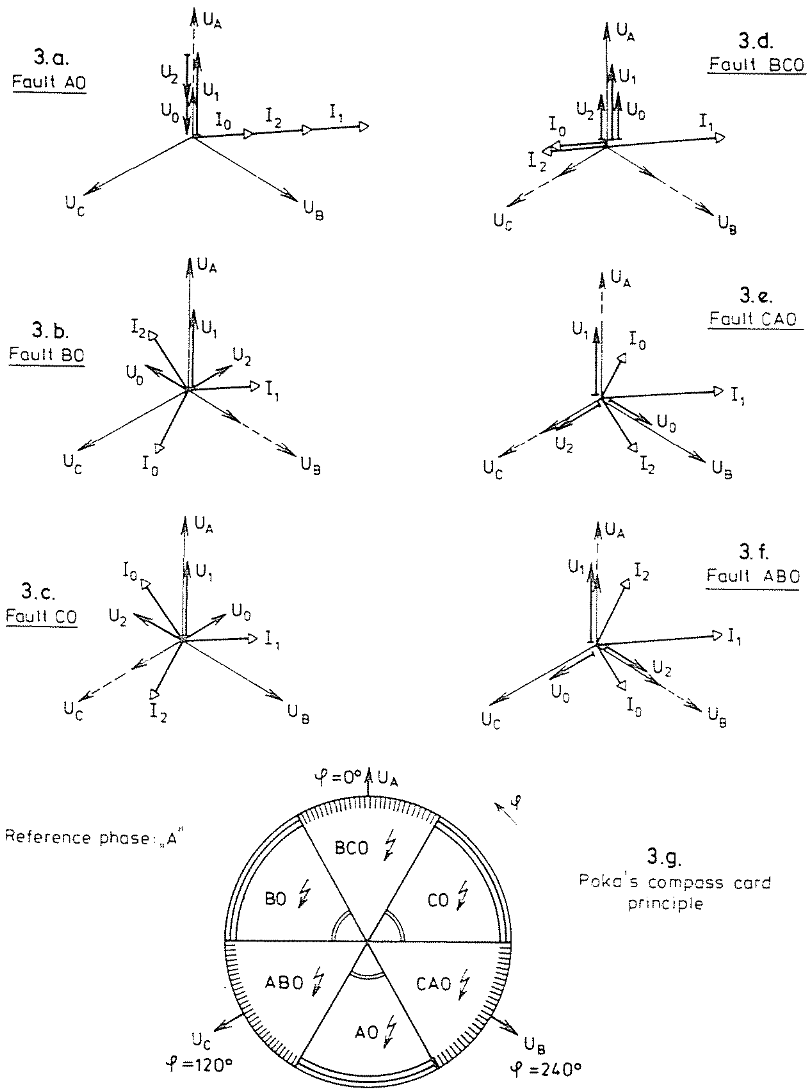



*Fig. 3*

the impedances of all the network elements and also of the sequence impedances are about the same and there is no fault resistance. Hence the voltage drops caused by the fault do not turn the phase voltages, they remain in the original direction.

The above approach does not exist in reality exactly, therefore also the angle statements deduced from the vector diagrams are true only in tendency, approximately. Taking into account also the latter, the following statements can be made.

*A*. Choosing the direction of phase voltage A as the basic direction ($\varphi=0$), the *zero sequence voltage* $U_0$ *sets in the direction of Poka's compass card* showed in Fig. 3g, it is

A0 fault between 150° and 210°,
B0 fault between 30° and 90°,
C0 fault between 270° and 330°,
BC0 fault between 330° and 30°,
CA0 fault between 210° and 270°,
and AB0 fault between 90° and 150°.

*B*. The direction of $U_B$ and $U_C$ is also drawn in the compass card hence the angle between $U_0$ and the other phase voltages can be seen also directly.

*C*. The whole angle is divided into six parts by the fields of 60°. The six fields determine the type and phase of the fault occurred. The field includes the deviation of $U_0$ due to the approach written above.

If we determine the field $U_0$ in any way on ground fault, we surely know what type of fault has occurred and in what phase. For this aim, it is the best way to apply phase angle relays to which the voltages of $U_A\&U_0$, $U_B\&U_0$ and $U_C\&U_0$ are connected.

In order to determine the phase and type of the fault we need phase voltages only which are available directly and zero sequence voltage which can be got without special filter i.e. with voltage transformer in open delta connection. Hence the problem in the previous chapter is eliminated.

Furthermore, it should be noted that the phase angle relays will not operate if they protect a long line supplying an about infinite busbar because the zero sequence voltage at the relay will be about zero. To avoid the failure of operation, *zero sequence current is to be applied* instead of voltage, i.e. $U_A\&I_0$, $U_B\&I_0$ and $U_C\&I_0$ values are to be connected to the relays and they have $\varphi=-\vartheta_0$ inside angle instead of $\varphi=0$ but the field of $\pm 30°$ should be formed as previously.

*Increasing the security*

The basic principle or basic variation of the combined phase-symmetrical component angle relays for applying as phase selectors was presented in the previous chapter and in Fig. 3. The system is ready for proper operation and it needs only one more supplement, i.e. sensing the fault direction. Namely the compass card is valid only for the fault on the protected line or more away but it will turn with 180° on fault behind the protection. Applying fault directional relays is well known, hence they will not be shown here.

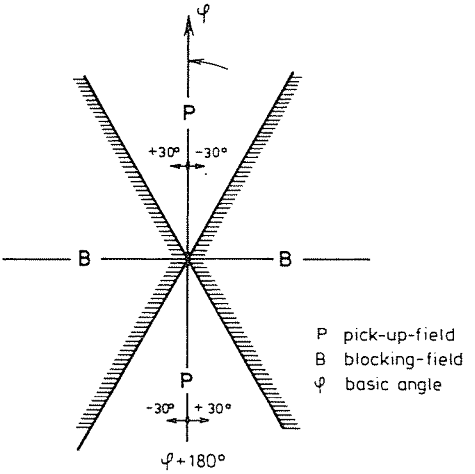



*Fig. 4*

However, it is possible to make a suitable phase selection without fault directional relays. The logical essence is as follows. If the relay applied can operate not only in the field of $\varphi=0\pm30°$ (based on $U_0$) but also in the opposite field of $\varphi=180°\pm30°$ (see Fig. 4) then it will operate on faults of $A0$ and $BC0$ in both directions. Limiter relays (e.g. impedance relays) should be always applied to the angle relays for eliminating the field of very high impedance. If only the $A$ of the limiter relays operates it is $A0$ fault, however if the relays operate in phases $B$ & $C$, BC0 fault occurs. Condition is given by the operation of $U_A-I_0$ angle relay.

Thus the $U_A-I_0$ relay is the phase selector, but the selection between the double phase to ground fault and the single one is the task of other relays. For increasing the security and for sensing extreme cases, it is advisable to apply more relays besides the limiter relays. One of the advantageous solutions will be presented as follows.

The *fault* $A0$ occurs if operation of

| | |
|---|---|
| $S_{A0}$ | phase selector angle relay in phase $A(U_A-I_0)$ |
| $X_A$ | impedance relay in phase $A$ (limiter relay) |
| $I_A$ | overcurrent relay in phase $A$ |
| $S_{AA}$ | phase angle relay in phase $A(U_A-I_A)$ |
| $I_0$ | zero sequence overcurrent relay, |

and the *fault* $BCO$ occurs if operation of

| | |
|---|---|
| $S_{AO}$ | phase selector angle relay in phase $A(U_A-I_0)$ |
| $\left.\begin{matrix}X_B\\X_C\end{matrix}\right\}$ | impedance relays in phase $B$ & $C$ (limiter relays) |
| $\left.\begin{matrix}I_B\\I_C\end{matrix}\right\}$ | overcurrent relays in phase $B$ & $C$ |
| $\left.\begin{matrix}S_{BB}\\S_{CC}\end{matrix}\right\}$ | phase angle relays in phase $B$ & $C$ $\left\{\begin{matrix}(U_B-I_B)\\(U_C-I_C)\end{matrix}\right.$ |
| $I_0$ | zero sequence overcurrent relay |

The recognition of the fault as true is accepted only if all the above conditions are fulfilled.

Each relay in the list above for fault identification is clear except the relays $S_{AA}$, $S_{BB}$, $S_{CC}$ which are phase angle relays, too, but connected to the phase voltages and phase currents and they have the same characteristic as in Fig. 4, but with basic angle identical to the protected line angle.

The system written above is allowed to operate only for ground fault, therefore the presence of the zero sequence current at the protection is an important condition.

For identification of phase-to-phase fault without ground and three-phase fault, the same logic can be well applied. First condition is the absence of the zero sequence current and the following: three of phase angle relays connected to the line voltages and the differences of the relevant phase currents, three of impedance relays with the same values, and three of overcurrent relays with phase currents.

*Elimination of the effect of the fault impedance*

If a fault occurs far from the place of the protection, the effect of the fault impedance is not important to the angle of the phase voltages, hence the operation of the phase selector angle relays is suitable.

If a fault occurs near the protection, i.e. it is close-in fault the fault impedance can effect the whole impedance of the fault circuit in high degree and the field of $\pm 30°$ is probably not enough.

With an excellent method [18] the angle relay field of $\pm 30°$ will be enlarged on near fault depending on the dropping of the faulty phase voltage compared to the healthy phase one. On close-in fault, if the faulty phase voltage is nearly zero, the characteristic of the phase selector angle relay will be fully opened. This method solves the question of the fault impedance completely.

## Conclusions

The new phase selection method[1] presented in this paper is suitable for application as a control system in a distance protection for starting and for selecting the faulty quantities, as well as in a comparison protection as a phase selector. Compared to the devices applied till now for the same goal, it is excellently suitable to eliminate the missoperation caused by the load current and/or the equalizing current as well as the disturbances due to the fault impedance. Thus, its application field where it fulfills its function of phase selection is much wider than that of the similar previous devices.

## Appendix

The considerations given below are an approach only and not a method for exact calculation but the results demonstrate the orders and the qualitative relations very well.

F1. *Overcurrent sensing*

Simplifying conditions (see Fig. 5):

$$Z_{S1}=Z_{S2}=Z_{S0}; \qquad Z_{l1}=Z_{l2}=\frac{1}{3}Z_{l0}.$$

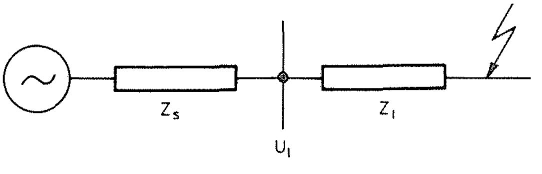



*Fig. 5*

[1] Protected by Hungarian Patent.

The data for sample calculation of single-phase-to-ground fault: $U_l = 120$ kV, the line conductor is ACSR (aluminum conductor steel reinforced) of 150 mm$^2$, thus $Z_{l1} = 0{,}46l$. $\varepsilon = 0.2$ (20%).

The designations are as follows.

| | |
|---|---|
| $I_S$ | relay setting current value, |
| $I_{f\min}$ | minimum fault current, |
| $I_{SPC}$ | sound phase current, |
| $Z_S$ | source impedance, |
| $l$ | line length, |
| $Z_l$ | line impedance protected, |
| $S_{B\min}$ | minimum fault power on busbar, |
| $\varepsilon$ | security factor. |

On fault at the end of the line it can be written.

$$I_S = \frac{1}{1+\varepsilon} I_{f\min} \qquad \text{and}$$

$$I_{SPC} = (1-\varepsilon) I_S = \frac{1-\varepsilon}{1+\varepsilon} I_{f\min}$$

and

$$Z_S = \frac{U_l^2}{S_{B\min}}$$

hence

$$I_{f\min} = \frac{3U_l}{\sqrt{3}(Z_1 + Z_2 + Z_0)} = \frac{\sqrt{3}U_l}{3\dfrac{U_l^2}{S_{B\min}} + 2.3l}$$

thus

$$I_{SPC} = \frac{1-\varepsilon}{1+\varepsilon} \frac{\sqrt{3}U_l}{3\dfrac{U_l^2}{S_{B\min}} + 2.3l} = \frac{138560}{\dfrac{43200}{S_{B\min}^{MVA}} + 2.3l} A$$

The maximum tolerable SPC's (sound phase currents) deduced above can be seen in the Fig. 6. The real SPC should be compared with them. The real SPC is formed by the load current and the equalizing one.

### F2. *Voltage restrained overcurrent sensing*

A reliable phase voltage setting far enough from the operating voltage is about 71 p.c. taking into account 15 p.c. voltage drop and 20 p.c. security factor. It is about 49 kV at $U_t = 120$ kV. With the above fact and the data in the section

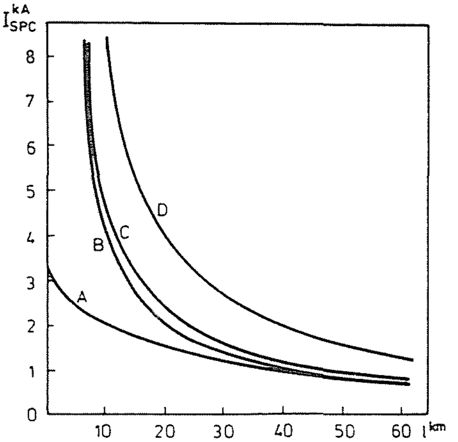
F1, a relationship can be got between the busbar fault power and the protected line length.

$$S_B = \frac{35270}{l}$$

and the maximum tolerable SPC

$$I_{SPC} = \frac{39310}{l}$$

The characteristic curve can also be seen in Fig. 6.




$I_{SPC}$ – maximum tolerable sound phase current, kA
$l$ – line length protected, km
A – overcurrent ($S_{Bmin}$=1000 MVA)
B – voltage restrained overcurrent
C – impedance
D – offset mho

*Fig. 6*

F3. *Impedance sensing*

The minimum setting impedance for sensing the fault is as follows.

$$Z_S = \frac{1}{1-\varepsilon} Z_l = 1.25 Z_l$$

and to avoid the false operation due to SPC

$$Z_S = 0.8 \frac{U_{ph}}{2 I_{SPC}}$$

and so, taking into account Fig. 5 and section F1, the maximum tolerable SPC is

$$I_{\text{SPC}}=\frac{48200}{l}$$

The curve is shown in Fig. 6, too.

### F4. *Offset mho sensing*

With reference to [5], the minimum setting value of the circle radius is

$$Z_S=0.75Z_l,$$

and the shift of the circle centre is

$$Z_C=0.5Z_l,$$

if the security factor is $\varepsilon=0.2$ (see Fig. 7).

Thus the maximum tolerable SPC taking into consideration also the section F3 is

$$I_{\text{SPC}}=\frac{80300}{l}$$

You can also see the curve in Fig. 6.

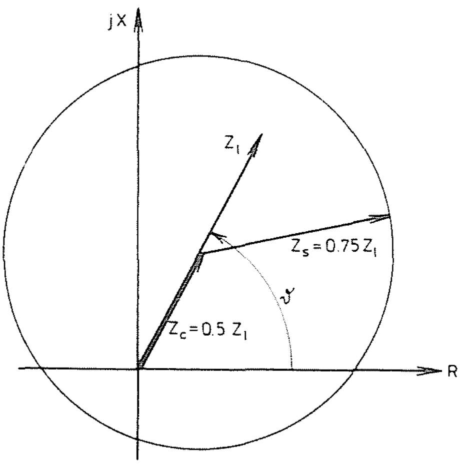



*Fig. 7*

## F5. *Evaluation*

In each case above, the real SPC values should be less than shown in Figure 6 for correct and secure phase selection. The current level is different and it is evident that the best solution is the last case with the offset mho relay. But it is also seen that the current values can easily be reached and stepped over, namely such a network formation can be found in which the SPC formed by the load current and the equalizing one will be greater than the tolerable maximum value ([5], [6], [8], [20]). Although it is valid for an impedance and offset mho relay, that the network condition unsuitable for them is rare, however it can appear.

To overcome the problems you can find more other phase selection methods as an impedance relay with elliptical characteristic or with two circle characteristic, etc., but this way can rise only the thereshold value of application but a qualitative change, i.e. a general solution can principally not give.

The question is more complicated, if there is an extremely high fault impedance.

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