Multi-sliced-level type phase-comparison carrier relaying system for multi-terminal lines

Slobodan Bjelic, Uros Jaksic, Nenad Markovic

Abstract — **In this paper principles of "sliced-level" type phase-comparison carrier relaying system which has several remarkable characteristics such as higher sensitivity and high speed tripping time are described. The paper also describes "Multi-sliced-levels" type phase-comparison carrier relaying system for multi-terminal lines which has the principle of advanced application of the above mentioned "sliced-level" type relays. Test results by 10 kV artificial transmission line are present, which confirm the higher performance of better phase-comparison relays.**

Keywords — **Effect of Load-Flow, Phase-Comparison Protection, Sensitivity, Sliced-level.**

I. Introduction

SLICED-LEVEL phase-comparison carrier relaying system (each phase current) has been widely applied to EHV transmission lines of Electric Power System Company-Serbia and other domestic utilities.

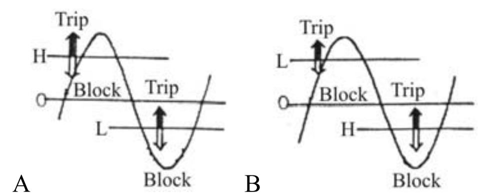
The communication system is mostly a microwave carrier relaying system. The phase-comparison relay has "sliced-level" instead of current-elements. "Sliced-level" type phase-comparison relay has several remarkable characteristics such as higher sensitivities and high speed tripping time (1-1.5 cycles). However, the principle of phase-comparison has the restrictions for application.

The difficulty is the outfeed effect in case of internal fault, and the method to get the information of currents at remote terminals. The second is delayed trip, caused by a transient higher harmonic oscillation, which may occur in case of faults at overhead lines adjacent to the underground power cables. However, the above mentioned restricts can be removed by advanced techniques of "sliced-level", which will be mentioned below.

II. Principle of operation and equipment

The principles of starting phase-comparison are determined by using "sliced-levels". Several kinds of "sliced-levels" are composed of H and L levels. H level is a "sliced-level" by which a local phase comparison signal is lade. The signal made by L level the remote terminal is received and compared with the local signal.

Fig. 2 shows the basic function of the equipment. The current from the three CT secondaries are combined into one current by summation network based on a preferred combination of phase segmentation and phase sequence quantities. The half cycle blocks of carrier frequency are injected into the transmission line via an amplifier and capacitor coupler (fig. 1.b).



Polarities of "Sliced-Levels"
Fig 1. Determination of polarities of "Sliced-Levels" and Operating Characteristics.

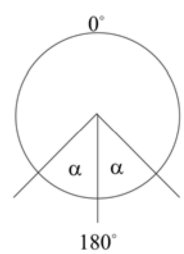
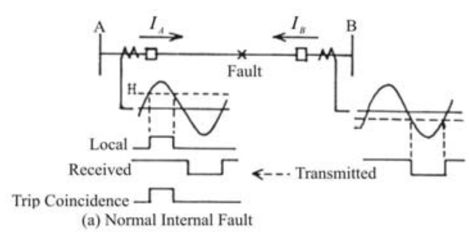


Fig. 2. Effect of stability angle upon operation of phase comparison carrier.

The following is a detailed description of "sliced-level" of Type A. L level is displaced in the negative direction, away from the zero-axis. H level is displayed positively. To maintain security, the absolute value of H level is greater than that of L level. Fig. 3 illustrates the square wave characteristic of the relay for normal internal faults, external faults, and internal faults with outfeed.



S. Bjelic, Faculty of technical sciences Kosovska Mitrovica, Kneza Milosa street, no 7, 38220 Kosovska Mitrovica, Serbia; (phone: 381-63-8822492; fax: 381-18-223383; e-mail: slobodan_bjelic@yahoo.com).

U. Jaksic, Polytechnical school of vocational studies Zvecan, Branislava Nusica street, no 6, 38227 Zvecan, Serbia (phone: 381-64-3360633; fax: 381-28-460993; e-mail: uros_jaksic@yahoo.com).

N. Markovic, Polytechnic school of vocational studies Urosevac, with temporary seat in Zvecan, Branislava Nusica street, no 6, 38227 Zvecan, Serbia (phone: 381-63-1898000; fax: 381-28-421624; e-mail: nen.mark@sezampro.yu).

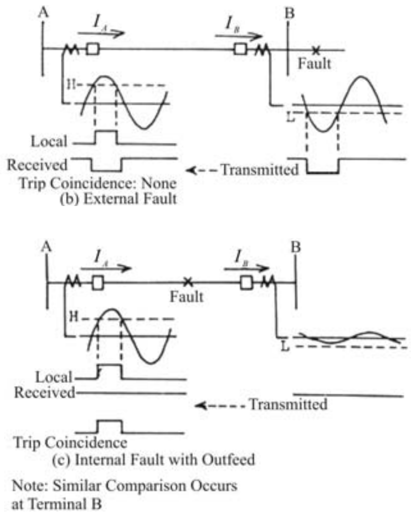


Fig. 3. Response of "Sliced-Level" Type Phase-Comparison Relay.

The relay can detect the internal faults when the absolute value of the local inflow-current is larger than H level, even if the current at remote terminal is zero, or absolute value of the outflow-current is less than L level. Therefore, operating characteristics of the relay are expressed as shown in Fig. 1. The relay of the Type B can detect the internal faults when the absolute value of the inflow-current at remote terminal is larger than L level, even if the local current is zero, or the absolute value of the outflow-current is less than L level.

The method of Type A is widely adopted because of the feature that the terminal with an outflow-current can be tripped even if the remote terminal has no inflow current.

III. Diagram of phase-comparasion protection

A fundamental block diagram of phase-comparison relay (Type A, in Fig. 1) is shown in Fig. 4. Input network is a band-pass filter, which consists of a current transformer with gapped iron cores and a capacitor. Each phase current is fed to the input network, and the phase-comparison signals are produced by level detectors, by which the output quantities of the input network are compared with the "sliced-level" L or H.

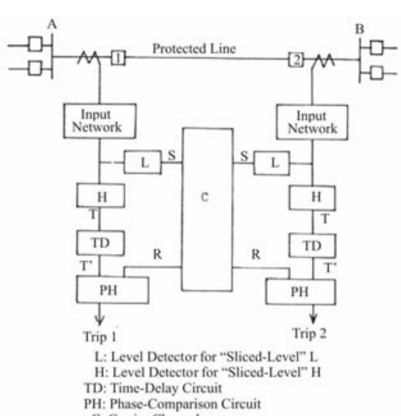


Fig. 4. Diagram of Phase-Comparison Protection.

Level detectors operate to produce an output when the amplitude of phase current exceeds their pick-up levels.

Tripping signal is transmitted to the remote terminal when the phase current exceeds the level L to the positive side, and is not transmitted when the phase current does not exceed the level L or exceeds the level L to the negative side. Local phase-comparison signal T is produced when the phase current exceeds the level H to the positive side. And tripping signal is produced when the overlapping time of signal $T^{'}$ and receiving signal R is longer that electrical angle 60°.

IV. The effect of load-flow and sensitivity

The effect of load-flow current is important for the sensitivity of the sliced-level type phase-comparison relay. Outfeed can occur in the case of internal faults at weak-feed or zero-feed terminal, particularly with heavy through load.

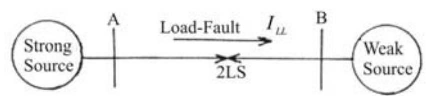


Fig. 5. Internal Fault.

Fig. 5 shows a line-to-line internal fault, while the load-flow current I_{LL} flows from the strong power source to the weak one. The inflow-current at terminal B is:

$$\frac{\sqrt{3}}{3} I_{3\phi s} - \frac{1}{2} I_{LL} \qquad (1)$$

where:

$I_{3\phi s}$ - inflow-current in case of three-phase fault,

I_{LL} -load-flow current.

The internal fault with zero-feed terminal is the worst case because of the outflow-current $\frac{1}{2} I_{LL}$ caused by load -flow current. The above mentioned internal fault can be detected by setting the "sliced-level" L larger then $\frac{1}{2} I_{LL}$.

V. Application to multi-terminal lines

As the principle of the phase-comparison relay is based on the phase of current, phase-comparison system are not usually applied to multi-terminal lines because of outfeed problem.

As the principle of the phase-comparison relay is based on the phase of current, phase-comparison system are not usually applied to multi-terminal lines because of outfeed problem.

There lines are the most difficult to protect, particularly with weak-feed terminal, whose source do not supply enough current for faults on the line.

Phase comparison relays of "multi-sliced-levels" can detect the internal faults notwithstanding outfeed effect as follows. Fig. 6. shows typical threshold setting for "multi-sliced-levels". The polarity of (1) in Fig. 6 is based on Type A in Fig. 1, and that' of (2) is based on Type B.

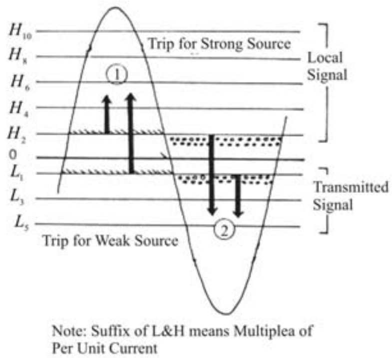


Fig. 6. Typical Threshold Setting for "Multi-Sliced-Levels".

Local signals of terminals A are compared with the signals, made by combining received signals from remote terminals B and C. The received "L_1 level" signals from terminal B and C are, for example, treated in the logical composition circuit, and are compared with the local "H_{2ABC} local" signals at terminal A. Analyzing results experimental cases and results of operating conditions of relay are shown in Table 1.

As shown in Table 1, local signals are applied to the phase-comparison techniques of Type A and B in Fig. 1.

TABLE 1: OPERATING CONDITIONS OF THE "MULTI-SLICED-LEVELS" PHASE-COMPARISON RELAY.

Polarity in Fig. 5	Amplitude of Current	
	Terminal A	Terminal B & C
1	$I_A > H_2$	$(I_B < L_1$ and $I_C < L_1)$
	$I_A > H_4$	$(I_B < L_1$ and $I_C < L_3)$ or $(I_B < L_3$ and $I_C < L_1)$
	$I_A > H_6$	$(I_B < L_1$ and $I_C < L_5)$ or $(I_B < L_3$ and $I_C < L_3)$
	$I_A > H_8$	$(I_B < L_3$ and $I_C < L_5)$ or $(I_B < L_5$ and $I_C < L_1)$
	$I_A > H_{10}$	$(I_B < L_5$ and $I_C < L_5)$
2	$I_A < H_2$	$(I_B > L_1$ and $I_C > L_1)$
	$I_A < H_4$	$(I_B > L_1$ and $I_C > L_3)$ or $(I_B > L_3$ and $I_C > L_1)$
	$I_A < H_6$	$(I_B > L_1$ and $I_C > L_5)$ or $(I_B > L_3$ and $I_C > L_3)$
	$I_A < H_8$	$(I_B > L_3$ and $I_C > L_5)$ or $(I_B > L_5$ and $I_C > L_1)$
	$I_A < H_{10}$	$(I_B > L_5$ and $I_C > L_5)$

Consequently, "H levels", so as to maintain security in case of external faults. Fig. 7 shows the inflow-outflow current characteristics of "multi-sliced-levels" phase-comparison relay. Encoding technique is adopted for time-delay compensation circuits as well as communication channels. Table 2 shows the relation between input current treated by "sliced-level" circuit.

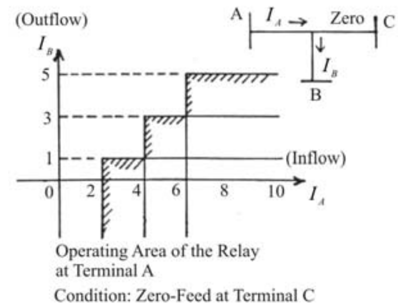


Fig. 7. Inflow-Outflow Characteristics of Strong Power Source Tripping.

TABLE 2: RELATION BETWEEN INPUT & TRANSMITTED SIGNALS.

Input Current i	Transmitted Signal	
	L_X	L_Y
$i < L_1$	0	0
$L_1 > i > L_3$	0	1
$L_3 > i > L_5$	1	0
$L_5 > i$	1	1

"Multi-sliced-levels" phase-comparison relay has been tested by the 10 kV artificial transmission lines, and has operated successfully. The higher performance of the relay has been proved by these tests. An inductance of the overhead line from faulted point to the terminal end of the power cable and C is a capacitance of the cable.

TABLE 3: AN EXAMPLE OF EHV LINE CONSTANTS.

	Overhead Line	Undergrounded Cable (4 circuits paralleled)
L (mH/km)	1	0.1
C (µF/km)	0.005	1.5
R (Ω/km)	0.03	0.02

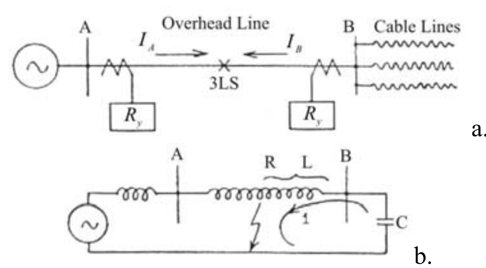


Fig. 8. The Simplified Equivalent Circuit in Case of Three-phase Fault.

The transient higher harmonic current i is given by the following equation.

$$i = \frac{2E}{\sqrt{\frac{4L}{C} - R^2}} e^{-\frac{t}{\tau}} sin\left(t\sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2} \right) \qquad (2)$$

where:
L - inductance of overhead line,
C - capacitance of undergrounded power cable,
R - resistance of overhead line,
E - voltage of capacitance immediately before fault,
τ - damping time constant.

The above equation can be simplified as follows

$$i = \frac{E}{\sqrt{\frac{L}{C}}} e^{-\frac{t}{\tau}} sin\left(t\sqrt{\frac{1}{LC}}\right)\frac{\sqrt{3}}{3} I_{3\phi s} - \frac{1}{2} I_{LL} \qquad (3)$$

of $R << L$ and $R << \frac{1}{C}$, $i = \frac{\omega}{\omega_0} \cdot i_0 e^{-\frac{t}{\tau}} sin\,\omega t$

$\omega = \sqrt{\frac{1}{LC}}$ - angular velocity at natural oscillation,

ω_0 - angular velocity at commercial frequency,

$i_0 = \omega_0 CE$ - charging current of capacitance.

In other words, the absolute value of the higher harmonic component is proportional to the natural oscillation frequency $\omega/2\pi$ and the charging current i_0 at the commercial frequency. As shown in Fig. 8.b, the frequency of the inflowing current at terminal B is higher harmonics, although that at terminal A is fundamental. The transmitted signal of phase-comparison relay at terminal B is chopped to pieces in time-domain, so the phase-comparison relay may not operate until the higher harmonic current at terminal B is damped to the "sliced-lever" L, as shown in Fig. 9.

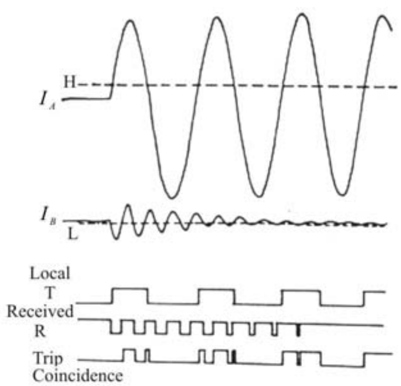


Fig. 9. Response of "Spliced-Level" Phase-Comparation Relay in case of the Natural Oscillation Frequency.

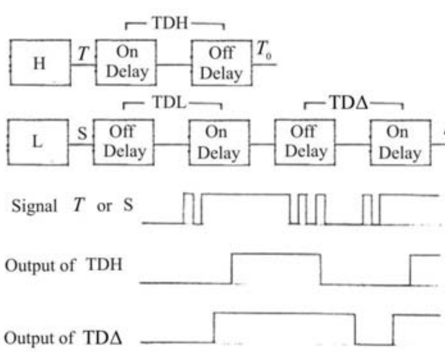


Fig. 10. Reforming Facilities of the Delay-Timers.

The duration without tripping signal in the transmitted signal S, of which width is narrower than OFF-delay time t_L, is changed to the tripping signal by the OFF-delay timers *TDL* and *TDΔ*. Conversely, the tripping signal in the local signal T, of which width is narrower than ON-delay time t_H, is changed to the blocking signal by the ON-delay timers *TDH*. The delay-timer *TDΔ* is applied to compensate the difference of delay-time $t_\Delta = t_H - t_L$. The delay-timers are chosen in consideration of the lowest natural oscillation frequency, such as $t_H = 5$ ms, $t_L = 4$ ms and $t_\Delta = 1$ ms. The charging current of the protected line must be considered for setting the "sliced-levels". Level H > Level L + charging current. The phase-comparison relay with the suitable filtering and reforming facilities against higher harmonics has been successfully tested by the 10 kV artificial transmission line. Fig. 11 shows the model power system of 10 kV artificial transmission line.

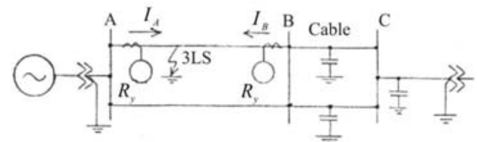


Fig. 11. Model Power System of 10 kV Line.

VI. Conclusion

The "sliced-level" type phase-comparison carrier relaying have several remarkable facilities and have been successfully applied to many lines. The "sliced-level" technique can be also applied to the composite-sequence current phase-comparison relay via a power-line carrier channel. Furthermore, advanced techniques described in this paper take away the restrictions of the "sliced-level" type phase-comparison relay.

References

[1] S. Tonic, S. Bjelic, "Informaticki model zastite bloka generator-transformator i sopstvene potrosnje", "Elektroprivreda" No 2, ISSN 0013-5755. UDK.621..316.9; 621.313; 621.316.22.27, str. 3-12, Kategorija rada 1 (Original science paper), 2008.

[2] V. Mladenovic, S. Bjelic, "Probability error of unideal extraction of discret phase shift using zero components", Republic of Serbia, Sesija D, INFOTEH 2006.

[3] U. Jaksic, V. Mladenovic, "Analogue and digital modular measuring instruments", Proceeding Technical Education Conference, Cacak, Serbia&Montenegro, April, 2006.

[4] S. Bjelic, U.Jaksic, "Measuring of nonsymmetrical components in power energy networks", The IASTED International Conference on Power, Energy, and Applications PEA, Gaborone, Botswana, ID#506-047, September 11-13, 2006.

[5] S. Bjelic, V. Mladenovic, "Algorithm of measurement-information system to make diagnosis faults in electrical networks", 14th TELECOMMUNICATIONS FORUM, TELFOR 2006, IEEE COM SOC Chapter Serbia&Montenegro, Belgrade, Serbia, PEL#7.6, 21, 22 and 23. November 2006.

[6] V. Mladenovic, M. Petrović, S. Bjelic, "Digital filter for obtaining inverse component in electrical networks", 14th TELECOMMUNICATIONS FORUM, TELFOR 2006, IEEE COM SOC Chapter Serbia&Montenegro, Belgrade, Serbia, OS#5.1, 21, 22 and 23. November 2006.

[7] N. Markovic, S. Bjelic, U. Jaksic, Z. Bogicevic, "Graphical zero-sequence cut-offs method of determining of fault to earth in electrical lines", pg 73-76, IEEE Catalog Number: CFP08481-PRT, ISBN: 978-1-4244-2903-5, 9th Symposium on Neural Network Applications in Electrical Engineering, Neurel-2008, Faculty of Electrical Engineering, University of Belgrade, Serbia, September 25-27, 2008.