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A Novel Adaptive Distance Protection Scheme Based on Variable Data Window

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Introduction

In recent years, with increasing voltage level and transmission capacity of power grid, the requirement for fault clearing time has become higher and higher in order to safeguard the system stability. Though pilot protection can fast trip the whole line fault, it is hard to reduce the trip time less than one frequency period under the consideration for reliability and the restriction of the rate of data exchange between two sides. Therefore, to fast clear the close-in fault, we still need to resort to distance protection which is operated based on single-end electric quantity. But traditional distance protection which is based on stable state quantity and integral period algorithm can not trip rapidly in some cases [1]. In this context, how to improve the trip speed of distance protection without impairing system safety has become a hot issue in research.

Researchers have made extensive study on ultra-speed distance protection. In order to break through the constraint placed by stable state quantity, researchers proposed to utilize the fault location information in fault transient component to realize distance protection. A typical example is traveling wave distance protection, which is capable of tripping in 5ms [2]. The key problem of traveling wave distance protection is to accurately identify the first backward traveling wave reflected from fault point and to determine the wave's precise arrival time at protective relay. To tackle this key problem, a series of algorithms are introduced into study, such as correlation analysis, maximum likelihood estimation, wavelet transformation, morphology, etc. [3, 4]. However, all of these algorithms demand high sampling rate, which is hard to achieve under current hardware level. What's more, the traveling wave distance protection is non-directional, and due to the effect of the bus structure on both ends of the line, the traveling wave distance protection has some difficulty in identifying the reflected wave from fault point, contralateral bus, and transmitted wave from dorsal bus. By now most of the study on traveling wave distance protection and other protection based on transient component is theoretical study and numerical simulation, which has a long way from application.

Another effective way to speed up distance protection is to retain the use of stable state quantity and to introduce superior variable data window algorithm to form the inverse time operation characteristics of zone 1 of distance protection. As for variable data window algorithms, the estimation precision of these algorithms depends on the length of data window and the magnitude of transient components [5]. Generally speaking, the longer the data window and the smaller the transient component is, the higher the accuracy will be; on the contrary, the shorter the data window and the larger the transient component is, the lower the accuracy will be. In order to prevent overriding under extreme conditions, the inverse time operation characteristics of zone 1 of distance protection needs to take step mode, this means when the data window is short, the scope of protection will be comparatively small; when the data window is long, the scope of protection will extend. However, with this mode, part of the line, particularly near the end of protected line will see no obvious improvement in trip speed.

Actually, transient component is related with a lot of factors, such as system operation mode, fault point, fault type, fault angle, etc. When there are abundant transient components, the computational error will be large, no matter that the data window is long; while when there is no obvious transient component, the computational error will be small, even if data window is short [6]. Reference [7] pointed out that when single-phase earth fault occurs, if using Kalman filtering algorithm which is based on adaptive variable data window, the computational result can converge to true value in half a cycle; while if using the traditional step mode distance protection with inverse time characteristics, which trips merely upon fault distance information, part of the line, particularly the end of the protected line, can not trip rapidly. To deal with this problem, a novel measured impedance convergence based variable data window distance protection is proposed in this paper. This method can adaptively decide the data window length of protective algorithm according to the result of real time measured impedance convergence. The faster the measured impedance convergence is, the shorter data window length of protective algorithm and the faster trip speed will be. Combining this novel method with traditional step mode inverse time operation characteristic can effectively improve the performance of distance protection.

Step mode distance protection with inverse time characteristics

Variable data window algorithms make it possible to realize the inverse time characteristic of distance protection. Though due to the transient noise, the estimated precision of these algorithms is not high when data window is short, it is still acceptable in the case of close-in fault because the protection against this kind of fault does not require much for the precision. As for the fault occurring at the end of setting range, the protection requires higher precision. Considering that the precision of variable data window algorithms increases with the length of data window, in general case, when the length of data window reaches one cycle, the reliability and security of protection can be guaranteed. According to this characteristic, the inverse time operation characteristic of distance protection usually takes step mode for convenience in practical application, which can be expressed as

$$Z(t)=\begin{cases}0.1Z_{\text{set}}, & 5\,\text{ms}\le t<10\,\text{ms},\\ 0.4Z_{\text{set}}, & 10\,\text{ms}\le t<20\,\text{ms},\\ 0.8Z_{\text{set}}, & 20\,\text{ms}\le t<30\,\text{ms},\\ Z_{\text{set}}, & t\ge 30\,\text{ms},\end{cases} \qquad (1)$$

where Z_{set} is the setting impedance of zone 1 of distance protection, $Z(t)$ is the real setting impedance of zone 1 of distance protection in different time period.

Measured impedance convergence based inverse time distance protection

As is mentioned above, the estimation precision of variable data window algorithms is not only related with the length of data window, but also depends on the level of transient noise. When there is little transient noise, high precision can be achieved regardless of short data window. In order to prevent distance protection from overriding during transient process when an external fault occurs, the highest possible level of transient noise needs to be taken into consideration and the scope of distance protection based on variable data window algorithms needs to be narrowed correspondingly. The step mode inverse time operation characteristic of distance protection is thus formed, which fails to meet the requirement of high speed protection because for any fault occurring at the end of protected line, it will take longer time than one cycle to trip. Through analyzing the statistical characteristic of fault-induced transient noise of EHV transmission lines, Reference [8] pointed out that the characteristic of current noise is different from that of voltage noise, and the noise characteristic is directly related with fault types. Reference [9] found that parameters of transient noise components were correlated with specific line parameters and fault conditions (such as fault distance), and the synthesized statistical characteristic of noise approximates white noise. For most kinds of faults occurring in real systems, the level of transient noise is lower than the severest noise level simulated numerically. Ideally, the tripping time should adjust according to real-time transient noise level. But currently it is technically infeasible to obtain real-time transient noise characteristics in all types of fault. However, it has been proved that the lower the level of transient noise is and the more quickly the noise attenuates, the quicker the convergence speed of the phase based on variable data window algorithm will be. As for distance protection, the impedance can be calculated by estimating current and voltage value. In general case, the estimated convergence speed of current is much larger than that of voltage, so the estimation of impedance is similar to voltage. To make the analysis more visually, taking a 500-kV, 100-km, transmission line for example, when different fault types occur at different points of the line, the magnitude and phase of impedance measured by use of recursive least square algorithm is demonstrated in Fig. 1 and Fig. 2.

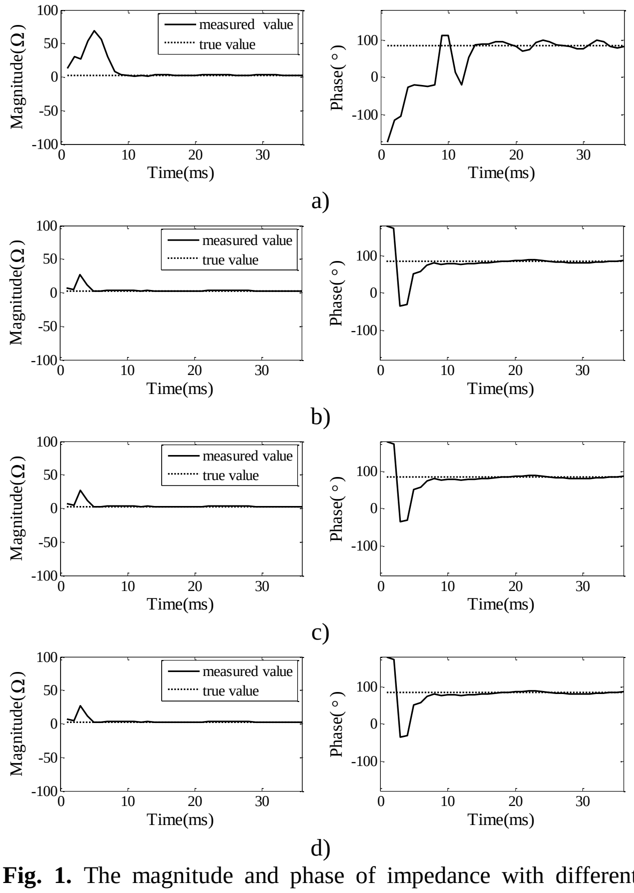


Fig. 1. The magnitude and phase of impedance with different fault types at 10km: a – single-phase earth fault; b – two-phase earth fault; c – two-phase short circuit fault; d – three-phase short circuit fault

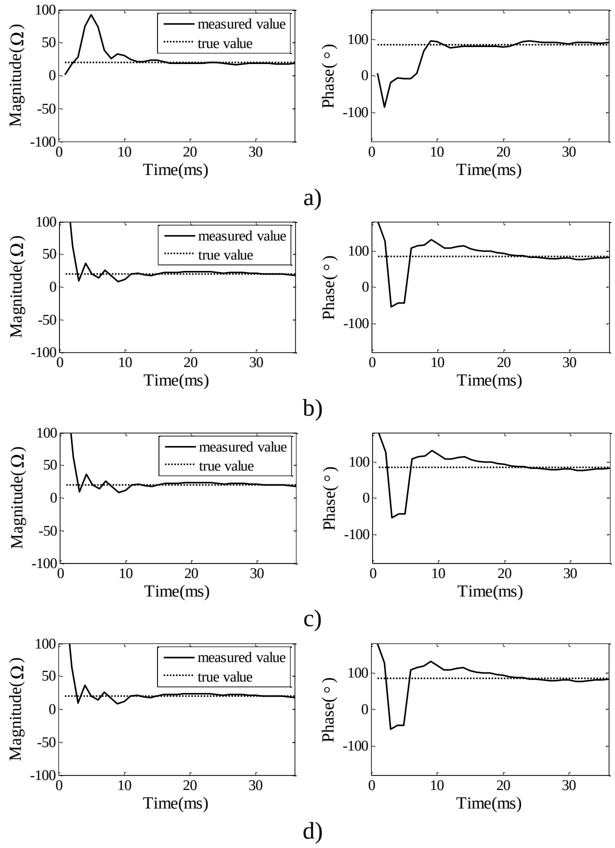


Fig. 2. The magnitude and phase of impedance with different fault types at 70km: a – single-phase earth fault; b – two-phase earth fault; c – two-phase short circuit fault; d – three-phase short circuit fault

As shown in Fig. 1 and Fig. 2, it can be seen that at the same fault point, single-phase earth fault and phase-to-phase short circuit fault vary greatly in terms of convergence tendency and convergence speed, while different types of phase-to-phase short circuit faults present similar impendence convergence. On the other hand, the same fault also presents varied impedance convergence at different locations. A common trend of above figures is that with the expansion of data window, the magnitude and phase of measured impedance will gradually converge to true value after a period of great fluctuation. Generally, the magnitude of measured impedance will stabilize after half a cycle; similarly, after half a cycle, the phase error of measured impedance will stay below 15°. In this regard, the convergence of measured impedance can be used to dynamically reflect the level and attenuation degree of transient noise. If the measured impedance is detected to converge in one data window, then all the impedance value estimated later by longer data window can be used directly in distance protection criterion, ceasing to be subject to the restriction of inverse time characteristics of step mode. It is obvious that the more quickly the impedance converge, the more rapidly the distance protection will trip; while conversely, the less quickly the impedance converge, the less rapidly the distance protection will trip. This kind of distance protection still possesses inverse time characteristic. Therefore, we call it as the measured impedance convergence based inverse time distance protection in this paper. The criterion to judge whether measured impedance converges is given by

$$\left|Z_{\mathrm{m}}(n)-Z_{\mathrm{m}}(n-1)\right|<k\left|Z_{\mathrm{set}}\right|, \tag{2}$$

where $Z_{\mathrm{m}}(n)$ is the impedance measured when the length of data window is n, Z_{set} is the setting impedance of distance protection, and k is the convergence factor, which is usually set 0.05.

If three continuous sampling points satisfy equation (2), it indicates that the impedance is converged.

In EHV transmission line, as the impedance angle is close to 90°, and reactance component predominates, in order to simplify computation, the reactance component can be used to judge impedance convergence, as shown by

$$\left|X_{\mathrm{m}}(n)-X_{\mathrm{m}}(n-1)\right|<k\left|X_{\mathrm{set}}\right|, \tag{3}$$

where $X_{\mathrm{m}}(n)$ is the reactance measured when the length of data window is n, X_{set} is the setting reactance of distance protection, and k is the convergence factor, which is usually set 0.05.

Likewise, if three continuous sampling points satisfy equation (3), it indicates that the impedance is converged.

In application, in order to guarantee the reliability of the identification of impedance convergence, the proposed measured impedance convergence based inverse time distance protection should be applied after data window length exceeds 10ms.

Adaptive variable data window distance protection scheme

Through comparing the features of two kinds of inverse time distance protection, it can be found that both have their own advantages and shortcomings. The step mode inverse time distance protection is capable of clearing close-in fault rapidly, but when dealing with fault occurring at the end of protected line, its trip speed is comparatively slow. The measured impedance convergence based inverse time distance protection is capable of quick clearing of the fault occurring at any point of the line when there is little transient noise. But when there is a high level of transient noise, even tripping of close-in fault may be delayed as a result of slowed impedance convergence. By integrating the advantages of above two distance protection, an adaptive variable data window distance protection scheme is proposed, which accelerates the trip speed of zone 1 of distance protection and improves the performance of distance protection. The logic diagram of adaptive variable data window distance protection scheme is shown in Fig. 3.

Among various variable data window algorithms analyzed in Reference [10], recursive least square algorithm is chosen in adaptive variable data window distance protection scheme, which possesses superior performance and has wide application.

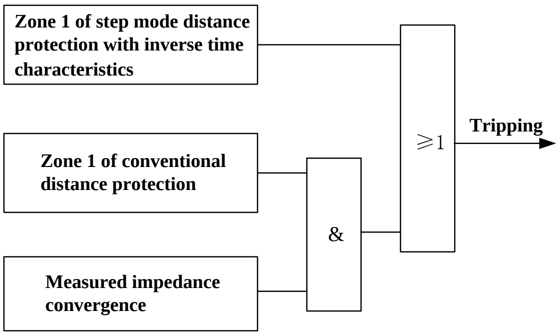


Fig. 3. Logic diagram of adaptive variable data window distance protection scheme

Simulation results and analysis

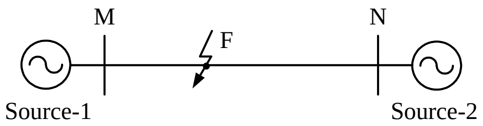


Fig. 4. Model of 500-kV transmission system

Using Electromagnetic Transients Program (EMTP) software, the simulation model of a 500-kV, 340-km transmission system is set up. This model comes from Pingdingshan-Wuchang 500-kV transmission system of China, and all the parameters in this model are from the real EHV project. The simulation model is illustrated as Fig. 4.

The performance of adaptive variable data window distance protection in case of different fault types, fault distances and fault angels is tested with this simulation model. In simulation, the mho relay based on positive sequence polarized voltage which is widely applied in zone 1 is adopted in this distance protection. The setting range of zone 1 of distance protection against phase-to-phase fault and earth fault both is 80% of the whole line. Recursive least square algorithm is adopted as protection algorithm, its fitting model adopts exponential function and fundamental wave model, and the attenuation time constant of exponential function is taken as time constant of transmission line.

Simulation results in Table 1 to Table 4 show that combine the advantages of step mode and measured impedance convergence based inverse time distance protection can improve the protection performance of zone 1. In the mean time, the simulation of fault occurring at 105% of zone 1 (286km) also shows that adaptive variable data window distance protection will not incur overriding and it ensures high reliability in case of external fault. In order to visualize the simulation results, the distance-time characteristic curves of adaptive variable data window distance protection when different types of fault occurs with different fault close angles are shown in Fig. 5 to Fig. 8.

Table 1. Simulation results of single-phase earth fault

Fault angel	Tripping time of different distance protection schemes (ms)	Fault distance (km)													
		20	40	60	80	100	120	140	160	180	200	220	240	260	286
0	Step mode	5	10	10	20	10	20	20	20	20	20	23	30	30	×
	Measured impedance convergence	13	13	13	13	17	13	13	13	13	13	13	23	13	×
	Adaptive variable data window	5	10	10	13	10	13	13	13	13	13	13	23	13	×
30°	Step mode	5	13	10	20	9	20	20	20	20	20	25	30	30	×
	Measured impedance convergence	13	13	13	13	18	13	13	13	13	13	13	25	14	×
	Adaptive variable data window	5	13	10	13	9	13	13	13	13	13	13	25	14	×
60°	Step mode	5	14	10	20	8	20	20	20	20	20	27	30	30	×
	Measured impedance convergence	13	13	13	15	18	13	13	13	13	13	13	24	14	×
	Adaptive variable data window	5	13	10	15	8	13	13	13	13	13	13	24	14	×
90°	Step mode	5	13	10	20	6	20	20	20	20	20	30	30	×	×
	Measured impedance convergence	13	17	13	15	18	13	13	13	13	13	13	14	13	×
	Adaptive variable data window	5	13	10	15	6	13	13	13	13	13	13	14	13	×

Table 2. Simulation results of two-phase earth fault

Fault angel	Tripping time of different distance protection schemes (ms)	Fault distance (km)													
		20	40	60	80	100	120	140	160	180	200	220	240	260	286
0	Step mode	8	10	5	5	5	20	20	20	20	20	30	30	30	×
	Measured impedance convergence	15	13	13	16	15	14	13	13	13	13	13	13	24	×
	Adaptive variable data window	8	10	5	5	5	14	13	13	13	13	13	13	24	×
30°	Step mode	10	5	10	11	12	10	20	20	20	20	30	30	35	×
	Measured impedance convergence	13	13	13	15	15	14	13	13	13	13	13	13	17	×
	Adaptive variable data window	10	5	10	11	12	10	13	13	13	13	13	13	17	×
60°	Step mode	11	10	10	12	11	5	20	20	12	20	10	30	10	×
	Measured impedance convergence	16	13	13	21	22	15	15	15	20	13	18	13	×	×
	Adaptive variable data window	11	10	10	12	11	5	15	15	12	13	10	13	10	×
90°	Step mode	11	20	10	12	11	10	20	20	11	20	31	30	×	×
	Measured impedance convergence	25	13	15	26	22	18	17	16	20	21	19	28	×	×
	Adaptive variable data window	11	13	10	12	11	10	17	16	11	20	19	28	×	×

Table 3. Simulation results of two-phase short circuit fault

Fault angel	Tripping time of different distance protection schemes (ms)	Fault distance (km)													
		20	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**	**220**	**240**	**260**	**286**
0	Step mode	8	10	5	5	5	20	20	20	20	20	30	30	30	×
	Measured impedance convergence	15	13	13	16	15	14	13	13	13	13	13	13	24	×
	Adaptive variable data window	8	10	5	5	5	14	13	13	13	13	13	13	24	×
30°	Step mode	10	5	10	11	12	10	20	20	20	20	30	30	35	×
	Measured impedance convergence	13	13	13	15	15	14	13	13	13	13	13	13	17	×
	Adaptive variable data window	10	5	10	11	12	10	13	13	13	13	13	13	17	×
60°	Step mode	11	10	10	12	11	5	20	20	12	20	10	30	10	×
	Measured impedance convergence	16	13	13	21	22	15	15	15	20	13	18	13	×	×
	Adaptive variable data window	11	10	10	12	11	5	15	15	12	13	10	13	10	×
90°	Step mode	11	20	10	12	11	10	20	20	11	20	31	30	×	×
	Measured impedance convergence	25	13	15	26	22	18	17	16	20	21	19	28	×	×
	Adaptive variable data window	11	13	10	12	11	10	17	16	11	20	19	28	×	×

Table 4. Simulation Results of three-phase short circuit fault

Fault angel	Tripping time of different distance protection schemes (ms)	Fault distance (km)													
		20	**40**	**60**	**80**	**100**	**120**	**140**	**160**	**180**	**200**	**220**	**240**	**260**	**286**
0	Step mode	10	10	10	10	10	20	20	20	20	20	30	30	30	×
	Measured impedance convergence	21	13	13	16	15	14	13	13	13	13	13	13	24	×
	Adaptive variable data window	10	10	10	10	10	14	13	13	13	13	13	13	24	×
30°	Step mode	10	10	10	17	12	10	20	20	20	20	30	30	35	×
	Measured impedance convergence	21	13	13	16	15	14	13	13	13	13	13	13	17	×
	Adaptive variable data window	10	10	10	16	12	10	13	13	13	13	13	13	17	×
60°	Step mode	20	20	10	18	12	8	20	20	12	20	30	30	10	×
	Measured impedance convergence	21	21	13	21	22	15	15	15	20	13	18	13	×	×
	Adaptive variable data window	20	20	10	18	12	8	15	15	12	13	18	13	10	×
90°	Step mode	20	20	10	16	11	10	20	20	11	20	34	30	×	×
	Measured impedance convergence	25	13	15	26	22	18	17	16	20	21	19	28	×	×
	Adaptive variable data window	20	13	10	16	11	10	17	16	11	20	19	28	×	×

It can be seen from Fig. 5 to Fig. 8 that except for few faults occurring at the end of zone 1, adaptive variable data window distance protection is capable of clearing most faults of zone 1 in less than one cycle (13ms in most cases).

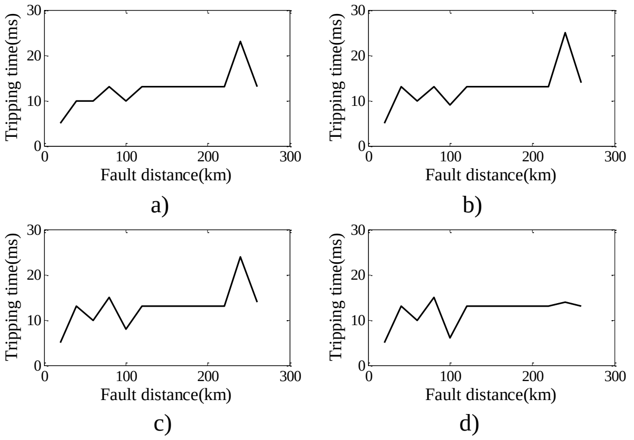
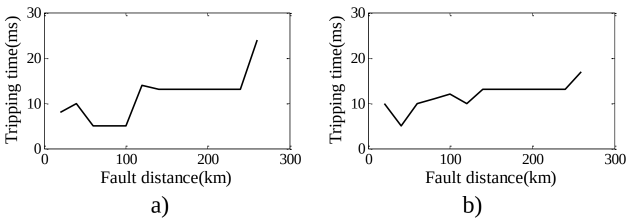


Fig. 5. Distance-time characteristic curve of single-phase earth fault: a –fault close angle is 0; b –fault close angle is 30°; c –fault close angle is 60°; d –fault close angle is 90°



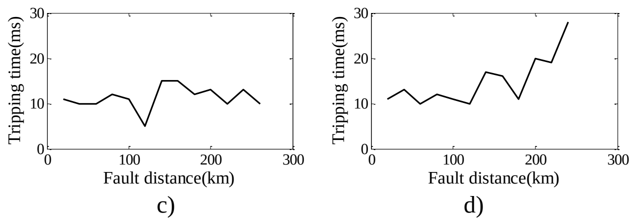


Fig. 6. Distance-time characteristic curve of two-phase earth fault: a –fault close angle is 0; b –fault close angle is 30°; c –fault close angle is 60°; d –fault close angle is 90°

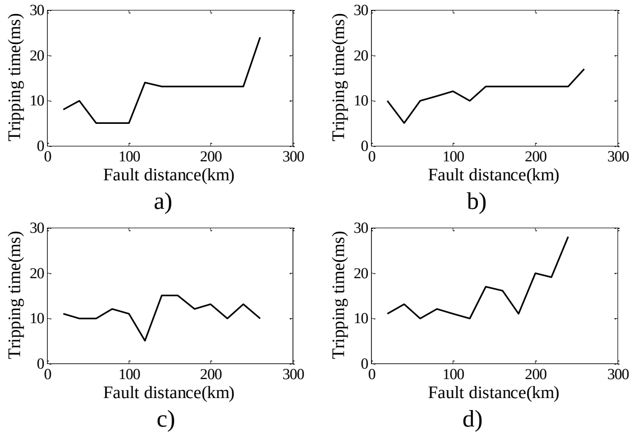


Fig. 7. Distance-time characteristic curve of two-phase short circuit fault: a –fault close angle is 0; b –fault close angle is 30°; c –fault close angle is 60°; d –fault close angle is 90°

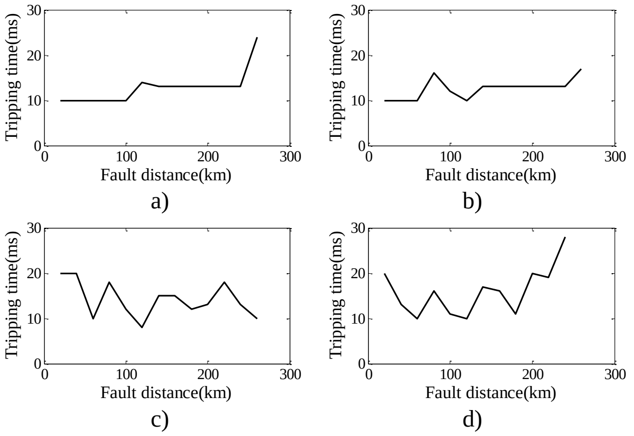


Fig. 8. Distance-time characteristic curve of three-phase short circuit fault: a –fault close angle is 0; b –fault close angle is 30^{o}; c –fault close angle is 60^{o}; d –fault close angle is 90^{o}

It makes up for the defects of traditional step mode inverse time distance protection at the end of protected line, improving the protection performance of zone I and exhibiting good engineering application prospects.

Conclusions

To make up for the defects that traditional step mode inverse time distance protection trips slowly at the end of protected line, the measured impedance convergence based inverse time distance protection is proposed. Simulation results show that the proposed measured impedance convergence based inverse time distance protection serves as a powerful supplement to traditional step mode inverse time distance protection. By integrating these two kinds of inverse time distance protection, an adaptive variable data window distance protection scheme is formed, which proves effective in improving the protection performance of zone 1, and it is capable of clearing most faults of zone 1 in less than one cycle.

Acknowledgements

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References

1. **Tarlochan S. S., Daljit S. G., Mohindar S. S.** An adaptive distance relay and its performance comparison with a fixed data window distance relay // IEEE Trans. on Power Delivery, 2002. – Vol. 17. – P. 691–696.
2. **Crossley P. A., Mclaren P. G**. Distance protection based on traveling waves // IEEE Power Engineering Review, 1983. – Vol. 3. – P. 30–31.
3. **Shehab–Eldin E. H., Mclaren P. G.** Traveling wave distance protection – problem areas and solutions // IEEE Trans. on Power Delivery, 1988. – Vol. 3. – P. 894–902.
4. **Liang Jie, Elangovan S.** Adaptive traveling wave protection algorithm using two correlation functions // IEEE Trans. on Power Delivery, 1999. – Vol. 14. – P. 126–131.
5. **Zhang Zhe, Li K. K.** Stochastic analysis of fault–induced transients for distance relaying application // Electric Power Systems Research, 2001. – No. 57. – P. 115–121.
6. **Li K. K.** An adaptive window length algorithm for accurate high speed digital distance protection // Electrical Power & Energy Systems, 1997. – Vol. 19. – P. 375–383.
7. **Zhang Zhe, Li K. K.** Adaptive application of impedance estimation algorithms in distance relaying // Proceedings of APSCOM’2000, 2000. – Vol. 1. – P. 269–274.
8. **Zhang Zhe, Chen Deshu.** On the characteristic of fault–induced transient noise // Journal of Huazhong University of Science and Technology, 1995. – Vol. 23. – P. 8–12.
9. **Huang Ying, He Benteng.** Noise evaluation based adaptive fast distance relay protection // Automation of Electric Power Systems, 2004. – Vol. 28. – P. 6–8.
10. **Xia Y. Q., Li K. K.** Development and implementation of a variable–window algorithm for high–speed and accurate digital distance protection // Proceedings IEE, 1994. – Vol. 141. – P. 383–389.

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The trip speed of traditional step mode distance protection with inverse time characteristics is quite slow when a short circuit fault occurs at the end of the protected line. To deal with this problem, a novel measured impedance convergence based inverse time distance protection is proposed in this paper. In this method, the convergence of measured impedance can dynamically reflect the level and attenuation degree of post-fault transient noise, and the method can adaptively decide the data window length of protective algorithm according to the result of real-time measured impedance convergence. More specifically, the faster the measured impedance convergence is, the shorter data window length of protective algorithm and the faster trip speed will be. Furthermore, a comprehensive adaptive variable data window distance protection scheme is established by using aforementioned two methods synthetically, which can overcome flaws of single method and efficiently improve trip speed of zone 1 of distance protection. Finally, the feasibility and effectiveness of the proposed scheme is proved with the simulation results. Ill. 8, bibl. 10, tabl. 4 (in English; abstracts in English and Lithuanian).

Xing Deng, Xianggen Yin, Zhe Zhang, Dali Wu. Nauja adaptyvi nuotolinės apsaugos schema pagrįsta kintamu duomenų langu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 7(123). – P. 3–8.

Tradicinė nuotolinė apsauga su inversinėmis laiko charakteristikomis yra gana lėta, kai saugomos linijos gale įvyksta trumpasis jungimas. Todėl siūloma nauja matuojamo impedanso konvergencijos inversinio laiko nuotolinė apsauga. Šiuo atveju matuojamo impedanso konvergencija gali dinamiškai atspindėti poavarinio pereinamojo triukšmo lygį ir slopinimo laipsnį. Atsižvelgiant į tai galima adaptyviai nustatyti apsaugos algoritmo duomenų lango ilgį: kuo spartesnė matuojamo impedanso konvergencija, tuo trumpesnis apsaugos algoritmo duomenų langas. Pateikiami siūlomos schemos efektyvumo tyrimo modeliavimo rezultatai. Il. 8, bibl. 10, lent. 4 (anglų kalba; santraukos anglų ir lietuvių k.).