Influence Of Frequency Offset On Sampling Value Differential Protection

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Abstract. The current sampling value differential protection gradually reflects its unique superiority among various differential protection. With the application of sampling value differential protection, the influence of frequency offset on it should be considered. In this paper, based on the analysis of the data window and the range of trip boundary, the influence of frequency offset is analyzed. The conclusion is proven by simulation.

Introduction

Current sampling value differential protection is a differential protection which is based on current sampling value. Compared with the conventional phase differential protection, the most obvious characteristic is that the action speed is fast. In order to ensure the reliability of the action criterion, it is usually adopted the method of multiple repeated discrimination. But the sampling value differential protection has the range of trip boundary. Frequency offset may influence the sampling value differential protection. Therefore, this article analyzes and discusses the influence of frequency offset on the sampling value differential protection.

Sampling Value Differential Criterion

Similar to the conventional phase differential protection, as shown in Fig.1, the action curve of sampling value differential criterion is generally composed of the broken line type braking characteristic curve (in the case of two broken lines).

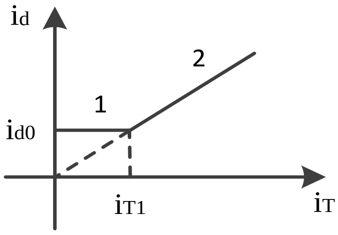

Fig. 1 Sampling value differential action characteristic curve

Usually, in order to overcome the influence of the sampling value differential fuzzy region on the test experiment, The braking curve crosses zero, the action criterion of sampling value differential is generally described as follows:

$$i_d \geq i_{d0}, i_d \geq K i_T \tag{1}$$

In the Eq.1 above, $i_d = |i_1 + i_2|$ represents differential current(Take the situation of two inputs as an example and the direction of current flow as the positive direction). i_T represent restraint current, i_T can be expressed in the following forms：

$$i_T = |i_1| + |i_2| \tag{2}$$

The two conditions in Eq.1 must be met at the same time. In order to simplify the analysis.

Selection Of Data Window

Compared with the conventional differential protection, sampling value differential has an obvious feature: In the state of steady, current rms value is used in conventional differential protection criterion, which is certain value and doesn't change with time. But for the sampling value differential protection, each quantity in the criterion is instantaneous value, which periodically changes with time. Before and after the current crossing zero, its value is very small and error is relatively large, making relative relationship between I_d and i_T become uncertain, which leads to the differences of the braking effect among various sampling points. The corresponding measures must be taken to avoid the influence of the sampling points whose braking effect are not good.

(1) $I_d \ge KI_T$

It is assumed that the fault current is only composed of the fundamental component, that is, the non power frequency components such as the harmonic component and the non periodic component have been filtered. Firstly, action criterion $i_d \ge Ki_T$ is analysized. It corresponds to the traditional differential criterion $I_d \ge KI_T$,which expressed in general form is $|\boldsymbol{A}| \ge |\boldsymbol{B}|$. Sampling value differential criterion can be expressed as follows:

$$|A\sin\theta| \ge |B\sin(\theta-\Delta\theta)| \quad (3)$$

$\Delta\theta$ represents phase difference between two phases, A and B respectively represent amplitude of **A** and **B.** It is assumed that $\Delta\theta \in [0,\pi]$.

When $\Delta\theta = 0$ or $\Delta\theta = \pi$,Eq.3 is true because of $|\boldsymbol{A}| \ge |\boldsymbol{B}|$, the effectiveness of the sampling value differential criterion is same as that of the conventional differential criterion. The sampling value differential criterion would not misjudge due to the change of the current value.

When $0 < \Delta\theta < \pi$, if A=B, then Eq.3 can be written as follows:

$$|\sin\theta| \ge |\sin(\theta-\Delta\theta)| \quad (4)$$

(a) When $\Delta\theta \le \theta \le \pi$, $\sin\theta \ge \sin(\theta-\Delta\theta)$, $2\sin\frac{\Delta\theta}{2}\cos\left(\theta-\frac{\Delta\theta}{2}\right) \ge 0$,Since $\sin\frac{\Delta\theta}{2} > 0$, Eq.4 is equivalent to $\cos\left(\theta-\frac{\Delta\theta}{2}\right) \ge 0$, thus $\Delta\theta \le \theta \le \frac{\Delta\theta+\pi}{2}$.

(b) When $\pi \le \theta \le \pi+\Delta\theta$, Eq.4 can be turned into $\sin\left(\theta-\frac{\Delta\theta}{2}\right) \le 0$, thus $\pi+\frac{\Delta\theta}{2} \le \theta \le \Delta\theta+\pi$.

In conclusion, Eq.4 is untrue in the interval $\left(\frac{\Delta\theta}{2}+\frac{\pi}{2},\frac{\Delta\theta}{2}+\pi\right)$. Therefore, the range of misjudgement of the sampling value differential criterion is $\pi/2$. As shown in Fig.2, when A=B, phase difference between the action function and braking function is 90° ,which is the most unfavorable situation. When A>B, the angle range of which the braking function B2 greater than the action function A is α and $\alpha < \pi/2$.In other words, the range of misjudgement when A>B is smaller than when A=B.

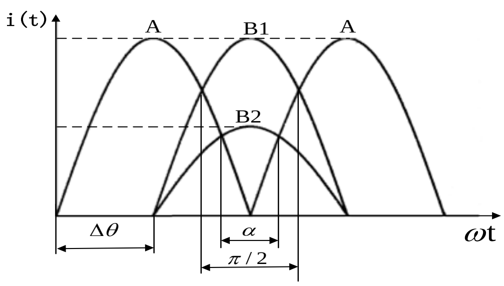

Fig.2 Misjudging range of $i_d \ge Ki_T$

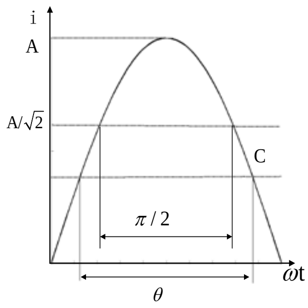

Fig. 3 Misjudging range of $i_d \ge i_{d0}$

(2) $i_d \ge i_{d0}$

Secondly, action criterion $i_d \geq i_{d0}$ is analysized. It corresponds to the traditional differential criterion $I_d > I_{d0}$, which expressed in general form is $|\boldsymbol{A}| \geq C$. Sampling value differential criterion can be expressed as $|A \sin\theta| \geq C$. From the analysis above, it is known that $C \leq \frac{A}{\sqrt{2}}$,Fig.3 shows that the range of misjudgement $\alpha = \pi - \theta$, $\alpha \leq \pi/2$.

Above all, without consideration of the influence of the non fundamental component and the anti jamming performance, for the sampling value differential protection, misjudging range of its action criterion is always smaller than $\pi/2$. In order to ensure the reliability of the sampling value differential protection and make its braking characteristic is equal to or better than the conventional phase differential protection, the angle of the data window for judgement should satisfy $\theta \geq \pi/2$.

Determination Of The Range Of Trip Boundary

Different with the conventional phase differential protection, operation of the sampling value differential protection should be based on the repetitive discrimination. Due to the discreteness of sampling value, there is a fuzzy area in the determination of the operation current of the sampled value differential protection.

Take 12 sampling points per period as an example.

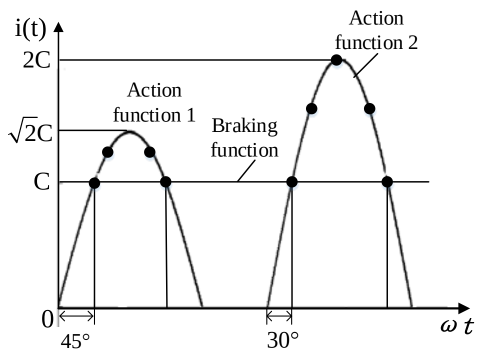

Fig.4 Trip boundary range of $i_d \geq i_{d0}$

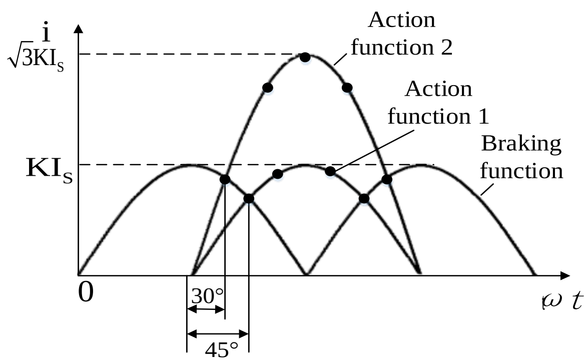

Fig.5 Trip boundary range of $i_d \geq Ki_T$

For criterion (4), as shown in fig.4, the comparison between the action function 1 and the braking function is the most favorable situation, that is, the two continuous sampling values near the peak of the action function are equal. At this time, the peak value of the action function is $\sqrt{2}$ times of C. The comparison between the action function 2 and the braking function is the most unfavorable situation. That is, a sampling point is the peak of the action function and the peak of the action function is 2 times of C. Therefore, trip boundary range of $i_d \geq i_{d0}$ is $(\sqrt{2}C, 2C)$.

For criterion (2), as shown in Fig.5, the comparison between the action function 1 and the braking function is the most favorable situation, that is, the two continuous sampling values near the peak of the action function are equal. At this time, the peak of action function and the peak of braking function are equal. The comparison between the action function 2 and the braking function is the most unfavorable situation. That is, a sampling point is the peak of the action function. At this time, the peak of action function is $\sqrt{3}$ times of the peak of braking function. Therefore, trip boundary range of $i_d \geq Ki_T$ is $(K, \sqrt{3}K)$,K is ratio coefficient.

Influence Of Frequency Offset

If the system frequency is shifted, and the sampling rate is constant, the criterion may not be correct. In particular, the effect of frequency offset must be taken into account when the cumulative effect occurs. Here are considered the most unfavorable situation, the amount of action and the amount of braking phase difference of 90 degrees.

(1) $i_d \geq i_{d0}$

When f=50Hz , as the most unfavorable situation shown in Fig.3 , the braking function is $i_d = C$, the action function is $i_T(t) = 2C\left|\sin 100\pi t\right|$. Sampling point is $t = \frac{n}{600}$ s ($n \in N$). Take the previous half period as an example, the sampling points satisfying the action criterion are $t_1 = \frac{1}{600}s$, $t_2 = \frac{1}{300}s$, $t_3 = \frac{1}{200}s$, $t_4 = \frac{1}{150}s$, $t_5 = \frac{1}{120}s$. In this case, the range of data window is $\theta = \frac{2\pi}{3}$.

If the frequency increases(50Hz<f<60Hz), when f=51Hz, the action function is $i_T'(t) = 2C\left|sin\left(102\pi t - \frac{\pi}{100}\right)\right|$, the sampling points are same as those when f=50Hz.

$i_T'(t_1) = 0.964C < C$, $i_T'(t_2) = 1.721C > C$, $i_T'(t_3) = 2C > C$, $i_T'(t_4) = 1.721C > C$, $i_T'(t_5) = 0.964C < C$.

Only three sampling points of above results satisfy the action criterion $i_d \geq i_{d0}$ and action criterion can not operate correctly. It can be seen from Fig.6, data window is less than $2\pi/3$ when the frequency increases. In the most unfavorable situation, sampling value differential criterion can not operate correctly.

If the frequency decreases(45Hz<*f*<50Hz), when f=49Hz, the action function is $i_T''(t) = 2C\left|sin\left(98\pi t + \frac{\pi}{100}\right)\right|$, the sampling points are same as those when f=50Hz.

$i_T''(t_1) = 1.036C > C$, $i_T''(t_2) = 1.742C > C$, $i_T''(t_3) = 2C > C$, $i_T''(t4) = 1.742C > C$, $i_T''(t_5) = 1.036C > C$.

All sampling points above satisfy the action criterion $i_d \geq i_{d0}$,In order to facilitate the observation, the action function curve and the brake function curve when f=50Hz and f=45Hz are shown in Fig.7. According to the above calculation and analysis, even in the most unfavorable situation, there still are five sampling points satisfying the action criterion when the frequency decrease. Thus, action criterion can operate correctly.

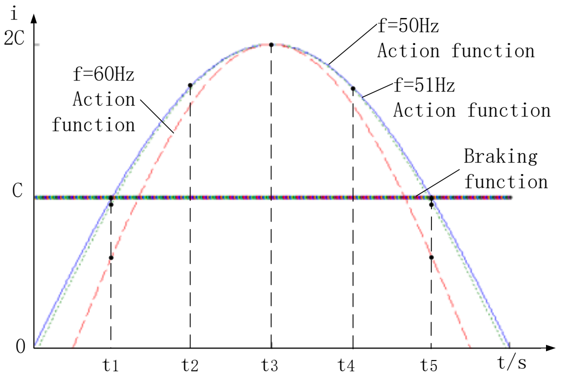

Fig.6 The action function and braking function of $i_d \geq i_{d0}$ when the frequency increases

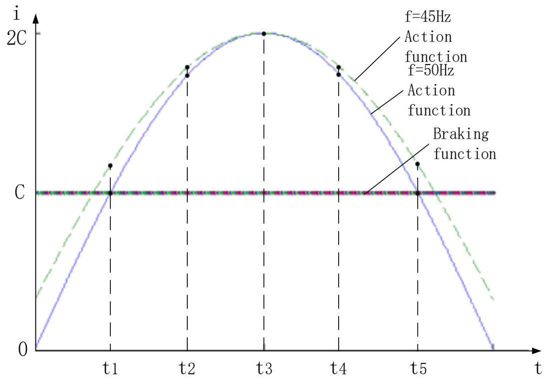

Fig.7 The action function and braking function of $i_d \geq i_{d0}$ when when the frequency decreases

(2) $i_d \geq Ki_T$

When f=50Hz , as the most unfavorable situation shown in Fig.4 , the braking function is $i_d(t) = \left|sin 100\pi t\right|$, the action function is $i_T(t) = \sqrt{3}\left|sin\left(100\pi t + \frac{\pi}{2}\right)\right|$. Sampling point is $t = \frac{n}{600}$ s ($n \in N$). Take the previous half period as an example, the sampling points satisfying the action criterion are $t_1 = \frac{1}{600}s$, $t_2 = \frac{1}{300}s$, $t_3 = \frac{1}{200}s$, $t_4 = \frac{1}{150}s$, $t_5 = \frac{1}{120}s$. In this case, the range of data window is $\theta = \frac{2\pi}{3}$.

If the frequency increases, when f=51Hz, the braking function is $i_d^{'}(t) = \left|sin\left(102\pi t - \frac{\pi}{50}\right)\right|$, the action function is $i_T^{'}(t) = \sqrt{3}\left|sin\left(102\pi t + \frac{12\pi}{25}\right)\right|$, the sampling points are same as those when f=50Hz.

$i_d^{'}(t_4) = 0.876 > i_T^{'}(t_4) = 0.834$, $i_d^{'}(t_5) = 0.509 < i_T^{'}(t_5) = 1.491$, $i_d^{'}(t_6) = 0 < i_T^{'}(t_6) = 1.732$, $i_d^{'}(t_7) = 0.509 < i_T^{'}(t_7) = 1.491$, $i_d^{'}(t_8) = 0.876 > i_T^{'}(t_8) = 0.834$.

Only three sampling points of above results satisfy the action criterion $i_d \geq Ki_T$ and action criterion can not operate correctly. In order to facilitate the observation, the action function curve and the brake function curve when f=50Hz and f=55Hz are shown in Fig.8. In the most unfavorable situation, sampling value differential criterion can not operate correctly.

If the frequency decreases, when f=49Hz, the braking function is $i_d^{''}(t) = \left|sin\left(98\pi t + \frac{\pi}{50}\right)\right|$, the action function is $i_T^{''}(t) = \sqrt{3}\left|sin\left(98\pi t + \frac{13\pi}{25}\right)\right|$, the sampling points are same as those when f=50Hz.

$i_d^{''}(t_4) = 0.855 < i_T^{''}(t_4) = 0.897$, $i_d^{''}(t_5) = 0.491 < i_T^{''}(t_5) = 1.509$, $i_d^{''}(t_6) = 0 < i_T^{''}(t_6) = 1.732$, $i_d^{''}(t_7) = 0.491 < i_T^{''}(t_7) = 1.509$, $i_d^{''}(t_8) = 0.855 < i_T^{''}(t_8) = 0.897$.

All sampling points above satisfy the action criterion $i_d \geq Ki_T$ .In order to facilitate the observation, the action function curve and the brake function curve when f=50Hz and f=45Hz are shown in Fig.9. According to the above calculation and analysis, even in the most unfavorable situation, there still are five sampling points satisfying the action criterion when the frequency decrease. Thus, action criterion can operate correctly.

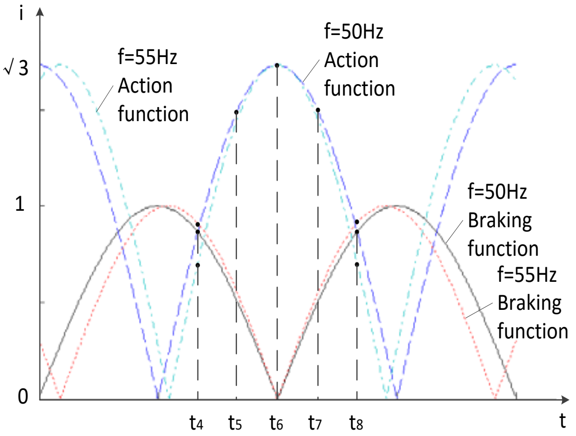

Fig.8 The action function and braking function of $i_d \geq Ki_T$ when f=50Hz and f=55Hz

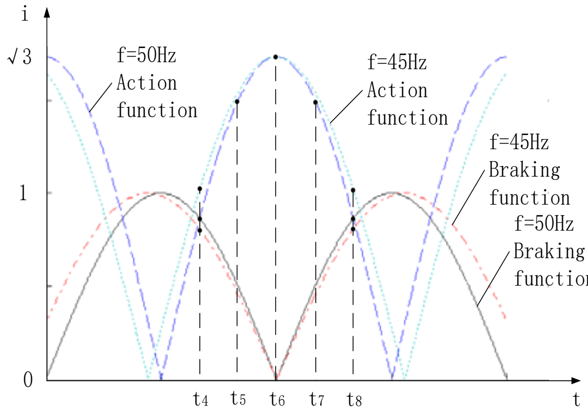

Fig.9 The action function and braking function of $i_d \geq Ki_T$ when f=50Hz and f=45Hz

Simulation

Simulation model is built in PSCAD, the algorithm is written in MATLAB to verify the above criteria. In different frequency conditions, action time are compared when the internal fault, external fault and transferring fault occur respectively.As can be seen from Table 1, when the internal fault and transferring fault occur, sampling value differential protection operates in a short time; when the external fault occurs, sampling value differential protection reliably refuses operate. In different frequency conditions, the criteria do work no matter which fault occurs.

Table 1 Action time comparison among different frequency

Frequency	Internal fault	External fault	Transferring fault
45Hz	8.2ms	——	9.1ms
50Hz	9.1ms	——	10.7ms
60Hz	9.9ms	——	16.6ms

Conclusion

According to the above analysis, to ensure the reliability of sampling value differential protection and make the braking characteristics is equal to or better than conventional phase differential protection, the angle of data window should be larger than π/2. If the grid frequency increases (50Hz<f<60Hz), in the most unfavorable situation, protection may refuse to operate. However, generally a certain margin will be retained ,therefore, sampling value differential protection will not be influenced; if the frequency decreases(45Hz<f<50Hz), the protection can still operate correctly.

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