OPERATING TIME OF LINE DISTANCE PROTECTIONS

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Abstract:

Papers deals with electric power system line distance protections. Methods of analog and digital signal processing used in static and numeric protections respectively were indicated. Estimation of minimal fault detection interval for both methods has been done. It was pointed out that minimal fault detection intervals are rather long and comparable for both methods.

To reduce minimal fault detection interval it is necessary to search for new principles and methods.

Key words:

Power system protection, distance protection, line protection, operating time, fault detection interval

INTRODUCTION

Reliable and fast fault clearing is main duty of any electric power system protection scheme.

Fault clearing time consists of time of operation of the electric power system protection scheme and time of operation of the circuit breaker. Taking an insight in their average durations, one can realize that they are discouraging close one to another (20 ms for fast electronic protections and 40-60 ms for circuit breakers), and first improvement in circuit breaker technology or construction could make operation time of power system protection as predominant one. Restricting considerations to (today predominately) semiconductor type of protections: static protections and (newer) numeric protections, it is difficult to find any substantial difference between two of them from the standpoint of reliability: used materials and technological process of production are the same.

The main difference arises from method of signal processing: so called "static protections" are based on analog signal processing while so called "numeric protections" are based on digital (computer oriented) signal processing. While reliability of both systems could be considered as the same, availability, degree of integration and communication aspects are in favor of so called "numeric protections". Speed of operation or minimum time of operation are comparable for both type of protections.

In determining of the minimum time of operation of power system protection unit, it is important to mention that it consists of two time periods: interval of fault detection and interval of operation of "executive organ- electromechanical relay" as output relay of protection system (or unit).

STATIC PROTECTIONS

As mentioned before, static protections are based on analog signal processing.

Originating from the principle of static line distance protection, one can see that for its proper operation, there is no need to find amount of the faulted line impedance, but to compare faulted line impedance to some predefined value.

Taking the phase comparison approach as more convenient one, and taking information about appropriate voltage ($\overline{U}$) and current ($\overline{I}$) it is possible to form new versors (vectors) $\overline{S_1}$, and $\overline{S_2}$ suitable for purpose of comparison of impedances:

$$\overline{S}_1 = k_1\angle\gamma_1\; U\angle 0 + k_3\angle\theta_1\; I\angle -\beta$$
$$\overline{S}_2 = k_2\angle\gamma_2\; U\angle 0 + k_4\angle\theta_2\; I\angle -\beta \qquad 1.$$

$\overline{k_1}...\overline{k_4}$ in relation 1. represent (generally dimensional) constants, and γ,θ and β appropriate phase angles. Versor (vector) ($\overline{U}$) was taken as referent one.

Phase angle between quantities $\overline{S_1}$ and $\overline{S_2}$ has the form:

$$\phi = \gamma_1 - \gamma_2 + \arg\frac{Z_V\angle\beta + \frac{k_3}{k_1}\angle\theta_1 - \gamma_1}{Z_V\angle\beta + \frac{k_4}{k_2}\angle\theta_2 - \gamma_2} \qquad 2.$$

(Z_L represents impedance of the line under consideration, and Z_1 reference impedance).

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By appropriate selection of quantities $\overline{k_1}$ to $\overline{k_4}$ it is possible to form versors (vectors) $\overline{S_1}$ and $\overline{S_2}$ in the form giving their phase angle as:

$$\phi = \arg \frac{\overline{I}\left(\overline{Z}_l - \overline{Z}_L\right)}{\overline{I}\,\overline{Z}_l} \qquad 3.$$

Relation 3 leeds to well known principle of comparison of the line impedance with some predefined value illustrated on figure 1.

Line impedance ($\overline{Z}_L$), reference impedance ($\overline{Z}_l$) as well as (upper) boundaries of the distance protection operating characteristic are depicted in the complex plane R, jX (interior of the operating characteristic represents operating zone).

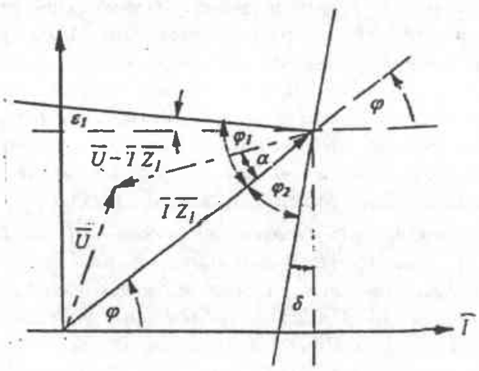

fig. 1. a

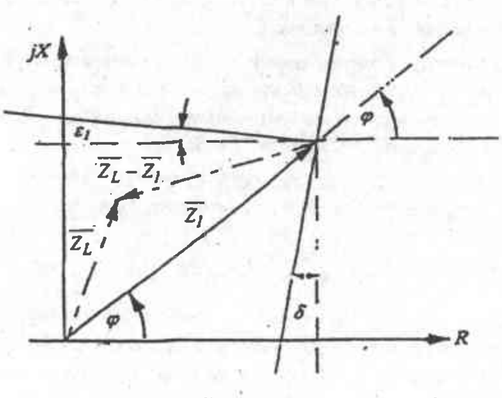

fig. 1. b

Evidently, impedance $\overline{Z}_L$ will bė into distance protection operating zone if phase angle denoted as α on fig. 1 will be in the range of angle φ_1 or angle φ_2.

Otherwise, line impedance $\overline{Z}_L$ is out of operating zone (out of protected zone - greater than redefined value).

If the same current $\overline{I}$ flows through the line and through the reference impedance, relations between $\overline{Z}_L$ and $\overline{Z}_l$ are the same as those between voltage drops on the line $\overline{I}\,\overline{Z}_L = \overline{U}$ and reference impedance ($\overline{I}\,\overline{Z}_l$), fig. 1.b.

Phase measurement between two electrical quantities means nothing but measurement of the time interval elapsing between their two characteristic points (par example: zero crossing points).

As it follows from fig.1., quicker phase measurement will result by measuring phase angle between quantities $-\overline{I}(\overline{Z}_L-\overline{Z}_l)$ and $\overline{I}\,\overline{Z}_l$.

It follows then, that line impedance will be into operating zone if

$$-\left(\varphi + \varepsilon_l\right) \le \arg \frac{\overline{I}\left(\overline{Z} - \overline{Z}_L\right)}{\overline{I}\,\overline{Z}_l} \le \frac{\pi}{2} - \varphi - \delta \qquad 4.$$

Given relation is valid for stationary state. For purposes of protection it is necessary to get information as soon as possible after occurrence of a fault, it means: measurement should be done during transient process.

In the "healthy" state versor (vector) $\overline{U} = \overline{I}\ \overline{Z}_L$ is out of the relay operating zone (out of its right border) and with appearing of a fault it enters relay operating zone (position defined by the fault location and character of the fault).

So, fault detection interval depends of the fault location. Fault detection interval depends also of the moment of a fault appearance.

If suppose versor (vector) $\overline{I}(\overline{Z}_L-\overline{Z}_l)$ before the fault and after the fault in positions shown in fig. 2.

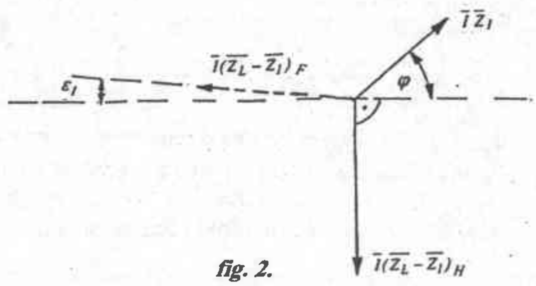

fig. 2.

and if the fault appears for some interval ε after $\overline{I}(\overline{Z}_L-\overline{Z}_l)$ passes its maximal value, phase relation between quantities $\overline{I}\,\overline{Z}_l$ and $\overline{I}(\overline{Z}_L-\overline{Z}_l)$, including moment of fault appearance (and shown *for basic harmonic component only) are as given on fig.3.*

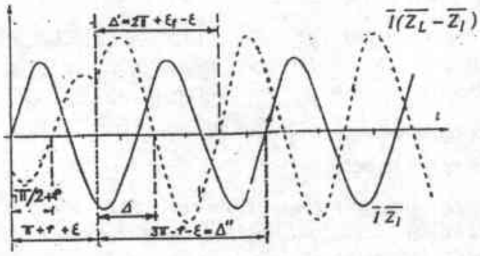

fig.3.

Taking minimal fault detection interval as the interval from moment of the fault appearance to the moment of its first detection, and taking measurements between $\bar{I}\,\bar{Z}_l$ and $-\bar{I}(\bar{Z}_L-\bar{Z}_l)$, it follows from fig. 3 that minimal fault detection interval amounts Δ:

$$\Delta=\pi+\varepsilon_l-\varepsilon. \qquad 5.$$

Having in mind that ε can take different values (including ε_l) it follows that:

- *for polygonal operating characteristics one can't guarantee that minimal fault detection interval is shorter then π (10 ms for of = 50 H_z) in general case.*

NUMERIC PROTECTIONS

For a difference to static protections, numeric protections are measuring amounts of voltage and current samples, and calculate amounts of impedance (or its components) and than compare it to some predefined values.

Always beginning with n π segment short circuited line model, exactly described by equations:

$$\frac{\partial u(x,t)}{\partial x}=\rho\, i(x,t)+\ell\frac{\partial i(x,t)}{\partial t}$$

$$\frac{\partial i(x,t)}{\partial x}=g\, u(x,t)+c\frac{\partial i(x,t)}{\partial t} \qquad 6.$$

(ρ, ℓ, g, c representing line parameters per unit of length) and simplifying it to one segment model fig.4. (R = ρ, ℓ' + R_F ; L=ℓ ℓ'; ℓ' = faulted line length) described by corresponding equation:

$$u(t)=R\,i(t)+L\frac{di}{dt}+e(t) \qquad 7.$$

many algorithms were proposed and analyzed.

If we take noise level $e_S\approx 0$, relation shows that even two measurement only could be enough to calculate faulted line parameters R and L.

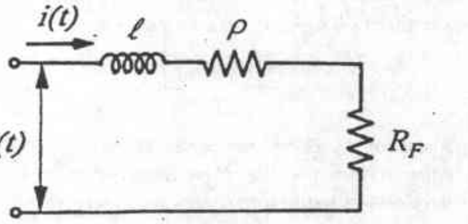

fig.4.

Theoretically, there is no limitation to the "vicinity" of the two consecutive samples and minimal fault detection interval seems could be extremely short.

Practically, higher sampling frequency means the request for higher accuracy of analog-to-digital converter (closer samples mean less difference in their amplitudes), and noise level is getting more influence. Besides, it was shown that product of expected mean square error (of the result) and data window width was constance (narrower data window - greater error of calculated line impedance, and vice versa).

Effects of noise, measuring errors and the fact that none algorithm was based on ideal model of faulted line are causing different results of consecutive calculations (of the same impedance), and to get satisfactory result, it is necessary to form average value of several consecutive results.

Therefore, to get first correct result it is necessary to spent more then (N-1) ΔT time. (N means number of samples requested by algorithm under consideration and ΔT period between two consecutive samples).

Investigations of many types of algorithms (L.1) have shown that first correct value of measured impedance can be got taking information during the period T/4 (5 ms for f = 50H_z).

To estimate minimal fault detection interval let's suppose that fault arises at the moment t_k

$$t_a\le t_k\le t_b \qquad 8.$$

(t_a and t_b represent moments of taking two consecutive samples) closer to t_π. Interval between two samples, ΔT should be long enough to make all necessary calculations and now it is usually 1,6 ms (corresponding to sampling rate of 12 samples per period for f=50 H_z; sampling rate is generally in the range of 4 to 64 samples per period - L.2).

So called "antialiasing filters" put in the path of input quantities (current and voltage) to prevent *influence of higher harmonics are introducing additional own delay (one to two milliseconds).*

- *So minimal fault detection interval represents the sum of input antialiasing filter delay, time interval t_b-t_k and interval T/4, and for frequency f=50 H_z it amounts about 8 ms. Even for highest sampling rates it is not less than 6 ms.*

CONCLUSION

Here given analysis was restricted to the signal processing methods used in modern semiconductor (static and numeric) electric power line protection.

In an attempt to estimate minimal fault detection interval (and to indicate, eventually, possibility to reduce it), it has been shown that existing (used) methods of signal processing are leading to very similar results.

If looking for shorter minimal fault detection intervals, we should not forget long time known traveling waves principle: traveling waves generated at the fault location have speed of propagation $v = 1/\sqrt{LC}$ what is of the order of $3 \cdot 10^8$ m/s (L and C are inductance and capacitance of the line per unit length) and even for very long lines, they are reaching "receiving" line end in the time less than 1 ms after incidence of the fault. Unfortunately, despite now existing very fast computers, and lot of work which has been done, there is no commercially available protection, based on traveling wave principle.

So, to get shorter minimal fault detection interval, it is necessary to search for new methods and principles.

Literature:

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