International Journal of Advanced Science and Technology
Vol.59, (2013), pp.123-130
http://dx.doi.org/10.14257/ijast.2013.59.10

Criterion Technical Efficiency of Line Distance Relay Protection

Tran Hoang Quang Minh and Nguyen Trung Thang

Faculty of Electrical and Electronic Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
thqminhtk@tdt.edu.vn, trungthangttt@tut.edu.vn

Abstract

The estimation technical efficiency of functioning of relay protection as differences potentially possible effect in the form of an index of faults on protected object and losses (refusals of work, false and excessive actions) are carried to potential effect is an actual problem for designing and operation relay protection of electric equipment and electric networks. Distance relay protections have some special features compared with the current relay protections and the criterion technical efficiency is an objective indicator quality of functioning distance relay protection. Therefore base on its extremum is possible to define the optimum values of interest of practical problems, in particular the optimal settings of distance relay protection.

Keywords: *Technical efficiency; distance relay protection; electric network; probability distribution density; probability distribution function; probability distribution density*

1. Introduction

The estimation technical efficiency of functioning of relay protection (RP) as differences potentially possible effect in the form of an index of faults on protected object and losses (refusals of work, false and excessive actions) are carried to potential effect, is an actual problem for designing and operation RP of an electric equipment and electric networks. Therefore to this question the attention was always paid at the statistical analysis of features of RP work, for example [1, 5-7]. However there are problems of imposing appearance different components of statistical data. Some data, for example, faults are mass enough, but such events as refusals of operation relay protection at RP, false actions at asynchronous modes, etc. are rather rare. In this connection it is wrongful to use statistical characteristics with different reliability in interesting criteria functional. Therefore there is an actual problem of support statistical adequacy of all components in considered functional.

Working out calculation methods of poor statistics formation of one event on enough full-value statistics of other events can be one of ways to solve the given problem. This way always is widely used at definition of probabilistic characteristics combined realization random events. It is realized in a known rule of multiplication probabilities, *i.e.*, multiplication of probability one event to conditional probability of other event, under the condition that the first has occurred. The first event is rather reliable, and the second is rare. But if the conditional probability of the second event as a small share of reliability of the first event is found in the logic or calculation way precisely enough and unambiguously, that it is lawful to consider insignificant values of probabilistic characteristics combination precisely and unambiguously received. Thus the guarantor is the probabilistic characteristic of rather reliable event.

ISSN: 2005-4238 IJAST

In a number of practical cases such combinations are possible to find out, then the problem is reduced to possibility of an exact estimation of a share or conditional probability of interesting rare event, for example, operation refusals at faults, false action at open-phase or asynchronous modes. Last thing in practical calculations can be defined not by a direct way, and through the full conditional probabilistic characteristic or the conditional probability distribution law (PDL) in type of probability distribution density (PDD) or probability distribution function (PDF), the sort and which parameters should be defined by logical-calculation way.

One of logical-calculation procedures for relay protection is the following chain of logic reasoning. To have smaller losses in a network from flow of reactive power aspire to provide the same or near voltage on along branches and in network nodes. It causes almost equal probabilities faults in different points of lines, and then equal probabilities of the resistance measured distance relay protection from places of its placing on the line to place faults on a line. The last means that probability distribution of resistance at faults on lines appears uniform law. This probability distribution is conditional. A condition of distribution is the space of a specific line on which fault has occurred.

Besides in Tomsk polytechnic university the method SBID (selection the borders of intervals of the in and out data) is developed [2–5], which allows on PDL arguments of functional dependence to receive approximately but quickly PDL different functional dependences of any dimension is developed. Such PLD is necessary to consider at definition of components of technical effect and losses as conditional since they concern quite certain functional dependence of electric size for a specific branch or node. For cases, when sort PLD of functional dependence is known in advance (for example, normal PLD for the multidimensional sums of components-arguments or their linear combinations), method SBID allows to find parameters PLD of functional dependences almost precisely.

2. Main Part

On the foundations of the worded definition and the analysis criterion of technical efficiency, and also numerator of this criterion (a difference of potential effect and losses) which is called as technical effect for distance relay protection lines is considered. Losses can be subdivided on two components, which are caused by refusals of equipment and by functioning relay protection. In the given work last component are considered, which is defined by conditions different topology of a network, modes of sources, switching conditions, types faults, abnormal modes, *etc.*, *i.e.*, different operational conditions. Such choice is made because a number of operational conditions can be changed the operational personnel at use of the same equipment, but hardware refusals depend on manufacturers of element base and devices.

In connection with feature distance relay protection, consisting in reaction to design parameter resistance from a relay protection installation place on the ends of a line to place fault, which is distributed on the most simple and with final concrete borders uniform PLD on space of each line and other components of the network, is expedient to construct algorithm of technical efficiency with obligatory preservation use of this PLD. This recommendation concerns all steps of distance relay protection, however most simply and unequivocally it is realized at measurements of resistance to places faults on a protected line. At measurement in the fault conditions on previous lines (opposite substations departing from buses) in a direction of distance relay protection action of network elements, it is necessary to consider feeds of place fault from the additional sources connected to opposite substation. And at measurement fault on previous line to the previous components, which are fixed by reserving step distance relay protection, the account of feeds from the sources connected to opposite substations of the previous elements is necessary considered [8].

Distribution of probabilities on each line, also resistance star-shaped replacements of transformer elements in the electric value conditions of each component is accepted uniform PLD, *i.e.*, PDD on each component or its heterogeneity part is inverse proportion to resistance of this part.

The technical effect E in the probable form of every step distance relay protection can be presented by expressions:

At phase-to-phase faults

$$E_{№,к}^{с,м} = \text{p}(\text{А}_{№}^{с,м}) - \text{p}(\text{О}_{№,к}^{с,м}) - \text{p}(\text{Л}_{№,к}^{э}) - \text{p}(\text{Л}_{№,к}^{ар,м}) - \text{p}(И_{№,к}^{с,м}),$$

At phase to ground faults

$$E_{№,к}^{с,1} = \text{p}(\text{А}_{№}^{с,1}) - \text{p}[\text{О}_{№,к}^{с,1}] - \text{p}(\text{Л}_{№,к}^{э}) - \text{p}(\text{Л}_{№,к}^{ар,1}) - \text{p}(\text{Л}_{№,к}^{нпф,1}) - \text{p}(И_{№,к}^{с,1}),$$

Where the letter p designates probabilities of events: A – faults on a protected line, O – operation refusals, Л – false, И – excessive actions;

The bottom indexes mean № – number protected line, к – a designation of its ends;

The top indexes: c – a designation of steps, for example I, II, III,...; м – phase-to-phase faults, 1 – phase to ground faults, э – working operational conditions, ар – asynchronous modes, НФП – open-phase modes.

The first component of expressions is a potential-possible effect on which pays off on distance relay protection, and the others – corresponding losses.

Further formation of components of technical effect for components distance relay protection from phase-to-phase faults for one of the line ends, for example, к=1 is resulted.

The first component of technical effect as having representative enough statistics at faults on a protected line is defined by expressions.

$$\text{p}(\text{А}_{№}^{с,м}) = \omega_{№}^{(2,3,4)}.\text{m}(T^{с,м}),$$

$$\omega_{№}^{(2,3,4)} = \omega_{№} - \omega_{№}^{(1)} = [\omega_{у} - \text{p}(\text{K}1)].\frac{l_{№}}{100},$$

Where $\omega_{№}^{(2,3,4)}$ – parameter of flow phase-to-phase faults,

$\omega_{№}^{(1)}$ – parameter of flow single-phase faults,

$\omega_{у}$ – specific parameter of flow faults on 100 km of the line length, which depends on a class voltage of the network,

$\text{p}(\text{K}1)$ – average value of probability single-phase faults in high-voltage networks,

$l_{№}$ – length on km of a protected line,

$\text{m}(T^{с,м})$ – average duration of detection and switching-off faults for c-th step at phase-to-phase faults.

Other components (losses) are defined by product of conditional probability of interesting loss under condition of a corresponding condition on unconditional probability of this event:

–Probability refusals of work $\text{p}(\text{О}_{№,1}^{с,м})=\text{p}(\text{О}_{№,1}^{с,м}/\text{А}_{№}^{с,м})\text{p}(\text{А}_{№}^{с,м})$;

–Probability false action at asynchronous modes

$$\mathrm{p}(\text{Л}^{\text{ар}}_{№,1})=\mathrm{p}(\text{Л}^{\text{ар}}_{№,1}/\text{АР}_{№})\mathrm{p}(\text{АР}_{№})\ ;$$

$$\mathrm{p}(\text{АР}_{№})=\omega^{\text{ар}}_{№}\mathrm{m}(T^{\text{алар}}_{№})\ ,\ \omega^{\text{ар}}_{№}=\frac{1}{\mathrm{m}(T_{\text{мар}})}\ ;$$

where $\text{АР}_{№}$ – event of an asynchronous mode on a protected line,

$\omega^{\text{ар}}_{№}$ – flow parameter in the offer exponential PLD time between these events,

$T_{\text{мар}}$ – average duration between observable events of asynchronous modes occurrence,

$T^{\text{алар}}_{№}$ – average duration (setting time) actions of automatics of liquidation asynchronous mode (АЛАР);

–Probability excessive action

$$\mathrm{p}(\text{И}^{\text{с,м}}_{№,1})=\sum_{\text{п}=1}^{n_{\Pi}}[\frac{1}{2}\mathrm{p}(\text{Д}^{\text{с,м}}_{\Pi,1}/\text{ВК}^{№,1}_{\text{п}})+\mathrm{p}(\text{О}^{\text{с,м}}_{\text{п},1}/\text{ВК}^{№,1}_{\text{п}})]\mathrm{p}(\text{ВК}^{№,1}_{\text{п}})\ ,$$

where $\mathrm{p}(\text{Б}^{\text{с,м}}_{№,1})$ – probability absence of blocking c-th step from phase-to-phase faults distance relay protection №, 1, for example, the first step distance relay protection i.e. $\mathrm{p}(\text{Б}^{\text{I,м}}_{№,1})$;

$\frac{1}{2}\mathrm{p}(\text{Д}^{\text{с,м}}_{\text{п},1}/\text{ВК}^{№,1}_{\text{п}})$, $\mathrm{p}(\text{О}^{\text{с,м}}_{\Pi,1}/\text{ВК}^{№,1}_{\text{п}})$ – conditional probabilities excessive actions c-th step of a component of protection №, 1 at faults (ВК_{Π}) on the previous П-th element and at action and refusal c-th step of component П, 1 previous element;

$\mathrm{p}(\text{ВК}^{№,1}_{\text{п}})$ – probability condition faults on П-th previous element getting to an operative range c-th step of the considered component №, 1;

–probability false action in service conditions

$$\mathrm{p}(\text{Л}^{\text{э}}_{№,1})=\mathrm{p}(\text{Л}^{\text{э}}_{№,1}/\text{Э})\mathrm{p}(\text{Э}).$$

Unconditional probability of the working condition is defined as probability of the opposite event all earlier specified conditions *i.e*.

$$\mathrm{p}(\text{Э})=1-\mathrm{p}(\text{А}^{\text{с,м}}_{№})-\mathrm{p}(\text{АР}_{№})-\sum_{\text{п}=1}^{n_{\text{п}}}\mathrm{p}(\text{ВК}^{№,1}_{\text{п}}).$$

The calculation forming probability excessive action requires the row of the motivations. Probability of the absence blocking the action of the steps to account of the endurance time at account only losses of the operation follows to take the equal zero since given probability is formed to account apparatus refusal only. However when blocking the action step-by-step protections under discrete endurance of time exist the periods, when time of the action step considered protection and steps of protection of the external entities coincide. Then exists work simultaneously protection on considered and external elements. This can be only at interaction of the steps with alike endurance of time. For such events follows to take the half of the events of the correct action step to previous line as excessive actions same time considered steps. For relay protections with hung by endurance of time under non calculation apparatus refusal absence of blocking impossible so probability of this event will always is a zero.

Probability of the conditions external faults $\text{p}(\text{ВК}_{\text{п}}^{№,1})$ are each step defined by border setting of considered relay protection № ,1 $z_{№,1}^{\text{с,м}}$ in coordinate of protection on seized relay protection № ,1 field of the previous element. Given border is defined through factor токораспределения between protection №, 1 and п, 1 moreover for relay protection from phase-to-phase faults can be used three-phase current faults, *i.e*.

$$z_{\text{гп}№,1}^{\text{с,м}} = (z_{№,1}^{\text{с,м}} - z_{№})k_{№,1\text{-п},1},$$

where $z_{№}$ – resistance to protectable line, but coefficient distribution $k_{№,1\text{-п},1} = i_{№,1} / i_{\text{п},1}$ between protection № ,1 and п,1 is defined by attitude three-phase current through these protection under faults on п-th previous element.

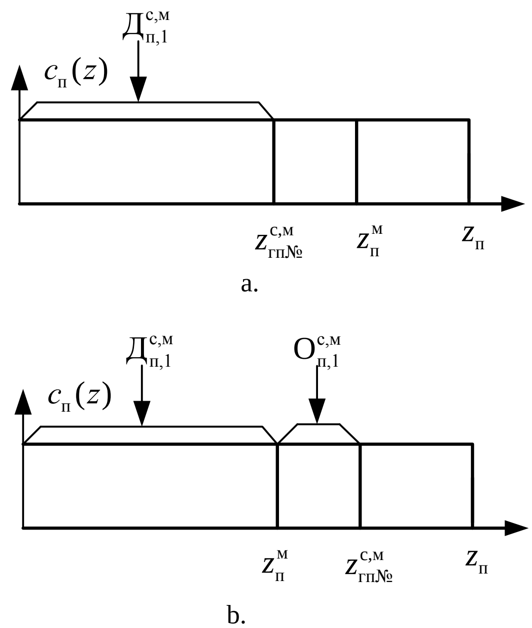

Figure 1

Probability $\text{p}(\text{ВК}_{\text{п}}^{№,1}) = \omega_{\text{п},№,1}^{\text{с,м}} \text{m}(T_{№,1}^{\text{с,м}})$ is defined by product of the parameter of the flow faults $\omega_{\text{п},№,1}^{\text{с,м}}$ defined by making in zone, which is seized on п-th previous element c-th step relay protection №,1 and average length of the action (the setting) this protection. The parameter of this flow $\omega_{\text{п},№,1}^{\text{с,м}}$ is defined by expression for п-th previous line:

$$\omega_{\text{п},№,1}^{\text{с,м}} = \omega_{\text{п},№,1} - \omega_{\text{п},№,1}^{(1)} = \omega_{\text{у}}[1 - \text{p}(\text{К}1)]\frac{l_{\text{п},№,1}}{100},$$

Where – a length in one kilometre (km), seized c-th step distance relay protection № ,1 on п-th previous element,

$\omega_{\text{у}}$ – resistivity on km length of previous line,

In the event that п-th previous element is transformer or autotransformer discussion flow parameter $\omega_{\text{п},№,1}^{\text{с,м}}$, can be found by expression:

$$\omega^{\text{с,м}}_{\text{п,№,1}} = \frac{z^{\text{с,м}}_{\text{гп№,1}}}{z_{\text{т}}} \omega^{\text{м}}_{\text{т}} ,$$

Where $z_{\text{т}}$ – between winding resistance of the transformer (autotransformer),

$\omega^{\text{м}}_{\text{т}} = [1 - \text{p(K1)}]\omega_{\text{т}}$ – a flow quantity phase-to-phase faults on transformer (autotransformer),

$\omega_{\text{т}}$ – a flow quantity faults transformer (autotransformer).

Conditional probability $\text{p}(\text{Д}^{\text{с,м}}_{\text{п,1}}/\text{ВК}^{\text{№,1}}_{\text{п}})$, $\text{p}(\text{О}^{\text{с,м}}_{\text{п,1}}/\text{ВК}^{\text{№,1}}_{\text{п}})$, under uniform PLD on space п-th previous element is defined by product PDD $c_{\text{п}}(z) = 1/z_{\text{п}}$ of uniform PLD and interval of the resistance positive sequence $z_{\text{п}}$ п-th previous element, which is defined by border c-th step of considered protection line №,1 and setting of step-by-step protection п,1 or protection with hard separation of the action area п-th previous element. For example, in the case of the п-th previous line:

if $z^{\text{с,м}}_{\text{гп№}} < z^{\text{м}}_{\text{п}}$ (fig.1a) $\text{p}(\text{Д}^{\text{с,м}}_{\text{п,1}}/\text{ВК}^{\text{№,1}}_{\text{п}}) = c_{\text{п}}(z).z^{\text{с,м}}_{\text{гп№}}$;

if $z^{\text{с,м}}_{\text{гп№}} > z^{\text{м}}_{\text{п}}$ (fig.1b) $\text{p}(\text{Д}^{\text{с,м}}_{\text{п,1}}/\text{ВК}^{\text{№,1}}_{\text{п}}) = c_{\text{п}}(z).z^{\text{м}}_{\text{п}}$

$$\text{p}(\text{О}^{\text{с,м}}_{\text{п,1}}/\text{ВК}^{\text{№,1}}_{\text{п}}) = c_{\text{п}}(z).(z^{\text{с,м}}_{\text{гп№}} - z^{\text{м}}_{\text{п}});$$

Where $z^{\text{м}}_{\text{п}}$ – a setting resistance relay protection on п-th previous element, moreover in the event that distance relay protection on this element $z^{\text{м}}_{\text{п}} = z^{\text{с,м}}_{\text{п,1}}$.

Similarly the algorithm for single-phase to ground of sets distance relay protection can be considered.

The presented algorithms were applying for the first step distance relay protection of the lines on Tyumen power systems (Russian Federation). Results are received:

A Technical effect first step distance relay protection at phase-to-phase faults $E^{\text{I,м}}_{\text{№,1}} = 35{,}9 \cdot 10^{-10}$.

A Technical effect first step distance relay protection at single-phase to ground faults $E^{\text{I,1}}_{\text{№,1}} = -132{,}45 \cdot 10^{-10}$.

Corresponding to technical efficiency at phase-to-phase faults $E^{\text{I,м}}_{\text{№,1*}} = 78{,}2\ \%$.

Corresponding to technical efficiency at single-phase to ground faults $E^{\text{I,1}}_{\text{№,1*}} = -116\ \%$.

The reception of the negative effect at single-phase to ground faults as can be seen from presented calculations, are conditioned much by large number false action, which can be reduced by way of changing setting value. The optimal setting values in both events exist at reduction setting value comparatively initial, equal resistance line. Follows to note the small specific gravity excessive action under taken factor of the adduction them to refusal work. Here with exists the evident dependency from amount and nomenclature of the previous connections that is not taken into account in accountable and reference statistics. Small is forming false action under asynchronous mode. The influence open-phase mode is taken into account at determination of probability of the working conditioned only, but at calculation of the technical effect is not taken into account in suggestion of the conclusion from work of distance relay protection by device single-phase recloser.

3. Conclusions

1. Presented probabilistic algorithm of setting distance relay protection on the networks, which is founded on quantitative measure of technical efficiency, allows to define the optimal setting value and evaluates the degree to objective usefulness chosen setting value, which is got by using expert-managing method or simply intuitive fixed by professional.

2. Offered probabilistic method allows optimum to set all channels of relay protections on network, as well as objective to value the possibility of the desired change setting value.

References

[1] A. M. Fedoseev, "Relay protections power system", M.:Energoatomizdat, **(1984)**. pp. 520.
[2] A. V. Shmoilov, "Probability technologies in electric power industry", Proc. 6-th Russian-Korean Intern. Symp. On Science and Technology KORUS-2002, vol. 2, **(2002)**, pp. 421-424.
[3] A. V. Shmoilov, L. V. Krivova, E. I. Stoyanov and K. V. Ignatiev, "Probabilistic method select of the borders interval data for electroenergetic problems", Proc. THE HIGH SCHOOL "Problems of energy, no. 7-8/1, **(2008)**, pp. 146-157.
[4] A. F. Prutik and A. V. Shmoilov, "Setting-up algorithms of relay protection", The Forth International Forum On Strategic Technology (IFOST 2009), **(2009)**, pp. 45-50.
[5] E. M. Schneerson, "Digital relay protection", - M. Energoatomizdat, **(2007)**, pp. 549.
[6] G. S. Nudelman and A. I. Shalin, "Microprocessor-based relay protection", News of electrical engineering, **(2008)**, pp. 74-79.
[7] A. F. Prutik, T. Minh and A. V. Shmoilov, "The selectivity and the technical efficiency of relay protection and automatics", Journal "Energy problems", **(2010)**, pp. 154-163.
[8] A. V. Shmoilov, "Probability technologies in electric power industry", Proc. 6-th Russian-Korean Intern, Symp. On Science and Technology KORUS-2002, Novosibirsk, vol. 2, **(2002)**, pp. 421-424.

Authors

Tran Hoang Quang Minh defended his PhD thesis at Tomsk Polytechnic University, Tomsk City, Russian Federation in 2012. The author's major fields of study are High-voltage Power System and Relay Protections. He is working as Lecturer in Faculty of Electrical and Electronic Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.

Nguyen Trung Thang received his M.Sc. from University of Technical Education, Ho Chi Minh City, Vietnam. The author's major fields of study are High-voltage Power System. He is working as Lecturer in Faculty of Electrical and Electronic Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.