International Journal of Control and Automation
Vol.8, No.12 (2015), pp.195-206
http://dx.doi.org/10.14257/ijca.2015.8.12.18

Algorithm and Recommendations for Setting Line Distance Relay Protection

Tran Hoang Quang Minh

Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
tranhoangquangminh@tdt.edu.vn

Abstract

In this paper author want to present new algorithm and recommendations for setting distance relay protection. This algorithm bases on technical effect criterion with using probability statistical method. Main approach is to study and develop technical effect criterion for selection of differential relay protection setting and technical efficiency criterion for estimating this setting. The probability statistical algorithms are used to calculate the above criteria.

Keywords: *Technical efficiency, technical effect, differential relay protection, electric network*

1. Introduction

In the modern world of relay protection (RP), due to electrical networks found metrological advances (inhibition of the currents, the configuration of the characteristics of operating in the complex plane of the resistance, the drop voltage negative and zero sequence on the lines), and circuit solutions almost entirely (differential relay protection) or partially (distance relay protection). These eliminated the refusals of work, false and excessive actions. For relay protection with the exchange information on operation between these ends of lines, the operation principles are spread on the principle of differential relay protection, and achieved similar performance. However, there is not small quantity class steps current and distance relay protection (first line), in which the property is a failure for external faults is achieved by temporary blocking system levels. These actions take place unrecoverable loss of functioning relay protection like: refusals of work, false and excessive actions. These actions are depending on the classification regime -switching states of the network, the types of faults, interference, generally expressed as a function of the selected setting [1,3,4,8-10].

The technical efficiency estimation of functioning relay protection (RP), as differences potentially possible effect in the form of an index of faults on protected object and losses (as: refusals of work, false and excessive actions) are carried to potential effect, is an actual problem for designing and operation relay protection of an electric equipment and electric networks. Therefore to this question the attention was always paid at the statistical analysis of features of relay protection work, for example [1,3]. 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, false actions at asynchronous modes, etc. are very 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

ISSN: 2005-4297 IJCA

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. 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.

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. In this paper this problems are analyzed, developed and solved with criterion technical efficiency and technical effect [2-4].

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 in 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 [6]. 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. PDD on each component or its heterogeneity part is inverse proportion to resistance of this part.

In this paper, the 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 into three components, which are caused by refusals of equipment, mistake servicing personnel and by functioning relay protection. In the given work last component (functioning relay protection) is considered, which is defined by different topology of a network, modes of sources, switching conditions, types faults, abnormal modes, etc., i.e. Such choice is made because a number of operational conditions can be changed the operational personnel at use of the same equipment. Hardware refusals depend on element base of manufacturers and devices and mistake servicing personnel depends on the qualification and psychological factors of people [5-7].

Parameter resistance from a relay protection installation place on the ends of a line to place fault is distributed on the most simple and with final concrete borders uniform probability distribution law (PDL) on space of each line and other components of the network. In connection with this algorithm of technical efficiency is constructed with obligatory preservation use of the uniform probability distribution law. 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. Under uniform law PDL on all element of the network appears the natural requirement to convert the borders of the stages distance protection lines in coordinate’s external (previous and adjacent) elements. Since in feeds continuously change, borders also change continuously. For accounting these changes in the calculation of technical efficiency, need to know the range of these boundaries, especially maximum and minimum values. These boundaries can be determined by converting the captured spaces (resistance) of the external elements through the current distribution coefficients between the protected line and the previous lines. Expressions of criteria technical effect and its components are given below:

1. For first zone (stage) of distance relay protection:

$$E^{\text{I}}_{\text{№}1} = \text{p}(\text{A}^{\text{I}}_{\text{№}}) - \text{p}(\text{O}^{\text{I}}_{\text{№}1}) - \sum_{1\text{p}i=1}^{n_{\text{p}}} \text{p}(\text{И}^{\text{I}}_{\text{№}1\text{-}1\text{p}i}) \qquad (1)$$

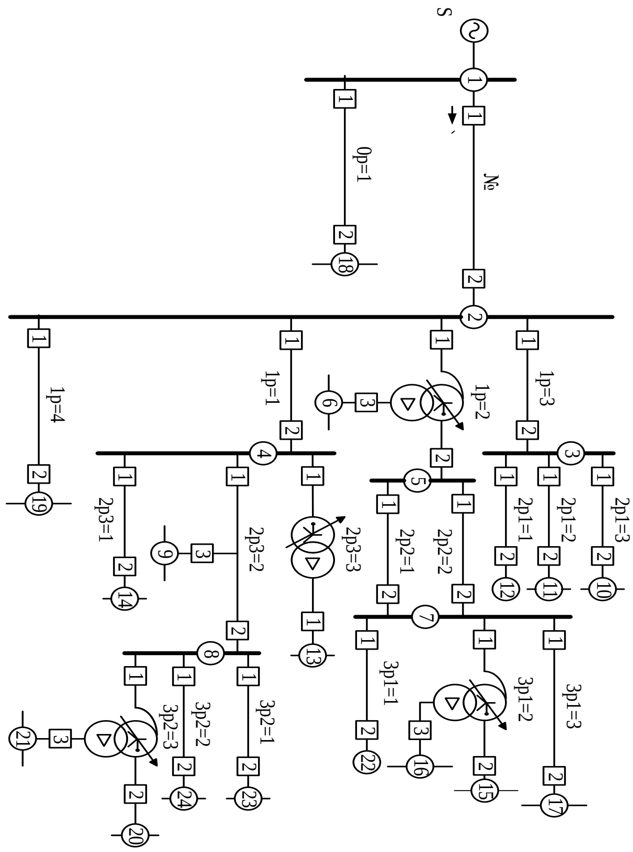

Figure 1. The Structure of a Given Network

2. For second zone (stage) of distance relay protection:

$$E^{II}_{\text{№}1} = p(A^{II}_{\text{№}}) - p(O^{II}_{\text{№}1}) - \sum_{1pi=1}^{n_p} p(И^{II}_{\text{№}1\text{-}1pi}) \tag{2}$$

3. For back-up zone (stage) of distance relay protection:
With Figure 1:

$$E^{III}_{\text{№}1} = p(A^{III}_{\text{№}}) + \sum_{1pi=1}^{n_{1pi}} p(A^{III}_{1pk}) - p(O^{III}_{\text{№}1}) - \sum_{1pk=1}^{n_{1pk}} p(O^{III}_{1pk}) - \sum_{jp=1}^{n_{jp}} \sum_{jpi=1}^{n_{jpi}} \sum_{jpik=1}^{n_{jpik}} p(И^{III}_{\text{№}1\text{-}jpik1}) \tag{3}$$

With Figure 3:

$$E^{III}_{\text{№}1} = p(A_{\text{№}}) + \sum_{p=1}^{n_p} p(A_p) - p(O^{III}_{\text{№}1}) - \sum_{p=1}^{n_p} p(O^{III}_p) - \sum_{p=1}^{n_p} \sum_{pp=1}^{n_{pp}} p(И^{III}_{\text{№}1p\text{-}pp}) \tag{4}$$

Where the lower indexes: № - protected line, p – previous lines (elements), pp – previous (elements) of previous lines (elements) (Figure 1, Figure 2). The letter p designates probabilities of events: A – faults on a protected line, O – operation refusals, И – excessive actions; I – first stage, II – second stage, III – back-up stages of line distance relay protection.

4. Probabilities Faults $p(A)$:

4.1. For the First Stage

$$p(A^{I}_{№}) = \omega_{№} m(T^{I}_{№}) \tag{5}$$

4.2. For the second stage

$$p(A^{II}_{№}) = \omega_{№} m(T^{II}_{№}) \tag{6}$$

Where $\omega_{№}$ – the flow parameter of interest fault types on the protected lines, $m(T^{I}_{№})$ и $m(T^{II}_{№})$ – average duration of detection (lock) fault channels of the first and second stages (substantially the setting time of the first and second stages).

4.3 And for back-up (third) stage

$$p(A^{III}_{№}) + \sum_{1pi=1}^{n_{1p}} p(A^{III}_{1pk}) = \omega_{№} m(T^{III}_{№}) + \sum_{1pi=1}^{n_{1p}} \omega_{1pk} m(T^{III}_{1pk}) \tag{7}$$

Where ω_{1pk} – the flow parameter of fault types on 1pk-th line,

$m(T^{III}_{№})$, $m(T^{III}_{1pk})$ – average duration of detection (lock) fault channels of the third stages (third stage time setting).

5. Excessive Actions

5.1. Excessive Actions of the First Stage Take Place in the External Fault

1) As a joint action with isochronous speed protections (the first stage, the protection on the differential principle) for faults on previous lines,
2) As refusals of the first stages on the previous lines.

Proceeding from the above, to the probability of excessive action of the first stage of the protected line should be show below:

$$\sum_{1pi=1}^{n_p} p(И^{I}_{№1\text{-}1pi}) = \sum_{1pi=1}^{n_p} [\frac{1}{2} p(Д_{№1pi} / ВК_{1pi}) p(ВК_{1pi}) + p(О_{№1pi} / ВК_{1pi}) p(ВК_{1pi})] \tag{8}$$

Where Д, О - joint action, refusals of protection for the 1pi-th elements, ВК – faults on the 1pi-th elements.

The definition of conditional probabilities of the joint action, refusals of the previous elements protections (first stage) are show in (9).

$$\begin{aligned} p(Д^{I}_{№1pi} / ВК_{p}) &= [p_{max}(Д^{I}_{№1pi} / ВК_{p}) + p_{min}(Д^{I}_{№1pi} / ВК_{p})] / 2 \\ p(О^{I}_{№1pi} / ВК_{p}) &= [p_{max}(О^{I}_{№1pi} / ВК_{p}) + p_{min}(О^{I}_{№1pi} / ВК_{p})] / 2 \end{aligned} \tag{9}$$

Where maximum (max) and minimum (min) are the maximum and minimum boundaries of the first stage (protection of the protected line) in the space of each the previous elements. Conditional probabilities are the formulas on the basis of uniform PDL resistance from the start of the previous element to the fault.

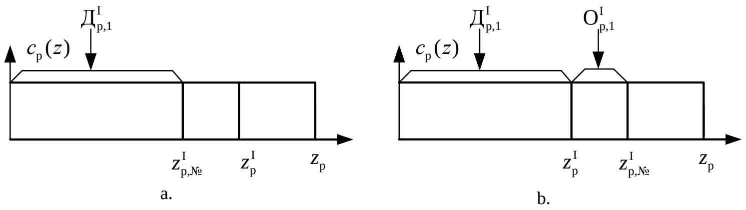

Figure 2. Excessive Actions of the First Stage

The unconditional probability of the external faults at 1pi-th previous elements $p(ВК_{1pi}) = \omega_{1pi} m(T^{I}_{1pi})$ determined by the product of the flow parameter fault on the previous line ω_{1pi} and the average duration of detection (lock) fault channels of the first stage (protection) of the previous line $m(T^{I}_{1pi})$.

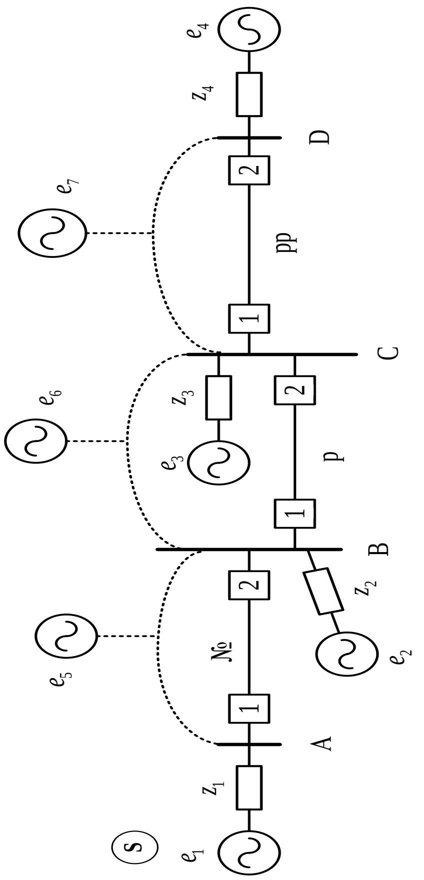

Figure 3. Scheme of Second Predetermined Network

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

$$z^{I}_{p,№,1} = (z^{I}_{№,1} - z_{№}) k_{№,1\text{-}p,1} \tag{10}$$

where $z_{№}$ – resistance to protectable line,

$k_{№,1\text{-p},1} = i_{№,1} / i_{\text{p},1}$ - current factor between protection № ,1 and p,1 is defined by attitude three-phase current through these protection under faults on p-th previous element. (Figure 3)

5.2. Excessive Actions of the Second Stage Take Place if the Setting is Selected on the Basis of Sensitivity. These losses are due to the action of the second stages isochronous protected and previous appearance of lines and areas of action the second stage of the protected line faults in the space of the previous short lines above the parameter response (measured resistance) range of the first stages of the lines and within their space (the action of the second stages preceding lines), and if the second coverage level line protected by short circuiting the space is more than the previous line coverage will be the second stage of the lines within their area (second speed earlier failures lines). Calculations done similar calculations for the first stage:

$$\sum_{1\text{p}i=1}^{n_p} \text{p}(И^{\text{II}}_{№1\text{-}1\text{p}i}) = \sum_{1\text{p}i=1}^{n_\text{p}} [\frac{1}{2}\text{p}(Д_{№1\text{p}i} / ВК_{1\text{p}i}) \\ \text{p}(ВК_{1\text{p}i}) + \text{p}(О_{№1\text{p}i} / ВК_{1\text{p}i})\text{p}(ВК_{1\text{p}i})] \quad (11)$$

The definition of conditional probabilities of the joint action, refusals of the previous elements protections (second stage) are show in (12).

$$\text{p}(Д^{\text{II}}_{№1\text{pi}} / ВК_\text{p}) = [\text{p}_{\max}(Д^{\text{II}}_{№1\text{pi}} / ВК_\text{p}) + \text{p}_{\min}(Д^{\text{II}}_{№1\text{pi}} / ВК_\text{p})] / 2 \\ \text{p}(О^{\text{II}}_{№1\text{pi}} / ВК_\text{p}) = [\text{p}_{\max}(О^{\text{II}}_{№1\text{pi}} / ВК_\text{p}) + \text{p}_{\min}(О^{\text{II}}_{№1\text{pi}} / ВК_\text{p})] / 2 \quad (12)$$

Where maximum (max) and minimum (min) are the maximum and minimum boundaries of the second stage (protection of the protected line) in the space of each the previous elements. Conditional probabilities are the formulas on the basis of uniform PDL resistance from the start of the previous element to the fault.

The unconditional probability of the external faults at 1pi-th previous elements $\text{p}(ВК_{1\text{p}i}) = \omega_{1\text{p}i}\text{m}(T^{\text{II}}_{1\text{p}i})$ determined by the product of the flow parameter fault on the previous line $\omega_{1\text{p}i}$ and the average duration of detection (lock) fault channels of the second stage (protection) of the previous line $\text{m}(T^{\text{II}}_{1\text{p}i})$.

5.3. Mechanism of excessive Actions of the Third Stages is Similar Formation of Excessive Action of the Second Stage. However, unlike the main stages in which the same names delay stages are almost identical, in meshed networks setting time of the back-up stages may be different: setting time of the back-up stage of considered protected line and back-up stages of the peripheral elements may be equal or greater than the considered back-up stage of the protected line stage. Therefore it is necessary to consider separately these cases mentioned by the time the interaction with all elements of the network:

$$\sum_{jn=1}^{n_{jn}} \sum_{jni=1}^{n_{jni}} \sum_{jnik=1}^{n_{jnik}} \text{p}(И^{\text{III}}_{№1\text{-}jnik1}) = \sum_{jn=1}^{n_{jn}} \sum_{jni=1}^{n_{jni}} \sum_{jnik=1}^{n_{jnik}} [\frac{1}{2}\text{p}(Д^{\text{III}}_{№1jnik1} / ВК_{jnik})\text{p}(ВК_{jnik}) \\ + \text{p}(О^{\text{III}}_{№1jnik1} / ВК_{jnik})\text{p}(ВК_{jnik})] \quad (13)$$

6. From above algorithm and methods of calculating technical effect for setting and technical efficiency for estimating quality setting of distance relay protection allowed recommending:

1) Setting options of second and third stages based on the sensitivity and starting from the minimum of excessive actions;

2) Setting the first stage by optimizing the technical efficiency, taking into account all the components of losses, setting of the first stage with an enhanced high-speed operation area. This reduces the complexity of choosing settings, and technical efficiency of the tool allows to choose the desired quality of the distance relay protection functioning.

3. Experimental

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

A Technical effect first stage distance relay protection at phase-to-phase faults $35{,}9 \cdot 10^{-10}$, corresponding to technical efficiency at phase-to-phase faults $78{,}2\ \%$.

A Technical effect first stage distance relay protection at single-phase to ground faults $-132{,}45 \cdot 10^{-10}$, corresponding to technical efficiency at single-phase to ground faults $-116\ \%$.

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 [8].

2. Second system: A numerical results with using the developed algorithms are shown below on the example of the calculation and analysis of distance relay protection line 220 kV Substation Surgust – Substation Contur (Distance relay protection on side of the substation Surgust) on one of the Russian power system. The topology of the analyzed area is shown in Figure 4. Line p1, p2 and p3 are previous lines (the first periphery); pp1 and pp2 lines are lines of second peripheral.

The settings of the first and second stages of the distance relay protection on the lines p1, p2, p3 are chosen by the guidelines [1,3]. For the considered № 1 distance relay protection №,1, setting the first and second stages are based on the high technical efficiency at the opposite end of the line №. The results of calculation technical efficiency by varying the settings are presented in the tables 1 and 2.

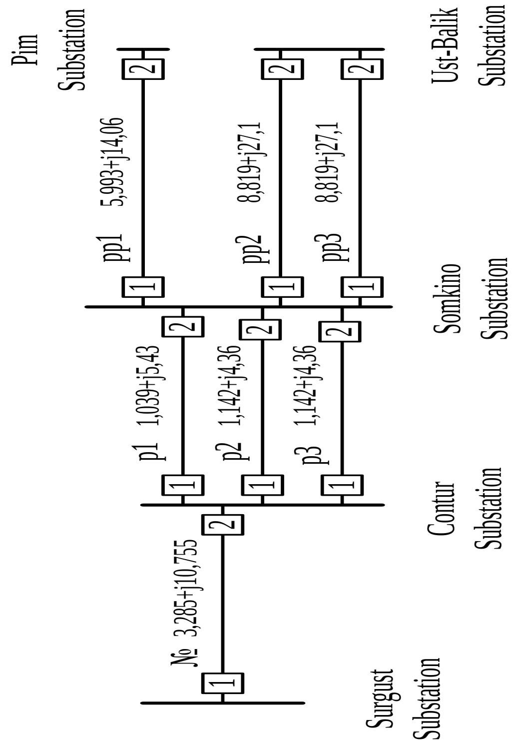

Figure 4. The Topology of the Analyzed Area

The numerical results under specific restrictions confirm derived from the phenomenological analysis of the findings of the maximum technical efficiency and its changes. It is evident that excessive actions in the second stage there are no set-point until it reaches the end of the first stages of previous lines and will not begin the second stage of action isochronous protect the protected line № 1 with the second stage of the protection p11, p21, p31 previous lines p1, p2 and p3. With these results, may be recommending:

1) Increase setting of the first stage to the resistance equal to resistance of all line or to near this value;

2) Setting of the second and third stages with the minimum of excessive actions, proceeding from their sensitivity. Positive values of technical efficiency, which are near to the one unit, are the highest technical quality of distance relay protection.

Table 1. The Numerical Results of Technical Efficiency by Varying the Setting of the First Stage Distance Relay Protection №,1

Setting of the first stage (Ohm)	Probability of refusals	Probability of excessive actions	Technical effect	Technical efficiency (%)
9,5	0,932.10-11	0	5,093.10-11	84,53
10	0,644.10-11	0	5,361.10-11	88,98
10,5	0,369.10-11	0	5,629.10-11	93,43
11	0,128.10-11	0	5,897.10-11	97,88
11,238	0	0	6,025.10-11	99,5

11,5	0	0,217.10-11	5,808.10-11	96,39
12	0	0,632.10-11	5,393.10-11	89,5
12,5	0	1,047.10-11	4,978.10-11	82,62
13	0	1,462.10-11	4,563.10-11	75,74

Table 2. The Numerical Results Of Technical Efficiency By Varying The Setting Of The Second Stage Distance Relay Protection №,1

Setting of the second stage (Ohm)	Probability of refusals	Probability of excessive actions	Technical efficiency (%)
14,048	0	0	99,6
14,5	0	0	99,44
15	0	0	99,16
15,5	0	0,25.10-10	96,22
16	0	0,559.10-10	91,55
16,5	0	1.10-10	84,9
17	0	1,44.10-10	78,26

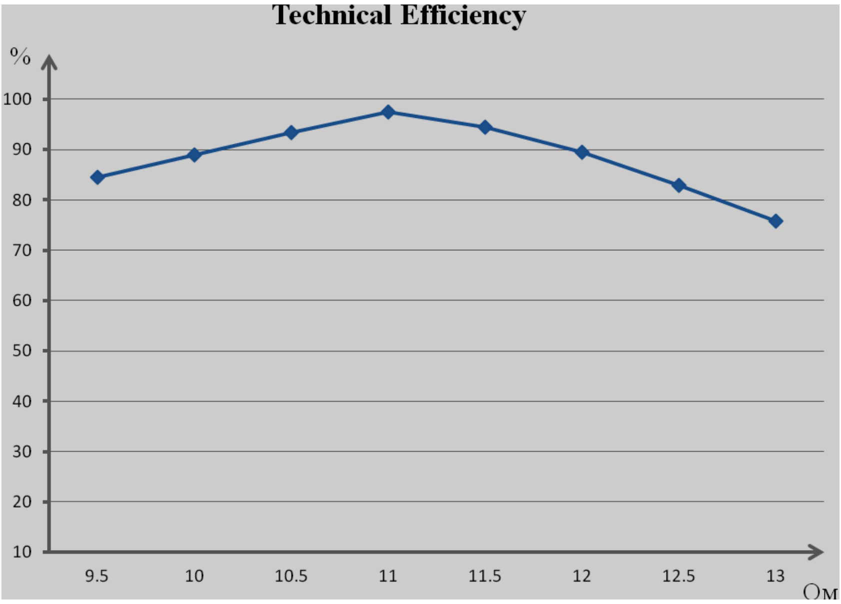

Figure 5. Technical Efficiency of First Stage (Distance Relay Protection of High-Voltage Line)

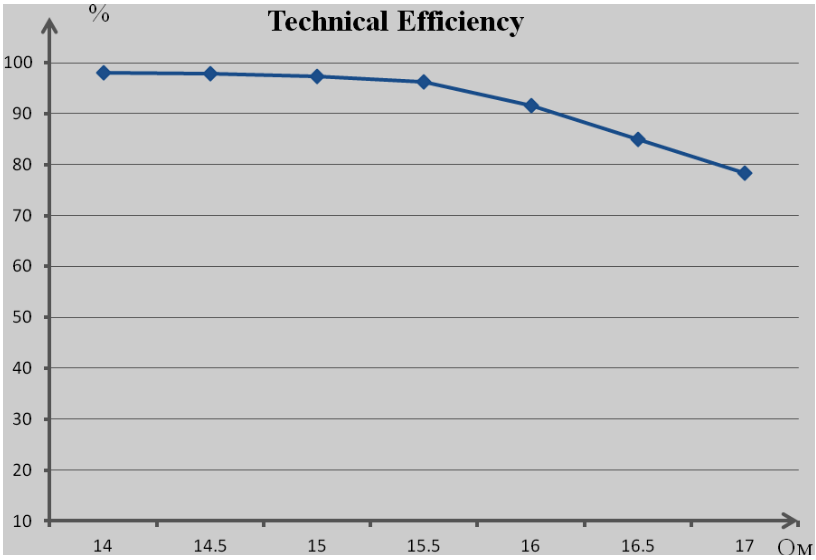

Figure 6. Technical Efficiency of Second Stage (Distance Relay Protection of High-Voltage Line)

4. Conclusion

The presented technical effect and efficiency criteria analysis of line distance protection stages allows:

1) recommending: 1) setting options of second and third stages based on the sensitivity and starting from the minimum of excessive actions; 2) setting the first stage by optimizing the technical efficiency, taking into account all the components of losses, setting of the first stage with an enhanced high-speed operation area. This reduces the complexity of choosing settings, and technical efficiency of the tool allows you to choose the desired quality of the distance relay protection functioning.

2) Positive values of technical efficiency near to the one unit are the highest technical quality of distance relay protection.

3) The development of the full program, which is realizing offered probabilistic algorithm of the setting of relay protection, will allow shortening or completely excluding the stale labor of the calculation setting value relay protection. Such program can serve the instrument for designing, usages and adjustments of relay protection and automatics.

4) Clear and objective criteria for determining time setting of the backup stage of distance relay protection of the hard-closed electrical network is excessive actions of technical efficiency, which allows choosing the optical option. In criteria of the technical effect and the technical efficiency of distance relay protection is necessary to include losses that accompany deformation characteristic resistance relay (which are used to achieve different interested effects).

References

[1] A. M. Fedoseev, “Relay protections power system”, M.:Energoatomizdat, **(1984)**, pp. 520.
[2] T. H. Q. Minh and A. V. Shmoilov, “Technical efficiency of line distance relay protection // The Fifth International Forum On Strategic Technology (IFOST 2010)”, Ulsan Korea, 2010. - Ulsan University of Technology, **(2010)**, pp. 335-340.
[3] A. F. Prutik Tran Minh and A. V. Shmoilov, “The selectivity and the technical efficiency of relay protection and automatics / / Journal “Energy problems”, **(2010)**, pp. 154-163.
[4] E. M. Schneerson, “Digital relay protection”, M. Energoatomizdat, **(2007)**, pp. 549.
[5] G. S. Nudelman and A. I. Shalin, “Microprocessor-based relay protection. News of electrical engineering”, **(2008)**, pp. 74-79.
[6] 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.

[7] 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.

[8] 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.

[9] Prutik A.F., Shmoilov A.V. Development of algorithms and software for relay protection setting / / Electricity, **(2009)**, pp. 19-26.

[10] 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.

Authors

Tran Hoang Quang Minh defended his PhD thesis at Tomsk Polytechnic University, Tomsk City, Russian Federation. 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 Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.

