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Setting Overcurrent Relay Protection with Using Statistical Algorithm

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Abstract

Among the relay protections, overcurrent relay protections have a large proportion. In this paper, technical effect of overcurrent relay protection settings (high-voltage lines) is proposed and analyzed. And then technical efficiency for estimating this setting is purposed and investigated. For both above criteria, the probability statistical algorithms are used to calculate. Finally base on these criteria, setting options and recommendations for setting of overcurrent relay protection is given.

Keywords*: Technical effect, technical efficiency, overcurrent relay protection, setting, criterion, criteria*

1. Introduction

In many years, probabilistic approaches, algorithms and methods for designing and setting of relay protection and automation are developed [1, 2]. The latest works of Fedoseyev A.M., Smirnov E.P. are based on the definition of efficiency of relay protection [3,4,5]. In these materials the concept technical efficiency relay protection is specified as the difference between the potentially possible effect p(A) (the probability of faults on the protected object, which is designed to eliminate the faults) and probability of losses P(Л). Losses of relay protections are formed as: 1) refusals of work p(O) when faults are in the protected object, 2) excessive actions P(И) when faults are in the external elements of the electrical network, 3) false actions P(Л) when there are no faults at all. False actions are possible in the working and abnormal modes. 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.

The most importing thing is analyzed and proposed recommendations for designing and setting relay protections. Technical effect of channels (stages) relay protection lines is calculated as the difference between potentially possible effect (the probability of faults on the protected line) and losses (the sum of the probabilities of refusals of work, false and excessive actions). And technical efficiency is quotient of technical effect to the potentially possible effect is a very full measure of the quality operation of relay protection. Introduction, description, formulas for determining the technical efficiency, technical effects and losses of distance relay protections high-voltage lines were presented in [1,2], and were developed in [8,9].

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The modern technical solutions in the construction equipment of relay protection (differential protection, protection of lines with the information exchange) practical completely eliminate these losses [6,7]. However large number of these losses has occurred in operating of overcurrent relay protection and distance relay protection. Then the new algorithm for each stages settings of these relay protections is necessary to provide and develop. For distance relay protection, analysis, algorithm and recommendation for their setting are provided in many works [8, 9, 10, 15 and 16]. In this paper analysis, algorithm and recommendations for setting overcurrent relay protection with using criterion technical efficiency are provided, analyzed, developed and calculated.

2. Main Part

2.1 Analysis Technical Efficiency of Overcurrent Relay Protection

To calculate the technical efficiency of overcurrent relay protection is needed setting values and probabilistic characteristics of regime (current distribution coefficients) for the transfer of electrical quantities at its own coordinates to the neighboring previous and related network elements. For this purpose it is necessary to provide and learn about analysis technical efficiency of overcurrent relay protections in electrical network. Developed a mathematical description of the technical efficiency and algorithms allows to produce mode-switching analysis of technical efficiency of the line overcurrent relay protection in the area of high-voltage network. This analysis (Figure 1) shows the dependence of the technical efficiency of the overcurrent relay protection on setting time and current setting and their relations with setting overcurrent relay protection on previous lines. The parameter of protected and previous lines in Figure 1 is displayed in the form of positive sequence resistance. The analysis for setting overcurrent relay protection is illustrated in Figure 1, which indicated:

S - The structure of the electrical network: 1) A, B, C, D - substation network; 2) protected line №, previous line p and the previous to previous line pp; 3) 1, 2 – circuit breakers at the ends of lines; 4) e_1 ... e_6 – electrical sources; 5) z_1, ..., z_4 – resistance of other electrical sources; 6) OC1, OC2 - bypass shunt connection of the protected and the previous p lines.

T - change of the current (y-axis i) through the protection №1, p1, pp1 for faults along the lines of the network (the x-axis - positive sequence impedance z_1) and temporal characteristics (second ordinate axis t) protection stages along the same lines as the weak bypass sources OC1 and OC2. Indicated on the curves and straight lines: 1) letter i - currents with lower indices: max - the maximum, and min - the minimum currents through protection №1, p1, due to regime-switching state on the network; 2) the letter i - current setting with lower indices: №1, p1 and superscripts: I, II, III, IV corresponding stages; 3) the letter t - setting the time with the same subscripts: №1, p1 and superscripts: I, II, III, IV stages; 4) the letters z_i with the same subscripts №1, p1 and superscripts: I, II, III, IV stages - display current settings in the coordinates of the positive sequence impedance z_1 lines.

E - Change in the technical efficiency of I, II, III, IV stages overcurrent relay protection №1.

The solid lines in Figure 1 shows the curves and straight lines for ordinary cases, setting protection levels, points, dotted line - in the case of ordinary transfer settings setting the second stage protection №1 short of the previous line. The network shows only line, not transformers and auto-transformers because these not fundamentally affect to the discussed setting.

Based on the above, setting the first stage overcurrent relay protection without communication channel and the second stage based on sensitivity is the best option. The second option of setting overcurrent relay protection without communication channel

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defined by setting of the second stage on the basis of sensitivity, and the first stage by optimizing technical efficiency. Setting back-up stages according to minimizing excessive action and technical efficiency.

2.2. Algorithm of Technical Efficiency

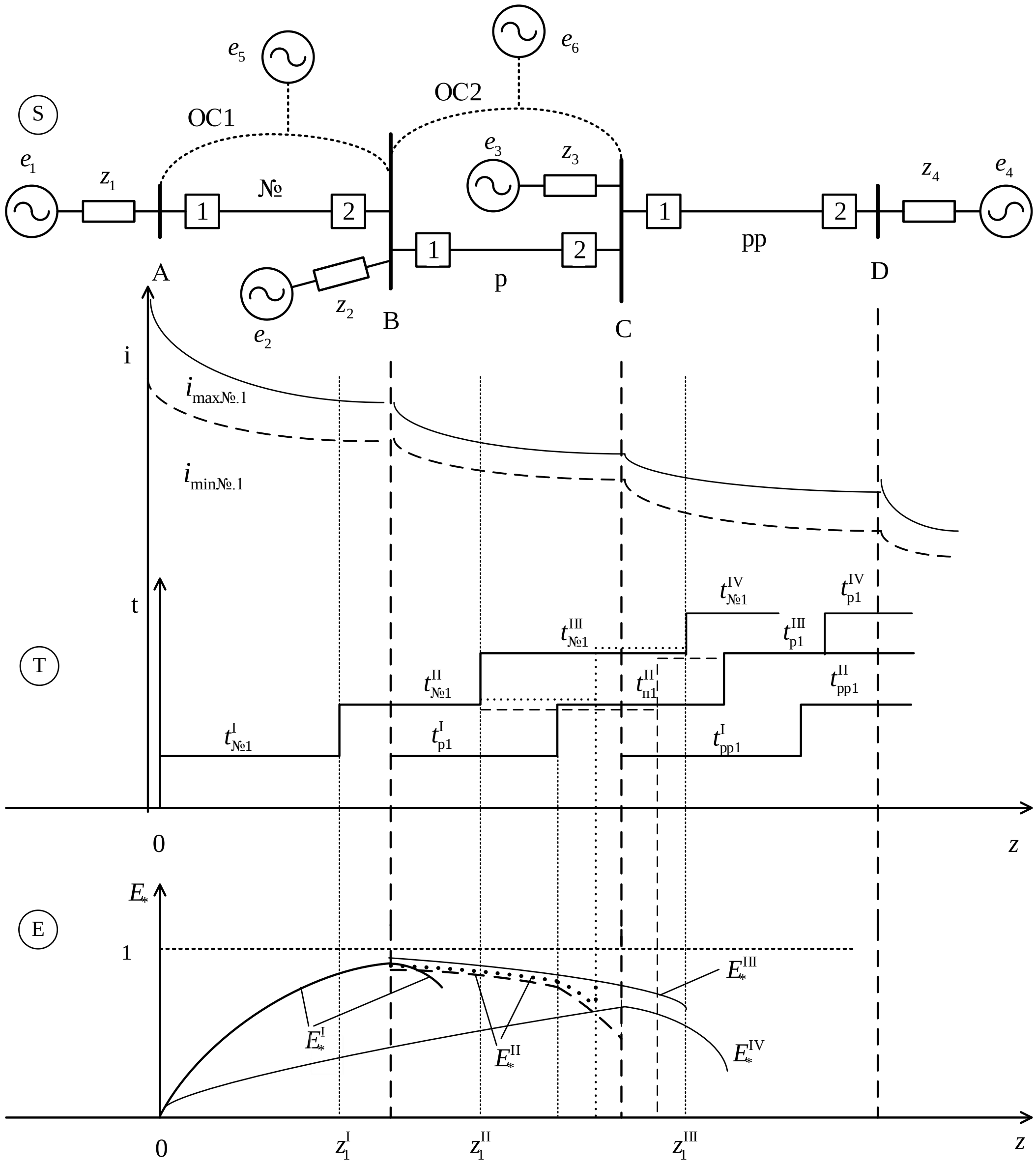

Figure 1. Scheme of a Predetermined Network

Technical effect and its components of overcurrent relay protection are given below:

$$\mathrm{E} = \mathrm{p(A)} - \mathrm{p(O)} - \mathrm{p(Л)} - \mathrm{p(И)} \tag{1}$$

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

1. For main stages of overcurrent relay protection:

$$\mathrm{E}_{№}^{\mathrm{m}} = \mathrm{p}(\mathrm{A}_{№}^{\mathrm{m}}) - \mathrm{p}(\mathrm{O}_{№}^{\mathrm{m}}) - \mathrm{p}(\mathrm{Л}_{№}^{\mathrm{m}}) - \sum_{i=1}^{n} \mathrm{p}(\mathrm{И}_{№\mathrm{pi}}^{\mathrm{m}}) \tag{2}$$

Where № - overcurrent relay protection, m – main stages.

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Probabilities faults $p(A^m)$ *:*

$$p(A^m_{№}) = \omega_{№} m(T^m_{№}) \tag{3}$$

Where $\omega_{№}$ – the flow parameter of interest fault types on the protected lines, $m(T^m_{№})$ – average detection fault duration of the main stages (substantially the setting time of main stages).

$$\omega_{№} = \omega^{(1,4)}_{№} = \left[p(1) + p(4)\right].\omega_0 . \frac{L}{100} \tag{4}$$

Where p(1) - the probability of a single-phase faults; p(4) - the probability of the two-phase ground faults; L - length of the line; ω_0 - the probability of faults on the 100 km line length.

Probabilities refusals of work.

$$p(O^m_{№}) = p(O^m_{№} / A^m_{№}).p(A^m_{№}) \tag{5}$$

Probabilities false actions.

$$p(Л^m_{№}) = p(Л^m_{№} / R^m_{№}).p(R^m_{№}) \tag{6}$$

Where R – type of the false actions

Excessive actions of the first stage:

$$\sum_{1pi=1}^{n_p} p(И^{I}_{№1\text{-}1pi}) = \sum_{1pi=1}^{n_p} [\frac{1}{2} p(Д_{№1pi} / ВК_{1pi}) p(ВК_{1pi}) + p(O_{№1pi} / ВК_{1pi}) p(ВК_{1pi})] \tag{7}$$

Where Д, O - joint action, refusals of protection for the 1pi-th elements, ВК – faults on the 1pi-th elements (Figure 2).

The definition of conditional probabilities of the joint action, refusals of the previous elements protections (first stage) are show in (7).

$$\begin{aligned} p(Д^{I}_{№1pi} / ВК_p) &= [p_{max}(Д^{I}_{№1pi} / ВК_p) + p_{min}(Д^{I}_{№1pi} / ВК_p)] / 2, \\ p(O^{I}_{№1pi} / ВК_p) &= [p_{max}(O^{I}_{№1pi} / ВК_p) + p_{min}(O^{I}_{№1pi} / ВК_p)] / 2 \end{aligned} \tag{8}$$

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. [11,12]

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 $m(T^{I}_{1pi})$.

Excessive actions of the second stage:

$$\sum_{1pi=1}^{n_p} p(И^{II}_{№1\text{-}1pi}) = \sum_{1pi=1}^{n_p} [\frac{1}{2} p(Д_{№1pi} / ВК_{1pi}) p(ВК_{1pi}) + p(O_{№1pi} / ВК_{1pi}) p(ВК_{1pi})] \tag{9}$$

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

$$\begin{aligned} p(Д^{II}_{№1pi} / ВК_p) &= [p_{max}(Д^{II}_{№1pi} / ВК_p) + p_{min}(Д^{II}_{№1pi} / ВК_p)] / 2, \\ p(O^{II}_{№1pi} / ВК_p) &= [p_{max}(O^{II}_{№1pi} / ВК_p) + p_{min}(O^{II}_{№1pi} / ВК_p)] / 2 \end{aligned} \tag{10}$$

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 (Figure 2). [11,12]

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The unconditional probability of the external faults at 1pi-th previous elements $\text{p}(\text{ВК}_{1\text{p}i}) = \omega_{1\text{p}i}.\text{m}(T^{\text{II}}_{1\text{p}i})$ 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 $\text{m}(T^{\text{II}}_{1\text{p}i})$.

2. For back-up stages of overcurrent relay protection:

$$E^{\text{b}}_{№1} = \text{p}(\text{A}^{\text{b}}_{№}) + \sum_{1\text{p}i=1}^{n_{1\text{p}i}} \text{p}(\text{A}^{\text{b}}_{1\text{pk}}) - \text{p}(\text{O}^{\text{b}}_{№1}) - \sum_{1\text{p}k=1}^{n_{1\text{p}k}} \text{p}(\text{O}^{\text{b}}_{1\text{pk}}) - \sum_{j\text{p}=1}^{n_{j\text{p}}} \sum_{j\text{p}i=1}^{n_{j\text{p}i}} \sum_{j\text{p}ik=1}^{n_{j\text{p}ik}} \text{p}(\text{И}^{\text{b}}_{№1\text{-jpik}1}) - \text{p}(\text{Л}^{\text{b}}_{№}) \tag{11}$$

Where the lower indexes: № - protected line, p – previous lines (elements), pp – previous (elements) of previous lines (elements) (Figure 1). The letter p designates probabilities of events: A – faults on a protected line, O – operation refusals, И – excessive actions.

Probabilities faults.

$$\text{p}(\text{A}^{\text{b}}_{№}) + \sum_{1\text{p}i=1}^{n_{1\text{p}}} \text{p}(\text{A}^{\text{b}}_{1\text{p}k}) = \omega_{№}\text{m}(T^{\text{b}}_{№}) + \sum_{1\text{p}i=1}^{n_{1\text{p}}} \omega_{1\text{p}k}\text{m}(T^{\text{b}}_{1\text{pk}}) \tag{12}$$

Where $\omega_{1\text{p}k}$ – the flow parameter of fault types on 1pk-th line, and $\text{m}(T^{\text{b}}_{№})$, $\text{m}(T^{\text{b}}_{1\text{pk}})$ – average duration of detection (lock) fault channels of the back-up stages (third and fourth stage time setting).

Probabilities refusals of work.

$$\text{p}(\text{O}^{\text{b}}_{№1}) + \sum_{1\text{p}k=1}^{n_{1\text{p}k}} \text{p}(\text{O}^{\text{b}}_{1\text{pk}}) = \text{p}(\text{O}^{\text{b}}_{№}/\text{A}^{\text{b}}_{№}).\text{p}(\text{A}^{\text{b}}_{№}) + \sum_{1\text{p}k=1}^{n_{1\text{p}k}} \text{p}(\text{O}^{\text{b}}_{1\text{pk}} / \text{A}^{\text{b}}_{1\text{pk}}).\text{p}(\text{A}^{\text{b}}_{1\text{pk}}) \tag{13}$$

Probabilities false actions.

$$\text{p}(\text{Л}^{\text{b}}_{№}) = \text{p}(\text{Л}^{\text{b}}_{№}/\text{R}^{\text{b}}_{№}).\text{p}(\text{R}^{\text{b}}_{№}) \tag{14}$$

Where R – type of the false actions

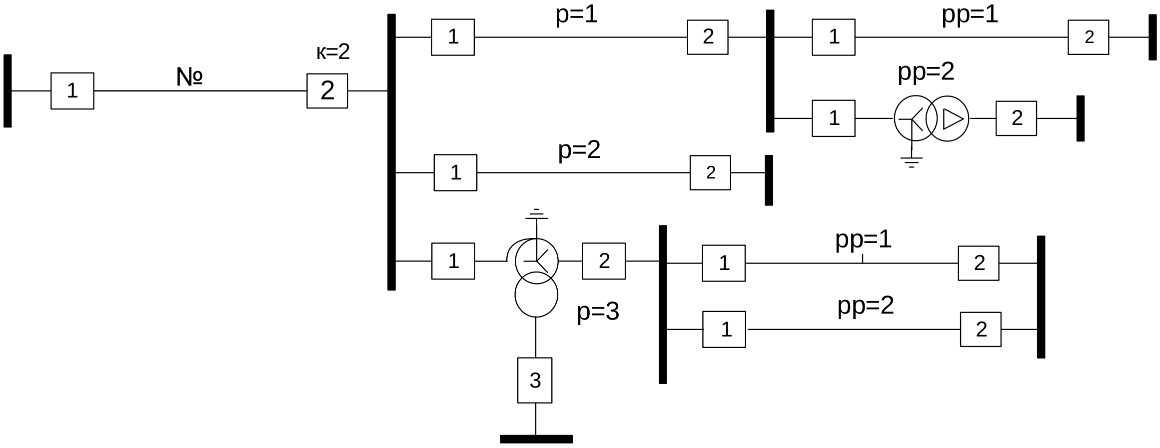

Figure 2. Scheme of a Predetermined Network

Mechanism of excessive actions of the back-up stages:

$$\sum_{jn=1}^{n_{jn}}\sum_{jni=1}^{n_{jni}}\sum_{jnik=1}^{n_{jnik}} p(И^{b}_{№1\text{-}jnik1}) = \sum_{jn=1}^{n_{jn}}\sum_{jni=1}^{n_{jni}}\sum_{jnik=1}^{n_{jnik}} [\frac{1}{2}p(Д^{b}_{№1jnik1} / ВК_{jnik})p(ВК_{jnik}) + p(О^{b}_{№1jnik1} / ВК_{jnik})p(ВК_{jnik})] \quad (15)$$

2.3. Numerical Results

A numerical results with using the developed algorithms and packet simulation program ARAM CZA (Russian Version) are shown below on the example of the calculation and analysis of distance relay protection line 220 kV Substation Surgust – Substation Contur (Overcurrent relay protection on side of the substation Surgust) on Russian power system. The topology of the analyzed area is shown in Figure 3. Line p1, p2 and p3 are previous lines (the first periphery); pp1 and pp2 lines are lines of second peripheral.

The settings of the overcurrent relay protection on the lines p1, p2, p3 are chosen by the guidelines [1, 13, 14]. The maximum technical efficiency of overcurrent relay protection №,1 by varying the settings are presented in the Tables 1 and 2.

Numerical results show that: setting overcurrent relay protection with criterion technical efficiency is closed to and better than setting overcurrent relay protection with [13,14] (value technical efficiency is nearer to 1). For first and second stage, from the results setting value can choose setting value of overcurrent relay protection from maximum value of technical efficiency.

Table 1. Technical Efficiency of the Main Stages Overcurrent Relay Protection №,1

Stage	Setting value, A	Setting method	Technical efficiency	Sensitivity
I	2292	[13,14]	99,7881	$\frac{1203}{2292}=0,52$
I	1830	Criterion technical efficiency	99,8178	$\frac{1203}{2292}=0,65$
II	1706 (Optimal)	Criterion technical efficiency	99,8254	
II	1500	Criterion technical efficiency	99,7362	
II	1000	Criterion technical efficiency	80,7519	

Table 2. Technical Efficiency of the Back-Up Stage Distance Relay Protection №,1

Stage	Setting value, A	Setting method	Technical efficiency	Sensitivity
III	896	[13,14]	99,8727	$\frac{1203}{2292}=1,34$
III	360	Criterion technical efficiency	99,8913	$\frac{1203}{2292}=3,34$
IV	127	Criterion technical efficiency	99,9439	

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2.4. Recommendations for Setting

On the basis of the analysis and criterion technical efficiency, the method of selecting the settings presented below in the form of customization options. The choice of a particular variant is due to the technical capabilities of its implementation and economic considerations.

a) Main stages:

Option 1: In the previous short lines (short lines of the first periphery) is set relay protection with the information exchange at the ends of these lines (Relay protection with absolute selectivity) [1,2]. Then, setting the second stages of the protected line may not be consistent with the previous lines, and it is selected on the basis of the conditions of sensitivity.

Option 2: On all lines of electrical network set overcurrent relay protection with absolute selectivity [13]. Wherein the second stage are reserved for relay protection with absolute selectivity. Settings such steps clearly and logically selected based on the sensitivity or high technical efficiency.

Option 3: The second stage are selected with sensitivity and the first stage with maximum technical efficiency.

b) Back-up stages:

Setting back-up stages of overcurrent relay protection can be carried out both on the basis of the criterion of technical efficiency, and on the basis of its components - the minimum probability of excessive operations.

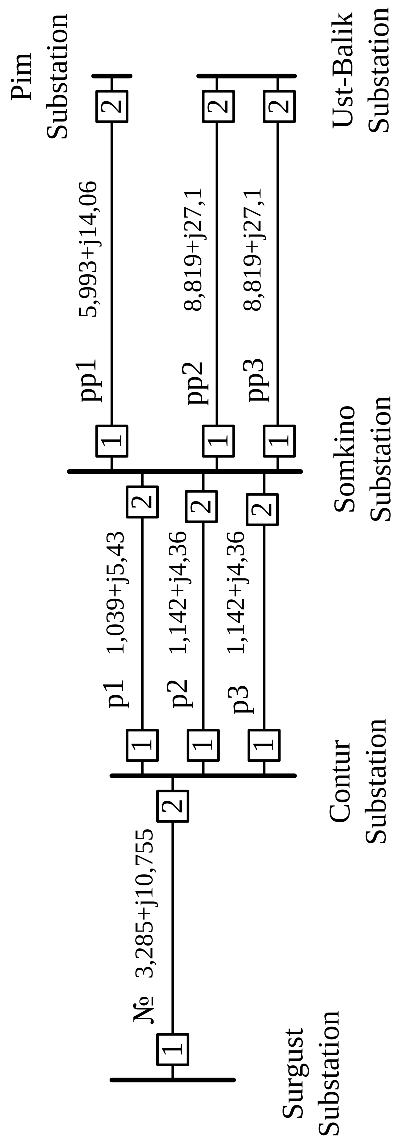

Figure 4. The Topology of the Analyzed Area

3. Conclusion

The main results obtained in the paper are as follows:

1. Analysis technical efficiency of overcurrent relay protection in connection with electrical network regime is given.

2. In connection with the criterion of technical efficiency, the mathematical description of the technical efficiency of overcurrent relay protection is designed.

3. Based on regime analysis and mathematical description of the technical efficiency, setting options and recommendations are proposed.

4. Numerical results in the paper is closed to and better than the results from the analysis and the setting guide.

5. For future research, full mathematical algorithm and automatic program for setting and estimating setting of overcurrent relay protection is necessary to propose, develop and apply on electrical network.

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