오차확률 가반 송전계통 보호계전기 보호도 평가방법 연구

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Protectability Evaluation of Distance Relay based on a Probabilistic Method for Transmission Network

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Abstract - This paper defines a concept of "protectability" for the performance evaluation of distance relay considering its sensitivity and selectivity. The paper starts from the probabilistic modeling of the errors, and based on this model, a detailed explanation of protectability calculation for each zone of the distance relay is presented. An effect of the Weighting Rate and the Measurement Deviation on the protectability evaluation is also given. By considering this effect, the optimization of relay setting can be realized. The proposed method is applied to a typical model system to show its effectiveness.

1. INTRODUCTION

For transmission system, distance relay plays a very importance role. Reports on the blackout showed that because of the hidden failure of the relay system, backup distance relay mis-operation is one of the main cases. Many works on the adaptive distance relay setting were presented to meet the practical needs [1, 2, 3].

"Protectability" was proposed to indicate the protection level of the system or how good the protection system is, given a certain set of settings [4, 5].

In this paper, protectability is defined by considering the measurement errors and its evaluation was proposed based on a probabilistic method for the distance relay.

2. PROBABILITY BASED PROTECABILITY EVALUATIN METHOD

2.1 Protectability Definition and probabilistic modeling

2.1.1 Protectability Definition

Protectability is an index to denote the protection level of both a single element and the whole system under current relay setting and variable system conditions. For distance relay, protectability is defined including two parameters:

1) Sensitivity: the ability to operate for the fault within its protection zone. Here, we take it to describe the probability to trip correctly for the fault within its zone.

2) Selectivity: the ability not to operate for the fault without its protection zone. Here this index is considered to describe coordination of relays.

2.1.2 Protectability Definition

There are errors in the measurement of the apparent fault distances. They were modeled by uniform probability distributions, and the combination yields an approximate Gaussian function[6].

If single ground fault happens, its ideal fault distance can be calculated by:

$$Z_L = \frac{V_A}{I_A - I_0 \times (\frac{Z_0 - Z_1}{Z_1})} \quad (1)$$

$$Z_M = \frac{V_{Am}}{I_{Am} - I_{0m} \times (\frac{Z_{0m} - Z_{1m}}{Z_{1m}})} \times (1 \pm 5\%) \quad (2)$$

$$Z_{error} = \frac{Z_M - Z_L}{Z_L} \times 100[\%] \quad (3)$$

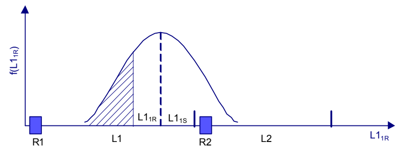
Because of the errors, setting L_S has an effective reach L_R which accords with a Gaussian Probability Distribution.

$$f(L_R) = \frac{1}{\sqrt{2\pi}\,\sigma} exp\left[-\frac{(L_R - L_S)^2}{2\sigma^2}\right] \quad (4)$$

2.2 Protectability Evaluation

2.1.1 Protectability of Zone1

Zone1 of distance relay is aimed to protect its own line, and not overreach the faults beyond the ending bus.



<Fig.1> Correct Trip Probability for Fault in L1

With setting $L1_S$, effective reach is $L1_R$, with a deviation σ_1, zone 1's probability density is:

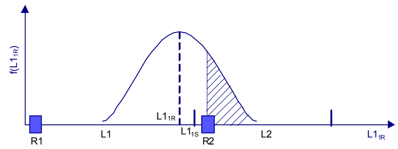
$$f(L_{1R}) = \frac{1}{\sqrt{2\pi}\,\sigma_1} exp\left[-\frac{(L_{1R} - L_{1S})^2}{2\sigma_1^2}\right] \quad (5)$$

Fault located at $l < L1_R$ (shaded area) can be tripped correctly, so conditional probability of correct fault tripping at l can be defined by:

$$P(l|l < L1_R) = \int_l^{+\infty} f(L1_R)\,dL1_R \quad (6)$$

Fault location l is itself a random variable with probability density function $P(l) = 1/L1$. zone1's sensitivity can be defined as:

$$F_1(L1_S) = \frac{1}{L1}\int_0^{L1} P(l|l < L1_R)\,dl \quad (7)$$



<Fig.2> Correct Trip Probability for Fault in L1

With setting $L1_S$, for the fault at length l, zone1 would not trip the fault when effective reach $L1_R < l$. So its conditional probability of un-tripping fault in L2 and the selectivity of zone1 are shown as:

$$P(l|l > L1_R) = \int_0^l f(L1_R)\,dL1_R \quad (8)$$

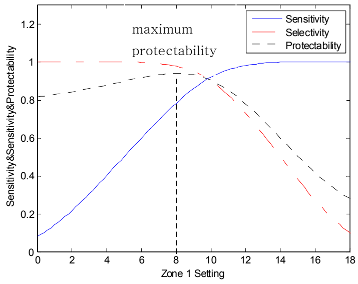
$$F_2(L1_S) = \frac{1}{L1}\int_{L1}^{L1+L2} P(l|l > L1_R)\,dl \quad (9)$$

The objective function of protectability is given as follows:

$$F(L1_S) = \omega_1 F_1(L1_S) + \omega_2 F_2(L1_S) \quad (10)$$

with $F_1(L1_S)$ is the sensitivity of zone1 $F_2(L1_S)$ is the selectivity. ω_1 and ω_2 are the weighting factors $\omega_1 + \omega_2 = 1$.

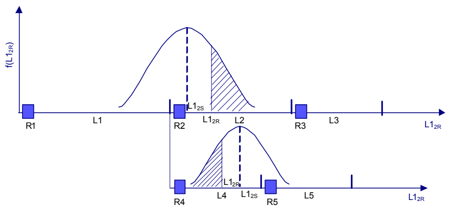
Seen from Fig.3, with an increasing setting, the sensitivity which means the probability to trip all fault in L1 would also increase. but the selectivity which means the probability of mis-tripping the fault in the next lines would increase. The point of maximum protectability corresponding to the optimal setting.



<Fig.3> Sensitivity, Selectivity and ㅐrotectability of Zone1

2.1.2 Protectability of Zone2

Zone2 has two requirements to fulfill: 1) to guarantee the protection of its own line beyond the setting of zone 1, and 2) to provide the maximum fast back up for the neighbor lines starting at the end bus, without superposing zones 2 of their own primary relays[6]. Sensitivity of zone2 shares the same meaning with zone1, indicating the performance for the fault in line1. Selectivity means for the faults overreach setting $L1_{2S}$, but within reach of zone1 in next line.



<Fig.4> Mis-Trip Probability of R1 and Un-Trip Probability of R2, R4

Seen from Fig.11, Zone 2 of R1 should not mis-trip the fault which the zone1 of Relay 2 and R4 un-tripped. So two parts would be included:

The mis-trip conditional probability of zone 2 of relay1:

$$P(l|l < L1_{2R}) = \int_{l}^{+\infty} f(L1_{2R})dL1_{2R} \tag{11}$$

The un-trip conditional probability of zone1 of neighboring relay2 and relay 4:

$$P(l|l > L2_{1R}) = \int_{0}^{l} f(L2_{1R})dL2_{1R} \tag{12}$$

$$P(l|l > L4_{1R}) = \int_{0}^{l} f(L4_{1R})dL4_{1R} \tag{13}$$

So the incorrect probability is:

$$P_{in} = P(l|l < L1_{2R}) \times (K1 * P(l|l > L2_{1R}) + K2 * P(l|l > L4_{1R})) \tag{14}$$

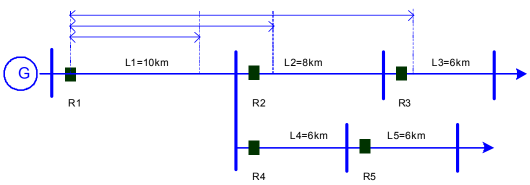
Here, $K_1 = L2/(L2+L4)$, $K_2 = L4/(L2+L4)$

$$F_2(L1_{2S}) = \frac{1}{L2}\int_{L1}^{L1+L2}(1-P_{in})dl \tag{15}$$

2.1.2 Protectability of Zone3

Traditionally, zones 3 of distances relays have the goal of providing back up to all the neighbor lines connected to their ending buses. Zone3 is decided to provide the maximum back to the neighbor lines, but without intersecting the zones 3 of their own primary relays. Its sensitivity has the same meaning. Selectivity calculation is similar to what was done for zone2, but a larger set of computation.

2.3 Case Study



<Fig.5> Model System

Setting data and evaluation results for R1 are shown in Table.1 L_{AVE} means the traditional setting length, L_{MAX} denotes the length with maximum protectability, L_{MIN} means for the length with minimum protectability, L_{MIS} the mis-setting length. And σ=20 %*(Line Length). P means the protectablility corresponding to setting length, k is defined as normalized protection factor, calculated by:

$$k = \frac{P - P_{MIN}}{P_{MAX} - P_{MIN}} \tag{16}$$

<Table 1> Evaluation Results for Model System

R1	Setting	Length	P	k
Zone1	L_{MAX}	8	0.9400	1
	L_{MIN}	0	0.8160	0
	L_{AVE}	8	0.940	1
	L_{MIS}	7	0.9304	0.9226
	L_{MIS}	9	0.9325	0.9395
Zone2	L_{MAX}	11.4	0.9351	1
	L_{MIN}	18	0.8200	0
	L_{AVE}	12	0.9326	0.9783
	L_{MIS}	11	0.9335	0.9861
	L_{MIS}	12	0.9190	0.8527
Zone3	L_{MAX}	18.2	0.9511	1
	L_{MIN}	24	0.8213	0
	L_{AVE}	19.6	0.9364	0.8867
	L_{MIS}	18.8	0.9489	0.9831
	L_{MIS}	20.4	0.9166	0.7342

3. Conlusion

In this paper, a probabilistic model for the errors in the distance relay setting is presented, and a concept of "protectability" which indicates the protection degree of each element of the relay is proposed. Protectability is got through an objective function with given weighting rate by considering about the practical need of two index including sensitivity and selectivity. A full description of the developed procedures and the analysis of their results are also presented.

The concept of "protectability" can be used not only for checking the protection degree of the current system setting but also for the system setting optimization. This method would provide a good reference to the system setting optimization.

[Acknowledgements]

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[Reference]

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