Analysis of an Adaptive Overcurrent Relay for Transmission and Distribution Lines

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***Abstract* – This paper presents an adaptive overcurrent relay based on the principle of phase-to-phase differential currents, denominated as $\dot{I}_{AB}$, $\dot{I}_{BC}$ and $\dot{I}_{CA}$, to detect phase fault of transmission and distribution line. The characteristics of phase-to-phase differential currents under phase fault condition are analyzed. The trip criterion and coordination principle are described. This relay is adaptive to the type of phase fault, the operating conditions of power system and the disconnection of PT. It can also provide an adaptive backup protection for the secondary-side overcurrent relay of a delta-wye transformer. Comparing with conventional overcurrent relays, this relay has a larger zone of protection and higher sensitivity. Transient simulation results are presented, too.**

Keywords – overcurrent relay, adaptive protection, phase-to-phase differential current, line protection

I. INTRODUCTION

By far, the most commonly used protective relays are the overcurrent relays (OCR). They could be classified by operating quantities including individual phase, residual, and negative-sequence current. They are used as both primary and backup protective devices and are applied in every protective zone in the system [1,2].

Phase overcurrent protection is widely applied as line protection for the purpose of saving fuse, minimizing equipment damage, enhancing coordination, limiting outage time and voltage dip duration, et al [3]. To coordinate with downstream protections, it must be set to a magnitude greater than the full-load current [4]. This may decrease the sensitivity of overcurrent relays.

Unlike phase overcurrent relays, negative sequence overcurrent elements do not respond to balanced load current. So, it can be set below load current levels [5]. There is a drawback that it can't respond to balanced three-phase fault.

Using the adaptive setting capabilities, many microprocessor-based devices can optimize settings of overcurrent relays. With this feature, settings can be changed to comply with actual system operating conditions rather than being set on the worst-case condition [6]. But the above problems are still unresolved.

In this paper, an adaptive overcurrent relay is designed to detect phase faults by measuring the phase-to-phase differential currents (PDC), denominated as $\dot{I}_{AB}$, $\dot{I}_{BC}$ and $\dot{I}_{CA}$. Analysis shows that the maximal magnitude of the three PDC can indicate fault condition and it will not be influenced by the type of short-circuit fault. So it's unnecessary to calculate settings on the worst-case condition. It does not respond to normal load current so it can be set below load current levels. Moreover, when phase fault occurs in the secondary side of a delta-wye transformer, the PDC in the primary side are in direct ratio to those in the secondary side. Thus the coordination can be simplified. The sensitivity can be improved, too.

II. CHARACTERISTICS OF THE PDC AND THE OPERATION CRITERION OF OVERCURRENT RELAY BASED ON PDC

The three phase currents flow through the protective device are $\dot{I}_A$, $\dot{I}_B$ and $\dot{I}_C$. Then the PDC can be defined as:

$$\begin{cases} \dot{I}_{AB} = \dot{I}_A - \dot{I}_B \\ \dot{I}_{BC} = \dot{I}_B - \dot{I}_C \\ \dot{I}_{CA} = \dot{I}_C - \dot{I}_A \end{cases} \quad (1)$$

Their amplitudes can be defined as:

$$\begin{cases} I_{AB} = \left|\dot{I}_{AB}\right| \\ I_{BC} = \left|\dot{I}_{BC}\right| \\ I_{CA} = \left|\dot{I}_{CA}\right| \end{cases} \quad (2)$$

A. Characteristics of the PDC In Single-source Power System

1) Single-source Power System with Load

To analyze the characteristics of the PDC, a typical single-source power system is shown in Fig. 1. It is an ineffectively grounded system so that only phase fault is considered. The protection device is installed at bus M. The system parameters are labeled in Fig. 1. It's assumed that the positive-sequence impedance of electrical apparatus is equal to their negative-sequence impedances. That is to say that the equivalent source impedance on the left side of bus M is represented as $Z_{SM} = Z_{SM1} = Z_{SM2}$. The three phase potentials of bus M are represented by $\dot{E}_{MA}$, $\dot{E}_{MB}$ and $\dot{E}_{MC}$. The sequence impedances of the line under protection are represented by $Z_L = Z_{L1} = Z_{L2}$. The sequence impedances of line segment from bus M to the fault location is $Z_l = Z_{l1} = Z_{l2}$. $Z_l^{'} = Z_L - Z_l$. The balanced load impedance is $Z'_{load} = Z'_{load1} = Z'_{load2}$.

When a phase-B-to-phase-C fault occurs on F, the sequence network is shown in Fig. 2. It can be derived that:

$$\begin{cases} \dot{I}_{AB} = \frac{\dot{E}_{MA}}{Z_{SM}+Z_l}[(\frac{3}{2}+\frac{\sqrt{3}}{2}j)-\frac{3}{2}\frac{Z_{load}}{Z'_\Sigma}] \\ \dot{I}_{BC} = -j\frac{\sqrt{3}\dot{E}_{MA}}{Z_{SM}+Z_l} \\ \dot{I}_{CA} = \frac{\dot{E}_{MA}}{Z_{SM}+Z_l}[(-\frac{3}{2}+\frac{\sqrt{3}}{2}j)+\frac{3}{2}\frac{Z_{load}}{Z'_\Sigma}] \end{cases} \tag{3}$$

Where $Z'_\Sigma = Z_{SM} + Z_l + Z_{load}$, $Z_{load} = Z'_l + Z'_{load}$.

Suppose that $Z_{SM} = jX_{SM}$, $Z_l = R_l + jX_l$, and $Z_{load} = jX_{load}$. Equation (4) can be deduced as below:

$$\begin{cases} I_{AB} < \sqrt{3}I_K^{(3)} \\ I_{BC} = \sqrt{3}I_K^{(3)} \\ I_{CA} < \sqrt{3}I_K^{(3)} \end{cases} \tag{4}$$

When three-phase fault occurs on F, there is $I_{AB} = I_{CA} = I_{BC} = \sqrt{3}I_K^{(3)}$.

That is to say that (5) exists when phase fault occurs in single-source system with load.

$$\max(|\dot{I}_{AB}|,|\dot{I}_{BC}|,|\dot{I}_{CA}|) \le \sqrt{3}I_K^{(3)} \tag{5}$$

2) Single-source no Load Power System

Assumes that the single-source power system (Fig. 1) operates in no load condition (Fig. 3) and fault occurs on F. Then $Z'_{load} = \infty$.

When a phase-B-to-phase-C fault occurs on F, the sequence network is shown in Fig. 4. It can be derived from (3) that:

$$\dot{I}_{AB} = \frac{\dot{E}_{MA}}{Z_{SM}+Z_l}[(\frac{3}{2}+\frac{\sqrt{3}}{2}j)-\frac{3}{2}] = \frac{\sqrt{3}}{2}j\frac{\dot{E}_{MA}}{Z_{SM}+Z_l},$$

$$\dot{I}_{BC} = \dot{I}_B - \dot{I}_C = -j\frac{\sqrt{3}\dot{E}_{MA}}{Z_{SM}+Z_l}$$

$$\dot{I}_{CA} = \frac{\dot{E}_{MA}}{Z_{SM}+Z_l}[(-\frac{3}{2}+\frac{\sqrt{3}}{2}j)+\frac{3}{2}] = \frac{\sqrt{3}}{2}j\frac{\dot{E}_{MA}}{Z_{SM}+Z_l}.$$

So, there is

$$\begin{cases} I_{AB} = |\dot{I}_{AB}| = (\sqrt{3}/2)I_K^{(3)} \\ I_{BC} = |\dot{I}_{BC}| = \sqrt{3}I_K^{(3)} \\ I_{CA} = |\dot{I}_{CA}| = (\sqrt{3}/2)I_K^{(3)} \end{cases} \tag{6}$$

When a three-phase fault occurs on F, it can be derived that $I_{AB} = I_{CA} = I_{BC} = \sqrt{3}I_K^{(3)}$.

Also, (5) exists when phase fault occurs in single-source no load system.

B. Operation Criterion of Overcurrent Relay Based on PDC

When phase fault occurs in single-source power systems, the fault currents flowing through the protective relay have following characteristics:

1) The magnitude of the PDC between two faulted phases is as $\sqrt{3}$ times as the magnitude of the phase current under three-phase short-circuit fault condition.
2) Among the three PDC, the magnitude of PDC between faulted phases has the maximum value.
3) Above relations will not be influenced by the type of phase fault.

In a word, (5) always exists. So, an overcurrent relay can be designed to detect phase fault by measuring the maximum of PDC. When the maximum exceeds the setting, the relay will operate. The zone of protection will not be affected by different type of phase fault. It is easy for setting and coordination, too. The operation criterion of this relay is descried in (7) and (8).

$$\max(|\dot{I}_{AB}|,|\dot{I}_{BC}|,|\dot{I}_{CA}|) \ge I_{op} \tag{7}$$

$$I_{op} = K_{rel}\left|\frac{\sqrt{3}\dot{E}_\phi}{Z_S+Z_L}\right| = K_{rel}\left|\frac{\dot{E}_l}{Z_S+Z_L}\right| \tag{8}$$

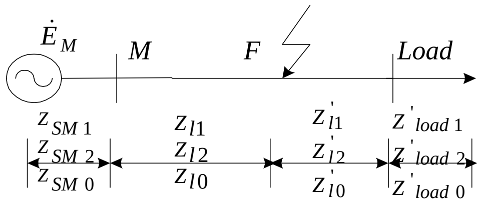

Fig. 1 Single source line with load

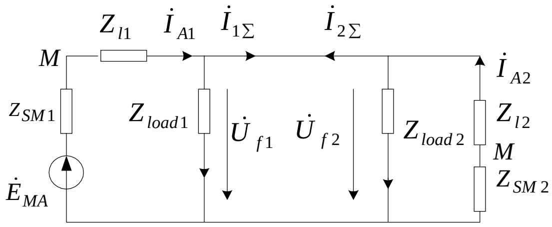

Fig 2. Sequence network under fault status of system in Fig. 1

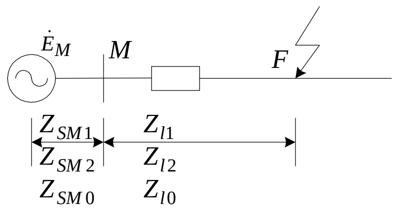

Fig. 3 Single source no load system

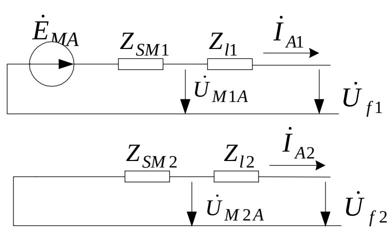

Fig. 4 Fault-condition sequence network of system in Fig.3

Where, K_{rel} is the coefficient to assure reliability, $\dot{E}_\phi$ is the phase potential of the equivalent source, $\dot{E}_l$ is the phase-to-phase potential of the equivalent source. The symbol Z_s represents the equivalent source impedance and Z_L the positive sequence impedance of the line to be protected. I_{op} is the setting of relay.

In some cases there is only two CTs for phase A and C, what is a common practice in ineffectively grounded system. In this system, there is $\dot{I}_B = -(\dot{I}_A + \dot{I}_C)$. So The PDC can be described as below:

$$\begin{cases} \dot{I}_{AB} = \dot{I}_A - \dot{I}_B = 2\dot{I}_A + \dot{I}_C \\ \dot{I}_{BC} = \dot{I}_B - \dot{I}_C = -\dot{I}_A - 2\dot{I}_C \\ \dot{I}_{CA} = \dot{I}_C - \dot{I}_A \end{cases} \tag{9}$$

The operation criterion is expressed as below:

$$\max(|2\dot{I}_A + \dot{I}_C|, |\dot{I}_A + 2\dot{I}_C|, |\dot{I}_C - \dot{I}_A|) \ge I_{op} \tag{10}$$

$$I_{op} = K_{rel} \left| \frac{\sqrt{3}\dot{E}_A}{Z_S + Z_L} \right| = K_{rel} \left| \frac{\dot{E}_l}{Z_S + Z_L} \right| \tag{11}$$

The symbols represent the same meaning as those defined in (7-8).

III. Adaptive Methods to Improve the Performance of the Overcurrent Relay Based on the Principle of PDC

Using adaptive impedance recognition can change relay settings to match them with power system conditions. With methods described below, the zone of protection can be extended, the sensitivity of protection can be increased, and the trip criterion and coordination principle can be simplified.

A. Recognition of Equivalent Source Impedance

Suppose that before fault occurs, the PDC are $\dot{I}_{AB}(0)$, $\dot{I}_{BC}(0)$ and $\dot{I}_{CA}(0)$. And the phase-to-phase voltages are $\dot{U}_{AB}(0)$, $\dot{U}_{BC}(0)$ and $\dot{U}_{CA}(0)$. After fault occurs, the PDC are $\dot{I}_{AB}(t)$, $\dot{I}_{BC}(t)$ and $\dot{I}_{CA}(t)$. And the phase-to-phase voltages are $\dot{U}_{AB}(t)$, $\dot{U}_{BC}(t)$ and $\dot{U}_{CA}(t)$. The equivalent source impedance can be calculated as following:

1) When three-phase fault occurs,

$$Z_S = -\frac{\dot{U}_{BC}(t) - \dot{U}_{BC}(0)}{\dot{I}_{BC}(t) - \dot{I}_{BC}(0)} = -\frac{\dot{U}_{AB}(t) - \dot{U}_{AB}(0)}{\dot{I}_{AB}(t) - \dot{I}_{AB}(0)} = -\frac{\dot{U}_{CA}(t) - \dot{U}_{CA}(0)}{\dot{I}_{CA}(t) - \dot{I}_{CA}(0)} \tag{12}$$

2) When phase-A-to-phase-B short-circuit fault occurs,

$$Z_S = -\frac{\dot{U}_{AB}(t) - \dot{U}_{AB}(0)}{\dot{I}_{AB}(t) - \dot{I}_{AB}(0)} \tag{13}$$

3) When phase-B-to-phase-C short-circuit fault occurs,

$$Z_S = -\frac{\dot{U}_{BC}(t) - \dot{U}_{BC}(0)}{\dot{I}_{BC}(t) - \dot{I}_{BC}(0)} \tag{14}$$

4) When phase-C-to-phase-A short-circuit fault occurs,

$$Z_S = -\frac{\dot{U}_{CA}(t) - \dot{U}_{CA}(0)}{\dot{I}_{CA}(t) - \dot{I}_{CA}(0)} \tag{15}$$

Among the three PDC, the differential current between faulted phases has the highest magnitude. So the faulted phases can be selected. Then the real-time setting can be calculated and the operation criterion can be simplified from (7) and (8).

For example, when phase-A-to-phase-B short-circuit fault occurs, $\max(|\dot{I}_{AB}|, |\dot{I}_{BC}|, |\dot{I}_{CA}|) = I_{AB}$. So phase-A and phase-B are selected as faulted phases.

$$\dot{E}_l = \dot{E}_{AB}(t) = \dot{U}_{AB}(t) + \dot{I}_{AB}(t) Z_S \tag{16}$$

$$Z_S = -(\dot{U}_{AB}(t) - \dot{U}_{AB}(0)) / (\dot{I}_{AB}(t) - \dot{I}_{AB}(0)) \tag{17}$$

Then, I_{op} can be expressed as (18):

$$\begin{aligned} I_{op} &= K_{rel} |\dot{E}_l / (Z_S + Z_L)| \\ &= K_{rel} \left| \frac{\dot{U}_{AB}(t)(\dot{I}_{AB}(t) - \dot{I}_{AB}(0)) - \dot{I}_{AB}(t)(\dot{U}_{AB}(t) - \dot{U}_{AB}(0))}{-(\dot{U}_{AB}(t) - \dot{U}_{AB}(0)) + Z_L(\dot{I}_{AB}(t) - \dot{I}_{AB}(0))} \right| \end{aligned} \tag{18}$$

B. Adaptive Schemes for the Disconnection of PT

When voltage is applied in the calculation of equivalent source impedance, the disconnection of PT may leads to malfunction of relays. To avoid this situation, a two-level adaptation is considered in this paper. The first level is to use only fault currents to realize the adaptive functions. The second one is to use both fault currents and fault voltages. In normal situation, the second scheme is applied. When PT is disconnected, the protection scheme will switch to the first one automatically. Thus the performance of overcurrent relay can be improved. This switching of operation criterion is very applicable to be installed in the unmanned substations or the field where no PT exists.

Equation (7) and (8) are the operation criterion and setting value for the second level. When only the first level is considered, the operation criterion and setting can be illustrated as following:

$$\max(|\dot{I}_{AB}|, |\dot{I}_{BC}|, |\dot{I}_{CA}|) \ge I_{op} \tag{19}$$

$$I_{op} = K_{rel} \left| \frac{\dot{E}_l}{Z_{S.\min} + Z_L} \right| = K_{rel} \sqrt{3} I_K^{(3)} \tag{20}$$

IV. Coordination Considerations When Served as Backup Overcurrent Protection

As it is described above, the operation criterions can switch automatically to achieve a two-level adaptation. Without communication, a protection can't know which criterion is really used in the upstream and downstream protections [7,8]. Therefore, when served as backup overcurrent relay, it is better to coordinate only on the first level, that is, coordinate without calculating the equivalent source impedance (see 19-20).

Applied on the primary side of a transformer, the overcurrent relay described above can provide backup protection for secondary-side faults of the transformer. To analyze the characteristics and sensitivity of the relay, a $Y/\Delta-11$ connected transformer will be considered [9].

When a phase-to-phase fault occurs, the magnitudes of the currents of two faulted phases are equal to half of the third one. This will decrease the sensibility of traditional overcurrent relays. But when relays based on the principle of PDC are used, it will be different.

When phase-B-to-phase-C short-circuit fault occurs on the wye-side of the transformer, the current distribution on both sides of the transformer is illustrated in Fig. 5. Suppose that the transformation ratio $n=1:1$.

It's obvious that

$$\begin{cases} \dot I_b = -\dot I_c \\ \dot I_a = 0 \\ \dot I_\beta = -(1/\sqrt{3})\dot I_b \\ \dot I_\gamma = -\dot I_\beta \\ \dot I_\alpha = 0 \\ \dot I_A + \dot I_B + \dot I_C = 0 \end{cases} \tag{21}$$

And it's easy to derive that

$$\begin{cases} \dot I_A = \dot I_\alpha - \dot I_\beta = (1/\sqrt{3})\dot I_b \\ \dot I_B = -\dot I_\gamma + \dot I_\beta = -(2/\sqrt{3})\dot I_b \\ \dot I_C = \dot I_\gamma - \dot I_\alpha = (1/\sqrt{3})\dot I_b \end{cases} \tag{22}$$

$$\text{So, } \begin{cases} \dot I_{AB} = \sqrt{3}\dot I_b = (\sqrt{3}/2)\dot I_{bc} \\ \dot I_{BC} = -\sqrt{3}\dot I_b = -(\sqrt{3}/2)\dot I_{bc} \\ \dot I_{CA} = 0 \end{cases} \tag{23}$$

Thus,

$$\begin{aligned} &\max(|\dot I_{AB}|,|\dot I_{BC}|,|\dot I_{CA}|) = (\sqrt{3}/2)|\dot I_{bc}| \\ &= (\sqrt{3}/2)\max(|\dot I_{ab}|,|\dot I_{bc}|,|\dot I_{ca}|) \end{aligned} \tag{24}$$

It's the same when other type of phase-to-phase fault occurs on wye-side. So, when phase-to-phase fault occurs on wye-side, there will always be:

$$\max(|\dot I_{AB}|,|\dot I_{BC}|,|\dot I_{CA}|) = \frac{\sqrt{3}}{2}\max(|\dot I_{ab}|,|\dot I_{bc}|,|\dot I_{ca}|) \tag{25}$$

It can also be derived that when phase-to-phase fault occurs on delta-side, (26) will exist:

$$\max(|\dot I_{ab}|,|\dot I_{bc}|,|\dot I_{ca}|) = \frac{\sqrt{3}}{2}\max(|\dot I_{AB}|,|\dot I_{BC}|,|\dot I_{CA}|) \tag{26}$$

From above it can be concluded that: when served as backup protection spanning a transformer, the sensitivity of the relay based on PDC will not be decreased. So, the operation criterion can be described as below:

$$\begin{aligned} \max(|\dot I_{AB}|,|\dot I_{BC}|,|\dot I_{CA}|) &\ge K_{rel.T}\, I_{op}^{\text{III}} \\ &= K_{rel.l}^{\text{III}} K_T \frac{\sqrt{3}}{2} I_{op}^{\text{III}} \end{aligned} \tag{27}$$

Where, $K_{rel.T}$ - the reliable coefficient of the backup protection of a transformer;

K_T - the reciprocal of the transformer ratio;

$K_{rel.l}^{\text{III}}$ - the reliable coefficient of the backup protection of the downstream line;

I_{op}^{III} - the setting value of the backup protection of the downstream line.

V. Analysis of the Zone of Protection and Sensitivity Comparing with the Traditional Overcurrent Relays

A. Zone of Protection of Traditional Overcurrent Relays

The traditional instantaneous overcurrent relay is set as (28):

$$I_{op} = K_{rel} \cdot \frac{E_\phi}{Z_{s.\min} + Z_L} \tag{28}$$

Where, I_{op} is the set value of fault current; K_{rel} is the reliable coefficient.

When fault occurs on the position of ∂Z_L, the fault current is:

$$I_F = \frac{K_d E_\phi}{Z_s + \partial Z_L} \tag{29}$$

Where, I_F is the fault current; K_d is coefficient of the fault type.

Suppose that $I_{op} = I_F$, the zone of protection of traditional overcurrent relays can be calculated from (30):

$$\partial = \frac{K_d(Z_{s.\min} + Z_L) - K_{rel} Z_S}{K_{rel} Z_L} \tag{30}$$

B. Zone of Protection of Adaptive Overcurrent Relay

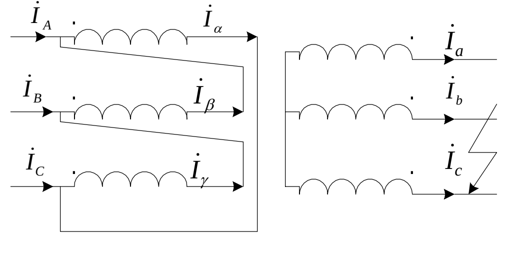

Fig. 5 Distribution of primary and secondary currents of transformer

Based on PDC

a) Consider the Real-time Calculation of Equivalent Source Impedance

If real-time equivalent source impedance is calculated, the set value of fault current is:

$$I_{op}^{'} = K_{rel} \cdot \frac{\sqrt{3}E_{\phi}}{Z_s + Z_L} \tag{31}$$

When fault occurs on the position of ∂Z_L, the fault current is :

$$I_F^{'} = \sqrt{3}E_{\phi} /(Z_s + \partial Z_L) \tag{32}$$

Suppose that $I_{op}^{'} = I_F^{'}$, the zone of protection can be calculated from:

$$\partial^{'} = [Z_L + (1 - K_{rel})Z_S]/(K_{rel} Z_L) \tag{33}$$

From (30) and (33), it can be derived that:

$$\frac{\partial^{'}}{\partial} = \frac{(1 - K_{rel})Z_S + Z_L}{(K_d Z_{S.\min} - K_{rel} Z_S) + K_d Z_L} \tag{34}$$

For traditional overcurrent relays, K_d have two possible values:

(1) When three-phase short-circuit fault occurs, $K_d = 1$.

$$\frac{\partial^{'}}{\partial} = \frac{(1 - K_{rel})Z_S + Z_L}{(Z_{S.\min} - K_{rel} Z_S) + Z_L} > 1$$

(2) When phase-phase short-circuit fault occurs, $K_d = \sqrt{3}/2$.

$$\frac{\partial^{'}}{\partial} = \frac{(1 - K_{rel})Z_S + Z_L}{(\frac{\sqrt{3}}{2} Z_{S.\min} - K_{rel} Z_S) + \frac{\sqrt{3}}{2} Z_L} > \frac{2}{\sqrt{3}}$$

So, to all type of phase fault, there is $\partial^{'} \geq \partial$.

b) Without Real-time Calculation of the Equivalent Source Impedance

When the equivalent source impedance is set as a constant, there are $I_{op}^{''} = K_{rel} \cdot \frac{\sqrt{3}E_{\phi}}{Z_{s.\min} + Z_L}$ and $I_F^{''} = \frac{\sqrt{3}E_{\phi}}{Z_s + \partial^{''} Z_L}$. Suppose that $I_{op}^{''} = I_F^{''}$, the zone of protection can be calculated from (35):

$$\partial^{''} = \frac{Z_{S.\min} + Z_L - K_{rel} Z_S}{K_{rel} Z_L} \tag{35}$$

Then $$\frac{\partial^{''}}{\partial} = \frac{Z_{S.\min} + Z_L - K_{rel} Z_S}{K_d (Z_{S.\min} + Z_L) - K_{rel} Z_S} \tag{36}$$

Also there are two possible values of K_d :

(1) When three-phase short-circuit fault occurs, $K_d = 1$.

Then, $\frac{\partial^{''}}{\partial} = 1$;

(2) When phase-to-phase short-circuit fault occurs, $K_d = \frac{\sqrt{3}}{2}$.

Then, $\frac{\partial^{''}}{\partial} > \frac{2}{\sqrt{3}}$.

So, to all type of phase fault, there is $\partial^{''} \geq \partial$ too.

Moreover, there is $\partial^{''} / \partial^{'} < 1$. So the zone of protection of the adaptive overcurrent relay based on PDC is larger than the traditional one. And when the equivalent source impedance is calculated, the zone of protection of the adaptive relay can be extended.

VI. TRANSIENT SIMULATION OF THE PDC-BASED OVERCURRENT RELAY USING ATP AND MODELS

To test the dynamic operational characteristics of relaying algorithm based on PDC, the Alternative Transients Program (ATP) is used for simulation.

ATP is a widely used program for digital simulation and analysis of power system transients. MODELS in ATP is a general-purpose description language supported by an extensive set of simulation tools for the representation and study of time-variant systems. MODELS allows the description of arbitrary user-defined control and circuit components, providing a simple interface for connecting other program/models to ATP [10,11]. With MODELS facilities, it is possible to simulate the process of real-time coordination and tripping (see Fig. 6).

The simulation system is shown in Fig.7. The parameters are listed in table I. By programming the line parameters, fault location can be changed along the line.

Some of simulation results of primary currents are shown in Fig.8. Here, fault occurs when t=0.1s. Responding to different fault type, the real-time settings are different (Table II). It's shows that this overcurrent relay can operate properly within about one cycle after fault occurs.

VII. CONCLUSIONS

In this paper, a novel adaptive overcurrent relay based on phase-to-phase differential current is proposed. The sensitivity of this relay will not be influenced by fault type. Through the real-time calculation of the equivalent source impedance, its sensitivity can be improved. The two levels of adaptation can be switched automatically or manually. The operation principle is simple. And it is easy to coordinate. Moreover, when applied as the backup protection of transformers, the sensitivity of protection can be improved remarkably. It is a promising protection scheme for the middle-low voltage transmission and distribution lines.

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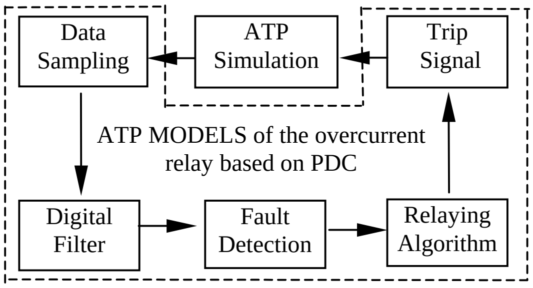

Fig. 6 Block diagram of ATP simulation

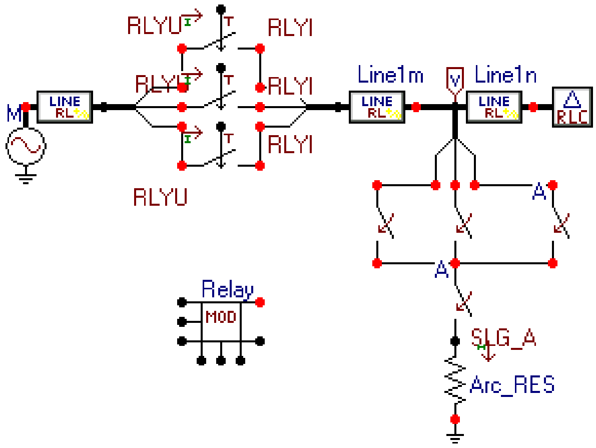

Fig. 7 Distribution network for ATP simulation

Table I Parameters of the simulation system

	Z_1[ohm]	Z_2[ohm]
Line	5.4+j55.66	5.4+j55.66
Source	0.2534+j20.046	0.2534+j20.046
Load	1470+j1102.5	1470+j1102.5

Table II Relay settings and the maximum of PDCs

Fault type	$f^{(BC)}$	$f^{(ABC)}$
Max. of PDCs [A]	526.48	526.69
Relay setting [A]	472.06	433.54

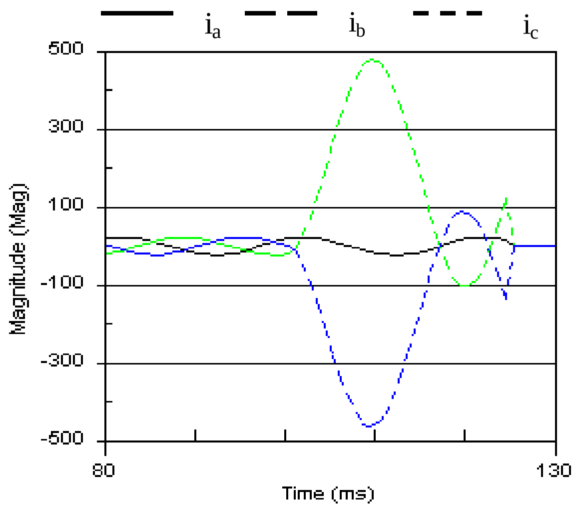

Fig.8 Phase currents when B-C phase fault occurs