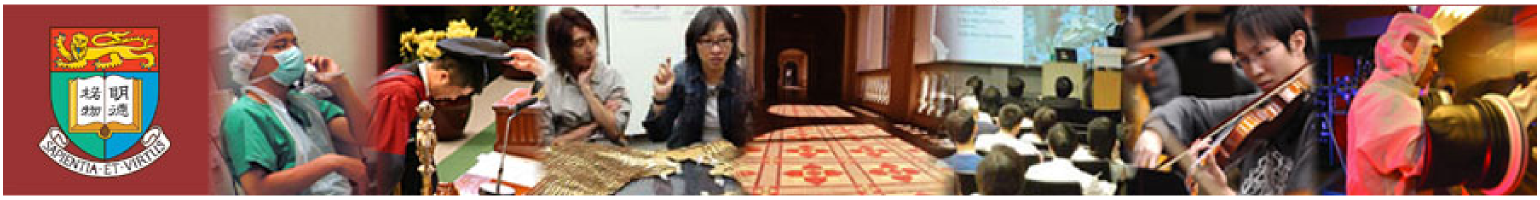

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A Novel Overcurrent Protection Method based on Wide Area Measurement in Smart Grid

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***Abstract*—Conventional overcurrent protection settings are fixed to detect faults. Power system operation mode varies while the settings of protection devices remain constant. As a result, overcurrent protection has a small protection range and a long operating time because it is incapable of adjusting its setting online. Wide Area Measurements System (WAMS) provides synchronized and real time data which can be utilized in new protection devices. This paper proposes a novel online setting scheme which utilizes online system data to calculate real-time system operation mode. Based on the real-time operation mode, real-time fault current is calculated before fault occurring. Settings of the protection devices are by this means adjusted in real time to expand the protection area and shorten the operating time. The calculation is expanded from single source model to multi-source with Π model. In addition, interval time of settings adjustment T_{change} is proposed and calculated by using hyperbolic function model. Based on this method, power system real-time operation condition can be better monitored and the real-time short circuit current can be obtained to improve protection performance.**

***Index Terms* -- Wide Area Measurements, Online Setting, Real-time Operation Mode Calculation, Protection Setting Interval Time.**

I. INTRODUCTION

Development of power grid and demand for high quality electric energy lead to a new requirement in the protection field of power system. In protection field, high sensitivity and fast operation during fault are required. Mal-trip is not expected for protection devices. Fast protection operating ensures that abnormal working conditions such as voltage drop, frequency vibration, can be quickly cleared, so as not to propagate new problems in the power system [1]. In order to achieve better performance of protection devices, new algorithms should be utilized to shorter the operating time and improve its sensitivity to fault. Moreover, better materials for devices should be used to guarantee the performance. Unfortunately, high sensitivity and low mal-trip ratio are contradictory in working principles. Power system switching such as induction motor starting and transformer energizing, are the most important sources of mal-trip. Its transient current has potential effects to affect correct trip of protection relays. In practical, transients current should not lead to protection relays tripping. Therefore a reliable and secure relay response becomes a critical matter. Fault identification methods that produce mal-trip and introducing procedures to discriminate them from real cases are very important. Normally, longer delay is initiated for relay tripping which is a solution to prevent mal-trip of over current protection due to transient current. However, this method imposed delay, slows down the protection relay operating time during fault occurring and consequently reduces sensitivity of protection devices [2-4].

The essential problem resulting in this phenomenon is that protection devices can not adjust themselves because they cannot see the real-time power system condition [5]. As phasor measurement units are installed in power systems, the synchronized information could be seen from the remote end. Based on current protection problems, an improved online setting method is proposed in this paper. Calculation methods in different systems under different faults are deduced in the paper.

As previous system estimation method is based on off-line coefficients [6], a new system evaluation method is proposed to calculate the outage probability so as to judge and identify the system operation mode. Combined with setting scheme model, a novel online setting scheme is designed to improve protection performance.

The structure of the paper is organized as following. Section I is the introduction. In Section II, the online system operation mode calculation method will be presented. The hyperbolic function and interval time of settings adjustment will be described in Section III. The simulation results of overcurrent protection improvements are presented and analyzed in Section IV. Conclusions are presented in Section V.

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II. MODELING AND FORMULATION FOR SHORT CIRCUIT CURRENT CALCULATION

In order to calculate the short circuit current, a model is needed to simulate the power system. When fault occurs, the power grid with single source can be simplified as the model in Fig. 1.

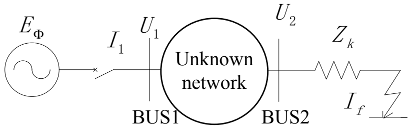

Figure 1. Power system network with single source

If regard this unknown network as an impedance, the system can be describe as the model in Fig. 2.

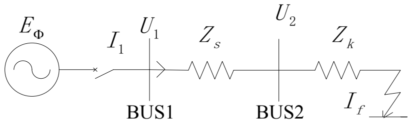

Figure 2. Simplified power system network

In this model, basic fault current calculation is shown as in (1).

$$I_k = \frac{E_\Phi}{Z_\Sigma} = K_\Phi \frac{E_\Phi}{Z_s + Z_k} \tag{1}$$

E_Φ equivalent source phase electromotive force of the system

Z_k impedance between the protection installation location and the fault point

Z_s impedance between the protection installation location and the equivalent source of the system

K_Φ coefficient of short circuit type: when three phase fault occurs, $K_\Phi = 1$, when two phase fault occurs, $K_\Phi = \frac{\sqrt{3}}{2}$ [7].

According to (1), the value of short circuit current is related to:

(1) System operation mode (Z_s) changing;

(2) System normal operation condition E_Φ changing;

(3) Type of short circuit;

(4) Distance between fault point and equivalent source .

If above information are obtain by Phasor Measurement Units (PMUs), the real-time short circuit current can be calculated.

$$Z_s = \frac{U_1 - U_2}{I_1} \tag{2}$$

In (2), U_1, U_2, I_1 can be obtained from PMUs installed on bus 1 and bus 2. Z_s is by this mean calculated. E_Φ can be obtained from PMU installed on BUS1. Z_k is the maximum impedance of line L. K_Φ is 1.

The real-time short circuit current is calculated based on (1).

Based on previous demonstration, the situation can be extended to a multi-source network..

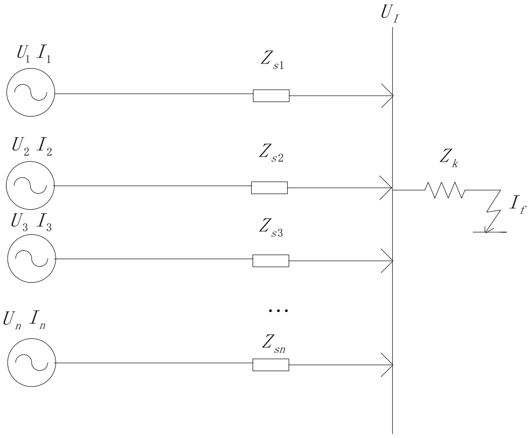

Figure 3. Power system network with multi-source

The online fault current calculation method is deduced in (3). In this model:

$$\begin{cases} Z_{s1} = \dfrac{U_1 - U_I}{I_1} \\ Z_{s2} = \dfrac{U_2 - U_I}{I_2} \\ \cdots \\ Z_{sn} = \dfrac{U_n - U_I}{I_n} \\ I_f = \dfrac{U_2 - U_I}{Z_{s1}} + \dfrac{U_2 - U_I}{Z_{s2}} + \cdots + \dfrac{U_n - U_I}{Z_{sn}} \\ \dfrac{U_I}{Z_k} = I_f \end{cases} \tag{3}$$

$$\Rightarrow I_f = \frac{\frac{U_1}{Z_{s1}}}{(\frac{Z_k}{Z_{s1}} + \frac{Z_k}{Z_{s2}} + \cdots + \frac{Z_k}{Z_{ss}})} + \frac{\frac{U_2}{Z_{s2}}}{(\frac{Z_k}{Z_{s1}} + \frac{Z_k}{Z_{s2}} + \cdots + \frac{Z_k}{Z_{ss}})} + \cdots + \frac{\frac{U_n}{Z_{sn}}}{(\frac{Z_k}{Z_{s1}} + \frac{Z_k}{Z_{s2}} + \cdots + \frac{Z_k}{Z_{ss}})} \tag{4}$$

I_n^* is defined in (5).

$$I_n^* = \frac{\frac{U_n}{Z_{sn}}}{(\frac{Z_k}{Z_{s1}} + \frac{Z_k}{Z_{s2}} + \cdots + \frac{Z_k}{Z_{ss}})} \tag{5}$$

As a result:

$$I_f = I_1^* + I_2^* + \cdots + I_n^* \tag{6}$$

By utilizing this method, online operation could be calculated when need. However, replacing the unknown network with impedance may results in inaccuracy. Applying Π model is a better solution. The model is shown in Fig. 4.

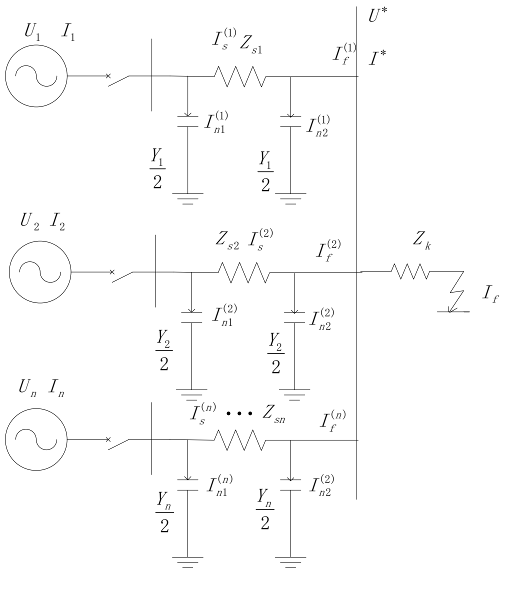

Figure 4. Multi-source power system with Π model

In this model:

$$\begin{cases} Z_{sn} = \frac{U_n - U*}{I_s^{(n)}} \\ I_s^{(n)} = I_n - I_{n1}^{(n)} \\ I_s^{(n)} = I_f^n + I_{n2}^{(n)} \\ I_{n1}^{(n)} = U_n * \frac{Y_n}{2} \\ I_{n2}^{(n)} = U^* * \frac{Y_n}{2} \\ I_f = I_f^1 + I_f^2 + \cdots + I_f^n \end{cases} \tag{7}$$

Z_{sn} and Y_n could be calculated from PMUs data.

$$Z_{sn} = \frac{(U_n - U^*)(U_n + U^*)}{I_n U^* + I^* U_n} \tag{8}$$

$$Y = 2\frac{I_n - I^*}{U_n + U^*} \tag{9}$$

The fault current from one source is calculated in (10).

$$I_f^n = \frac{\frac{U_1}{Z_s}}{(1 + Z_k * \frac{Y}{2} + \frac{Z_k}{Z_s})} \tag{10}$$

Short circuit current I_f is calculated in this system operation mode in (11) and (12).

$$I_f = I_f^1 + I_f^2 + \cdots + I_f^n \tag{11}$$

$$I_f^n = \frac{\frac{U_n}{Z_{sn}}}{(1 + Z_k * \frac{Y_n}{2} + \frac{Z_k}{Z_{sn}})} \tag{12}$$

III. SETTING SCHEME MODEL

Section II discusses how to calculate system operation mode online. Setting should be adjusted before fault occurring to expand the protective range of protection devices. There is one problem we have to consider. When should we change the setting of protection devices? Ideally, setting should be changed just before fault occurring. But in fact, fault is unpredictable which result in that setting is requisite to be adjusted frequently to ensure the online setting takes effect [8]. Paper proposed a method to decide when to change the setting of protection devices.

Model of Transmission Line's Real-Time Reliability is the foundation to evaluate system operation mode. The model should reflect the relationship between the system operation condition and the outage probability.

Define x_i represent the real time parameter affecting the outage probability. x_i may be frequency f, bus voltage U, power flow L, etc. The outage probability is the function of $x_i : F(x_i)$.

Increase of power flow leads to more heating which increase outage probability of devices. When power flow is larger than $x_{i,\max}^{normal}$, outage probability will be closer to 1 [9].

Obeying rules mentioned before, hyperbolic tangent function is proposed to simulate outage probability.

$$F(L) = \frac{1}{2}[1 + \tanh(a_l L + b_l)](L \geq 0) \tag{13}$$

In (13), L is power flow of transmission line. Because the Thermal stability limits is related to power flow. It is correlated to the active power and reactive power of transmission line. L is apparent power is, a_l and b_l are both undetermined parameters. The system outage probability is shown in Fig. 5.

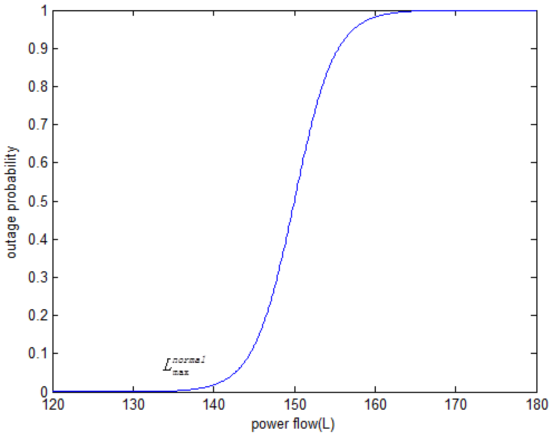

Figure 5. System outage probability

In Fig. 5, $L_{\max}^{normal}$ is the limit of normal condition power flow. When power flow exceeds $L_{\max}^{normal}$, transmission line is easily to fuse thus change system operation mode. T_{change} is the interval time between two setting. Every T_{change} time pasts, the setting should be re-adjusted to satisfy new operation mode. It has the same characteristic as inverse time relay [10] with definite minimum time overcurrent protection. Define T_{change} in (14).

$$T_{change} = \frac{0.14K}{(\frac{F_l}{F_{op}})^{0.02} - 1} + t \tag{14}$$

K, F_{op}, and t are undetermined parameters. K is the time setting coefficients. F_{op} is the normal operation mode outage probability. t is the minimum setting lasting time. T_{change} is shown in Fig. 6.

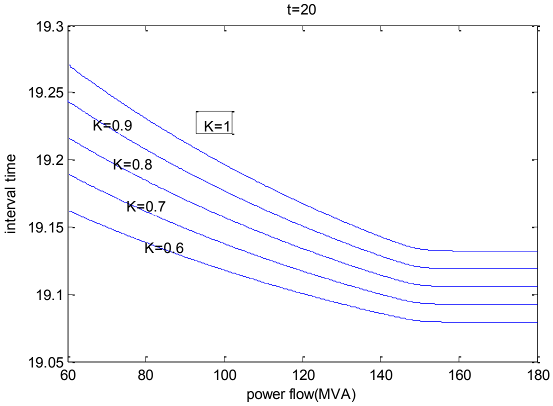

Figure 6. Interval time of setting change

IV. CASE STUDY

In order to test whether the calculated fault current is correct, different models are built in PSCAD/EMTDC, respectively.

1) Two source network with impedance model

In a two sources network, three phases to ground fault occurs at 1.5 s. If protection devices do not trip, the current of three phases is shown in Fig. 7. In this case, the unknown network is replaced with an impedance.

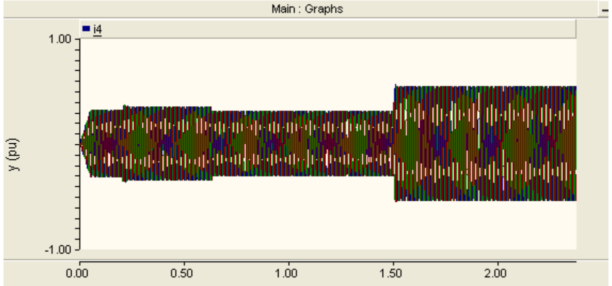

Figure 7. Phase current of the fault line

As shown in Fig. 7, before fault occurring, the power system is operating in minimum operation mode. However, the setting is determined based on its maximum operation mode. As a result, the instantaneous overcurrent protection will not trip.

If setting is adjusted in real-time, short circuit current I_f is calculated. After adjusting the setting of protection, the protection devices will trip in 0.02s thus quickly clear the fault. By utilizing the real time setting, instantaneous current of three phases is shown in Fig. 8.

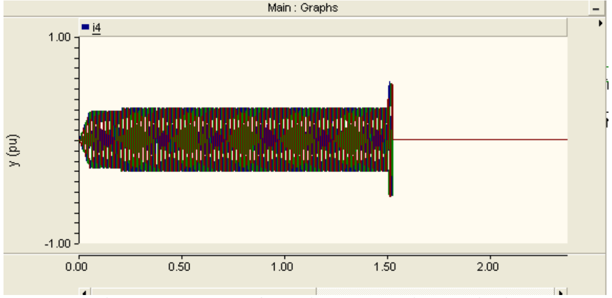

Figure 8. Current after using new setting method

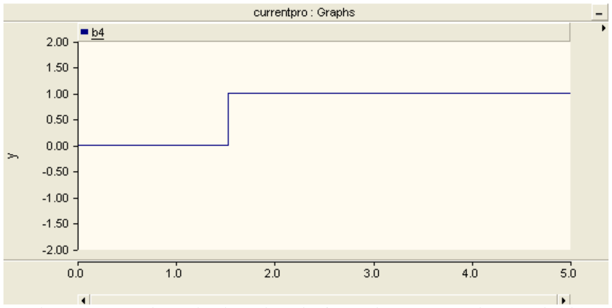

Figure 9. Breaker tripping signal after using new setting method

In Fig. 9, the breaker opens at 1.52s to cut off the phase to phase to ground fault.

2) Two source network with Π model

In a two sources network, single phase to ground fault occurs at 1.5s. If protection devices do not trip, the current of three phases is shown in Fig. 10. In this case, the unknown network is replaced with a Π model.

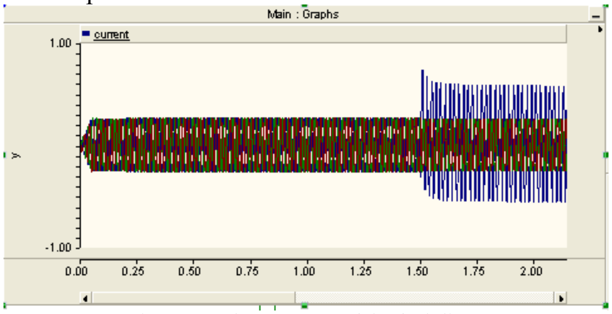

Figure 10. Phase current of the fault line

In Π model, the calculate process is different from the case A. By utilizing this setting, fault current is calculated and set to the protection devices. Then the fault can be cleared in 0.2s.

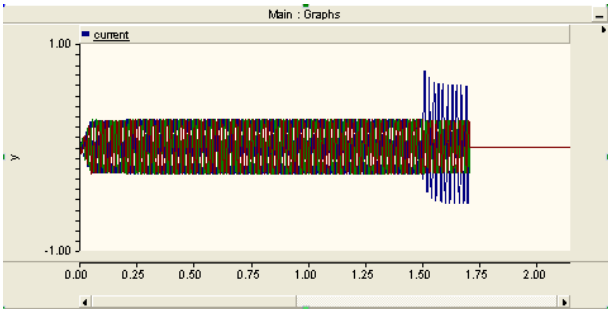

Figure 11. Current after using new setting method

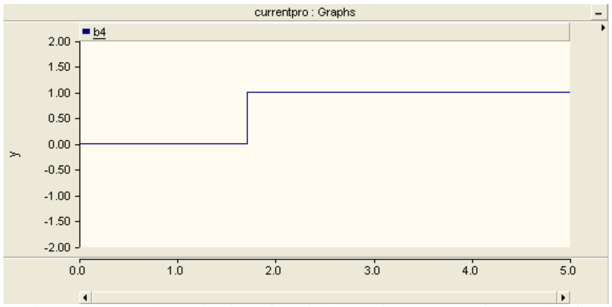

Figure 12. Breaker tripping signal after using new setting method

In Fig. 12, the breaker opens at 1.52s to cut off the single phase to ground fault.

V. CONSLUSION

Based on phase measurement unit, new online setting calculation method is proposed. It is verified in PSCAD/EMTDC and proved to be an effective method achieving fast operation in protection devices of transmission and distribution line.

Online setting for single source system without considering current flowing through the ground is firstly proposed and is verified in PSCAD/EMTDC. Based on that model, the calculation method is expanded to double-sources system and then to multi-sources system. Different cases in different system are discussed and verified respectively.

In addition, T_{change} is proposed for setting scheme which enable protection devices to adjust its setting in a specific frequency. By this mean, the online setting calculation method can be utilized for protection devices.

As synchronized real-time data could be used in next generation protection devices, it is promising to improve high sensitivity and avoid mal-trip for protection devices.

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