DIFFERENTIAL DIAGNOSIS OF FAULTS AND THE SEQUENTIAL SWITCHING COMMAND OF CIRCUIT BREAKERS CONSIDERING THE CURRENT DISPLACEMENT PHENOMENON

Fl. Munteanu, D-tru Ivas
Iaşi University of Technology
Department of Electrical Engineering
Splai Bahlui Stâng no. 51-53
Iaşi, cod 6600
Romania

G.C. PAAP
Delft University of Technology
Department of Electrical Engineering
Mekelweg 4
2628 CD, Delft
The Netherlands

1. Introduction

The 'current displacement' or 'zero passing missing phenomenon' is a frequently tackled subject of experts especially conceming the conditions when it can appear after faults in power systems and the performances of circuit breakers /1/, /2/, /3/.

The authors present a new method to detect the fault type in electric power circuits based on a **qualitative analysis** of the initial DC transient component in every line current.

A suitable method to process the information about this component for the prediction of the first zero passing of the full fault current and for the synchronized open command of circuit breakers is presented also. The paper includes an error analysis for the number of measurements-precision optimisation.

All these can be used to create the techniques for new intelligent circuit breakers.

2. The fault type and the initial DC components of line currents

This method must detect the fault type without any doubt. Supplementary, it must be not influenced by the momen of faul ha means by angle θ that defines the point on the source sinusoidal voltage when the fault occurs.

According to the fault type, the initial DC components of every phase are (phase R is the reference) /4/, /5/:

(a) Three-phase fault

$$i_{aR}=\frac{1}{x_g}\cos\theta \qquad i_{aS}=\frac{1}{x_g}\cos(\theta-\frac{2\pi}{3}) \qquad i_{aT}=\frac{1}{x_g}\cos(\theta-\frac{4\pi}{3}) \qquad (1)$$

(b) Line-to-line fault

$$i_{aR}=0 \qquad i_{aS}=\frac{\sqrt{3}}{2x_g}\sin\theta \qquad i_{aT}=-\frac{\sqrt{3}}{2x_g})\sin\theta \qquad (2)$$

(c) Line-to-ground fault

$$i_{aR}=(2KY_g+K_0Y_g)\cos\theta \qquad i_{aS}=(K_0Y_g-KY_g)\cos\theta \qquad i_{aT}=(K_0Y_g-KY_g)\cos\theta \qquad (3)$$

(d) Double line-to ground fault

$$i_{aR}=Y_{gg}(K-K_0)\cos\theta \qquad i_{aS}=-Y_{gg}(K_0+\frac{K}{2})\cos\theta+\frac{\sqrt{3}}{2}KYsin\theta \qquad i_{aT}=-Y_{gg}(K_0+\frac{K}{2})\cos\theta-\frac{\sqrt{3}}{2}KY\sin\theta \qquad (4)$$

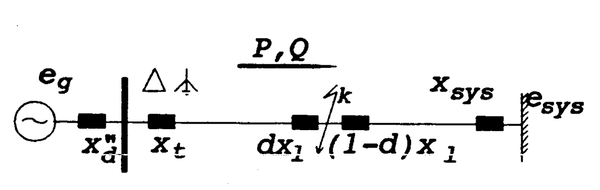

Fig.1 The diagram of the faulted line

Reffering to fig.1, the coeficients used in rel. (1), (2), (3) and (4) are given by:

$$x_g=x_d+x_t;\ x_s=(1-d)x_l+x_{sys};$$
$$K=x/x_g;\ x=x_gx_s/(x_g+x_s)$$
$$Y_g=1/(2x+x_0);\ x_0=x_{g0}x_{s0}/(x_{g0}x_{s0})$$
$$K_0=x_0/x_{g0};\ Y_{gg}=1/(x+2x_0);\ Y=1/x$$

The subscript zero denotes the quantity for the zero network of Clarke's transformation while the voltage at the fault point, before the fault, is considered 1 p.u.

We can write now the qualitative relations:

$$i_{aR}=i_{aS}=i_{aT} \qquad (5)$$

for three-phase fault (TPF),

$$i_{aR}=0 \quad and \quad i_{aS}+i_{aT}=0 \qquad (6)$$

for line-to-line fault (LLF),

$$i_{aR}=i_{aT} \qquad (7)$$

for line-to-ground fault (LGF), and

$$i_{aR}\neq i_{aS}\neq i_{aT} \qquad (8)$$

for double line-to-ground (DLG) fault.

The equations (5)÷(8) can univocally characterise the fault type excepting the situations in which the phase angle θ=nπ/2 (n=0, 1, 2, ...), table1. Consequently, information about the symmetrical components is necessary.

The following conditions must be attached to the equations (5)÷(8):

$$i_0 = 0 \text{ to eq. (5)}$$
$$i_1 = i_2 = i_0 \text{ to eq. (7)}$$
$$i_1 + i_2 = 0 \text{ to eq.(6) and (8)}$$

Based on these qualitative relations, the logical diagram of the hybrid multistate relay to detect the fault type is presented in fig.2.

A hybrid analogue-digital structure of the relay was preferred and not a digital one due to the most important feature of it, which has to be an instantaneous operation.

Table 1 Initial values of DC components for some particular θ

θ		The fault type			
		TPF	LLF	LTG	DLG
0	R	$1/x_g$	0	$Y_g(2K+K_0)$	$Y_{gg}(K-K_0)$
	S	$-1/2x_g$	0	$Y_g(K_0-K)$	$-Y_{gg}(K_0+K/2)$
	T	$-1/2x_g$	0	$Y_g(K_0-K)$	$-Y_{gg}(K_0+K/2)$
π/2	R	0	0	0	0
	S	$3/2x_g$	$3/2x_g$	0	$3/2x_g$
	T	$-3/2x_g$	$-3/2x_g$	0	$-3/2x_g$
π	R	$-1/x_g$	0	$-Y_g(2K+K_0)$	$Y_{gg}(K_0-K)$
	S	$1/2x_g$	0	$Y_g(2K+K_0)$	$Y_{gg}(K_0+K/2)$
	T	$1/2x_g$	0	$Y_g(2K+K_0)$	$Y_{gg}(K_0+K/2)$
3π/2	R	0	0	0	0
	S	$-3/2x_g$	$-3/2x_g$	0	$-3/2x_g$
	T	$3/2x_g$	$3/2x_g$	0	$3/2x_g$

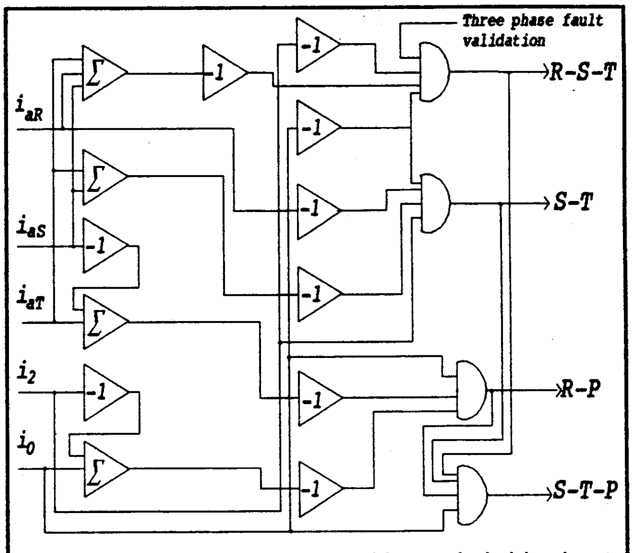

Fig.2 The structure of the multistate hybrid relay to detect the fault type

3. Prediction of the first zero passing of the fault line currents

To protect the circuit breaker a sequential switching command is necessary when the current displacement phenomenon appears.

The keys for a correct prediction of the zero passing of the fault line currents are summarized as follows:

-Δt_d the tripping time of circuit breaker;

-t_n, data acquisition time about DC phase component of fault current to predict its first zero passing;

-t_r, the real time between the fault occurrence (zero moment) and the first zero passing of the current.

The typical wave form of the fault current is shown in fig.3 where the AC fundamental component and DC transient component are generally comprised.

The condition for a sequential tripping of the circuit breaker is

$$t_n + \Delta t_d \leq t_r \qquad (9)$$

If the time for fault detecting t_i cannot be neglected, the condition is

$$t_i + t_n + \Delta t_d \leq t_r \qquad (10)$$

A suitable method to reconstitute in useful time (t_n) the DC component is to find out its parameters:

-a, the initial value;

-T_a, the decay time.

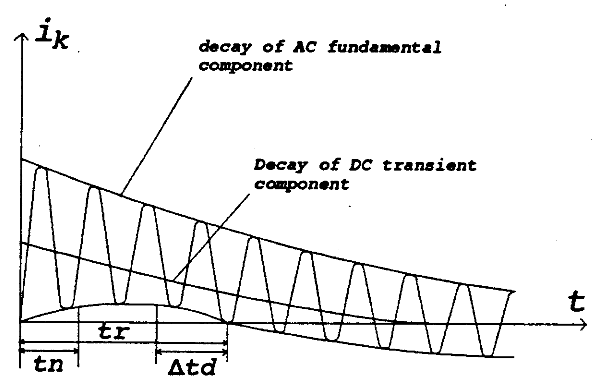

Fig.3 Typical current displacement phenomenon

The DC component is given by

$$i_a = ae^{-T_a t} \qquad (11)$$

The system of normal equations to find out the parameter a and T_a, is

$$\begin{aligned} &\sum_{i=1}^{n} \log a_i = 0.4343 \sum_{i=1}^{n} t_i + n \log a \\ &\sum_{i=1}^{n} t_i \log a_i = 0.4343\, T_a \sum_{i=1}^{n} t_i^2 + \log a \sum_{i=1}^{n} t_i \end{aligned} \qquad (12)$$

There is not any difficulty to compute the system (12) thus we must know the suitable measurement number (n) for an accurate and fast determination of DC component i_a.

The results of the error analysis are presented in table 2. We have considered the following DC component:

$$i_a = 2.95 e^{\frac{-100t}{2.6}}; \qquad a = 2.95; \qquad T_a = 38.4615 \qquad (13)$$

We considered 0.001 seconds as the time between two consecutive measurements as usually for digital data acquisition and computing systems.

The measurement errors of t_i have negligible values compared to those of i_{ai}. Therefore we can find out the average error of reconstituted DC component as a function of the measurement number, n. These errors are between -2.576% for n=2 and 0.01% for n=7. The real fault current has a shorter zero passing time compared to the zero passing time of the reconstituted fault current.

Table 2 The errors as function of measurement number

n	Predicted values		Method errors [%]	
	a	T_a	a	T_a
2	3.038	58.076	2.955	50.997
3	2.9757	42.795	0.871	11.267
4	2.9555	39.419	0.169	1.970
5	2.9579	39.365	0.167	2.348
6	2.9539	38.639	0.132	0.461
7	2.9508	38.547	0.027	0.424

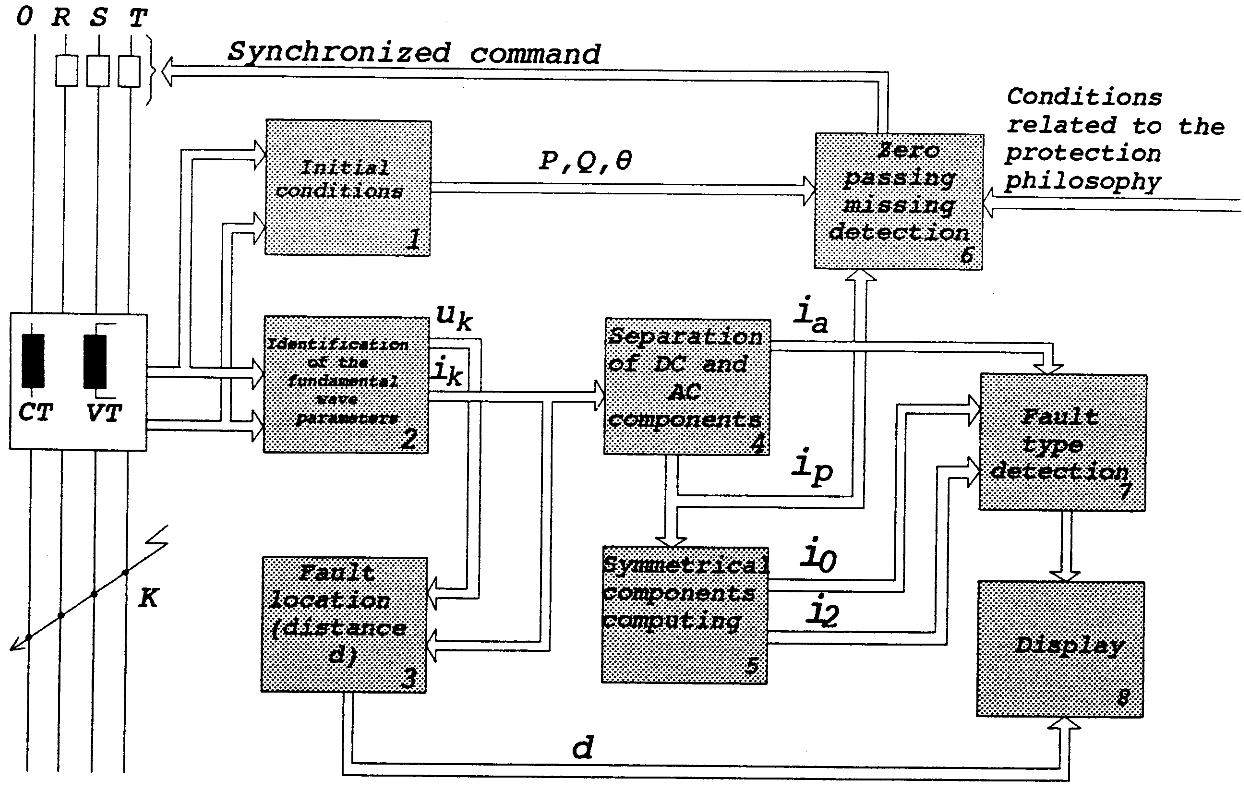

Fig.4 Diagram of the device for detection of fault type and location

Fig.4 presents the block-diagram of a sophisticated device capable to perform some important functions as the current displacement phenomenon detection and the synchronized command of the circuit breaker, if necessary.

As concerns the fault locations there are different methods from which a very detailed one is presented in /6/.

The inputs are the current and voltage of every phase. A special mention is necessary about the current transformers that must transfer the transient components with very small errors. Consequently, the Rogowski coils are suitable for this purpose /1/.

4. References

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