TWO TERMINALS BASED PROTECTION AND AUTOMATION SCHEMES FOR POWER TRANSMISSION LINES

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abstract – The data exchange between transmission line protective terminals provide additional options for autoreclosing procedure optimization and fault location accuracy and reliability improvement. The proposed fault location scheme simultaneously involves two algorithms: single-ended method based on measurements performed on one end of the power transmission line and method that in addition utilizes information obtained from the remote line end. The structure of hardware implementation is shown.

keywords - autoreclosing, transmission lines, fault location, disturbance recording, communication

INTRODUCTION

Current differential protection finds widespread application as a zone protection providing ideal fault selectivity and capability of high-speed operation. A communication link to transfer the current waveform information between ends of the line forms an integral part of the protection. In recent years, the differential protection realization has opened up with fiber optics and digital communication channel, GPS and current phasors comparison principle utilization. Wilson and Kusters [1], [2] point up the utilities interest on this technology application.

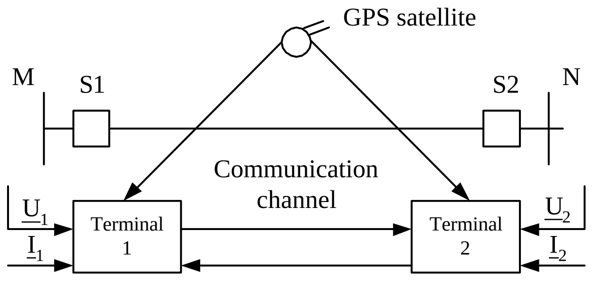

Fig. 1. Diagram of the line protection

Modern microprocessor technology application makes it feasible the implementation of protection terminals, which in addition to protection functions execution, support a number of important automation functions, namely, fault location and autoreclosing. Integrated realization of the automation functions in protection terminals does not require any significant additional hardware resources: these are carried out by software, and use the same controlled signals (Fig. 1). This paper illustrates algorithms of realization of the described automation functions, on condition that communication channels are shared with the differential protection operation.

AUTORECLOSING

If protection has tripped the faulted due to short circuit power transmission line, then, in a certain time interval, autoreclosing is performed.

Singh [1] points up several tasks that should be solved to make the operation of the circuit breakers more effective, in particularly:

- Determination of the breaker closing sequence;
- Setting of autoreclosing number (number of breaker closing attempts).

These tasks usually are solved by utilization of the defined in advance settings, i.e. a priori, in non-online mode.

When autoreclosing is performed, the probability of the short circuit retention is significant. If the line is switched on short circuit, the elements of power system are stressed by dynamic impact and stability violations can occur.

To minimize potential damage that commonly depends on fault point and type as well as on prefault conditions, one should solve a complicated, in general case, task of breaker reclosing sequence choice. The solution of the defined task can be achieved by the algorithm shown in Fig. 2. The determination procedure of the breaker switching sequence and number of autoreclosing is based on utilization of logical variables V_1, V_2, V_3 and logical functions F_1 and F_2, which freely could be programmed at the point of terminal operation. The choice of P_{const}, I_{const} and K settings values and logical functions must be made taking into account particular transmission line operating conditions as well as consequences of the line switching on sustained fault.

Obviously, the described algorithm provides wide possibilities for setting optimal breakers' autoreclosing number and sequence. For example, in simplified case, when the line pre-fault loading is high and phase-to-phase fault currents are significant, the chosen autoreclosing number will be equal to 1. The testing right could be assigned then to the breaker that tripped smaller current value. Simultaneously, for phase-to ground faults conditions, the number of autoreclosing can be set to 2.

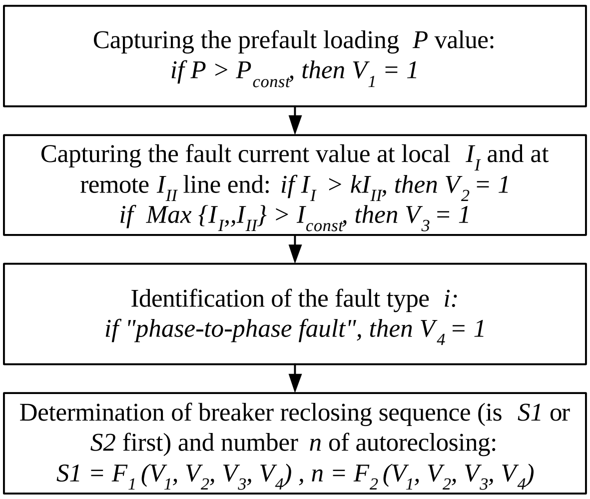

Fig. 2. Structure of autoreclosing algorithm

The digital communication tools could be used for improvement of the fault location accuracy as described below.

FAULT LOCATION

First, let us suppose deterministic case, when current and voltage measurements are ideal (contain no error), and equivalent impedances if the remote end system are known. Let us consider a faulted transmission line with distributed parameters connecting two power systems (Fig. 3.).

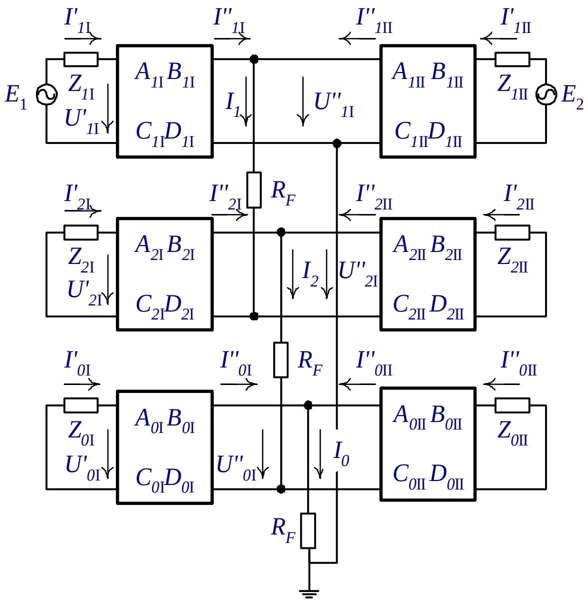

Fig. 3. Diagram of the single phase faulted transmission line

The two-port network theory as shown in Atabekov [4] assumes two equations of the following form (1) to express symmetrical components of voltage and current at one pair of terminals in terms of quantities at the other pair.

$$\begin{aligned} U''_{i\mathrm{I}} &= D_{i\mathrm{I}} U'_{i\mathrm{I}} - B_{i\mathrm{I}} I'_{i\mathrm{I}} \\ I''_{i\mathrm{I}} &= -C_{i\mathrm{I}} U'_{i\mathrm{I}} + A_{i\mathrm{I}} I'_{i\mathrm{I}} \end{aligned} \tag{1}$$

where U_i, I_i is respectively voltage and current of sequence i.

The $A_{i\mathrm{I}}, B_{i\mathrm{I}}, C_{i\mathrm{I}}, D_{i\mathrm{I}}$ parameters can be evaluated, as in [4]:

$$A_i = D_i = ch(\gamma \cdot L_F) \tag{2}$$

$$B_i = Z_c \cdot sh(\gamma \cdot L_F) \tag{3}$$

$$C_i = \frac{1}{Z_c} \cdot sh(\gamma \cdot L_F) \tag{4}$$

where L_F, g, Z_c - are respectively, the distance to the fault, the propagation constant and characteristic impedance of the line.

Taking into consideration that in the fault point there is an equality of powers [4]:

$$U_1 I_1^* = -(U_2 I_2^* + U_0 I_0^*), \tag{5}$$

where I^* is conjugate value of current I.

Proceeding with rearrangements, it is easy to obtain:

$$Im\left[\sum_{i=0}^{2} S_i\right] = Im\left[\sum_{i=0}^{2} \left(U''_{i\mathrm{I}} \cdot I_i^*\right)\right] = 0. \tag{6}$$

From the above, expressing the fault point currents I_i thought the currents in the monitored end of the line, the following can be obtained:

$$Im\left\{\sum_{i=0}^{2}\left[\left(D_{i\mathrm{I}} U'_{i\mathrm{I}} - B_{i\mathrm{I}} I'_{i\mathrm{I}}\right) \cdot \frac{\left(-C_{i\mathrm{I}} U'_{i\mathrm{I}} + A_{i\mathrm{I}} I'_{i\mathrm{I}}\right)^*}{k_{i\mathrm{I}}^*}\right]\right\} = 0, \tag{7}$$

where $k_{i\mathrm{I}}^*$ is the conjugate value of the current distribution coefficient.

The values of $A_{i\mathrm{I}}$, $B_{i\mathrm{I}}$, $C_{i\mathrm{I}}$, $D_{i\mathrm{I}}$ parameters as well as $k_{i\mathrm{I}}^*$ coefficient value are functions of unknown distance L_F. To find value of distance to the fault L_F, at which the non-linear statement (7) becomes valid, one of the known numerical methods can be employed (for instance *regula falsi* in Korn and Korn [5]. Furthermore, the procedure of the current distribution coefficients $k_{i\mathrm{I}}^*$ calculation should be run. This procedure can be built on the basis of several methods utilization that exploit:

- pre-defined (assumed) values of the system equivalent impedance at the remote line end. Then,

$$k_{i\mathrm{I}} = \frac{Z_{i\ \mathrm{inII}}}{Z_{i\ \mathrm{inI}} + Z_{i\ \mathrm{inII}}} = \frac{\dfrac{B_{i\mathrm{II}} + Z_{i\mathrm{II}} A_{i\mathrm{II}}}{D_{i\mathrm{II}} + Z_{i\mathrm{II}} C_{i\mathrm{II}}}}{\dfrac{B_{i\mathrm{I}} + Z_{i\mathrm{I}} D_{i\mathrm{I}}}{A_{i\mathrm{I}} + Z_{i\mathrm{I}} C_{i\mathrm{I}}} + \dfrac{B_{i\mathrm{II}} + Z_{i\mathrm{II}} A_{i\mathrm{II}}}{D_{i\mathrm{II}} + Z_{i\mathrm{II}} C_{i\mathrm{II}}}},$$

where $Z_{i\ \mathrm{inII}}$, $Z_{i\ \mathrm{inI}}$ are the equivalent impedances of the four-pole and the system behind as respects to the fault point;

- defined (measured) current and voltage values at the remote line end. Analyzing the diagram (Fig. 3.), one can easily derive the $k_{i\mathrm{I}}^*$ determination procedure Φ, so that $k_{i\mathrm{I}}^* = \Phi(L_F, U, I)$;
- time interval, when single one line end is switched on (during autoreclosing). In this case, $k_{i\mathrm{I}}^* = 1$.

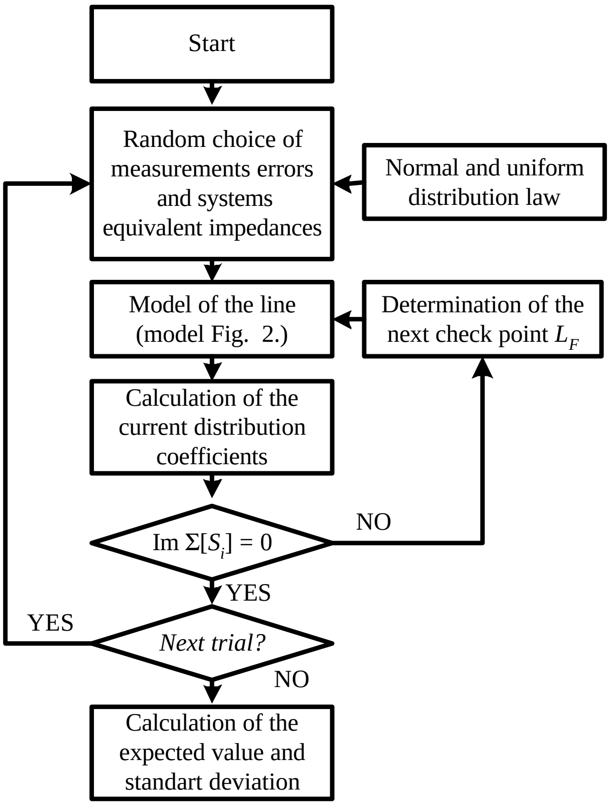

Fig. 4. Structure of the fault location algorithm

Summarizing the stated above, one can declare that the distance to the fault L is linked to the measured phasors of the currents I and voltages U and equivalent impedances $Z_{i\mathrm{II}}$ of the remote transmission line end system by relation of the following form:

$$L = \Phi(I, U, Z_{i\mathrm{II}}) \tag{8}$$

where Φ is for some procedure of the distance L calculation. The procedure employs the measurement results of the controlled currents and voltages, and information of the impedance $Z_{i\mathrm{II}}$ values.

The described approaches allow to obtain the exact estimate of the unknown distance to the fault L_F, if the measurement errors are not present.

However, taking into account that the measured current and voltage data contain random errors - correspondingly ΔI and ΔU, and impedance Z_{iII} values can also be treated as random, the equation (8) could be considered as basic one to determine the distribution law of the estimation of the distance to the fault L_{est} or its numerical characteristics. The algorithm for determination of these numerical characteristics is given in Fig. 4. As it was already shown in the previous works by Sauhats et al [6],[7],[8], these characteristics allow to define optimal strategy of the faulted point search on power transmission line.

The support of the data transfer between two terminals (Fig. 1) provides means for implementation of the discussed algorithm that employs several techniques of current distribution coefficients determination.

Fig. 5 shows results of the algorithm in Fig. 4 simulations. Here, to find the current distribution coefficients values two techniques were involved:

1. Algorithm 1 utilizes estimates of the system impedance $Z_{i\mathrm{II}}$ at the transmission line remote end and the procedure (8);
2. Algorithm 2 determines current distribution coefficient value from available measurement data of the negative sequence current and voltage.

The performance of the algorithms was tested on 330 kV system model. System parameters are given in table 1. The line length was 200 km, the pre-fault power flow through the line was 200 MW and the fault resistance value was 50 ohms. The errors of the current and voltage phasors measurements were assumed to be independent and normally distributed in two dimensions, moreover, it was assumed, in accordance with the equipment producers data, that real error existence margins ($3s$ rule [5]) is $\nabla m = 3\%$ percents for the measurements of currents and voltages vectors magnitudes, and $\nabla a = 1.5°$ degrees for the measurements of the vectors angles.

Fig. 5 shows the results of the calculations. Algorithm 2 provides higher accuracy, however in case of unavailability (or erroneous) of measurement data from the remote system and its subsequent inoperability, algorithm 1 results are essential.

TABLE 1: Model data

seq.	R_i	wL_i	wC_i	R_{iI}	X_{iI}	R_{iII}	X_{iII}
	ohm/km		$\times 10^{6}$ S/km	ohm			
1,2	0.040	0.314	3.52	0.066	62.15	0.24	46.87
0	0.188	0.785	1.63	0.012	68.01	0.008	28.66

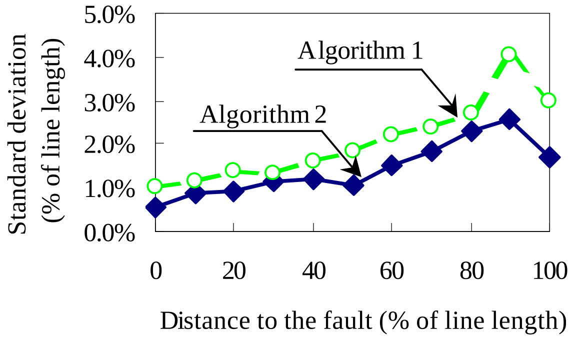

Fig. 5. Results of distance to the fault determination for various fault locations.

HARDWARE IMPLEMENTATION

The structure of the terminal hardware implementation and basic functions are shown in Fig. 6. 14-bit converter AD7863 digitizes controlled currents and voltages. 3 processors execute the software functions. 16-bit signal processors TMS320F206 run relay protection and automation functions as well as necessary service functions (analog-digital converter control, connection to external computer, settings input and availability control, external logical signals control, displaying of the processes, events and measurement results on the integrated indicator). One processor controls data transfer to/from the terminal at the remote end of the transmission line. The data transfer rate is set to 64 kbit/s. Two measurement synchronization methods are supported: based on response time measurement and on GPS synchronizing pulses. The terminal can be accessed by external computer through local area network or dial-up connection.

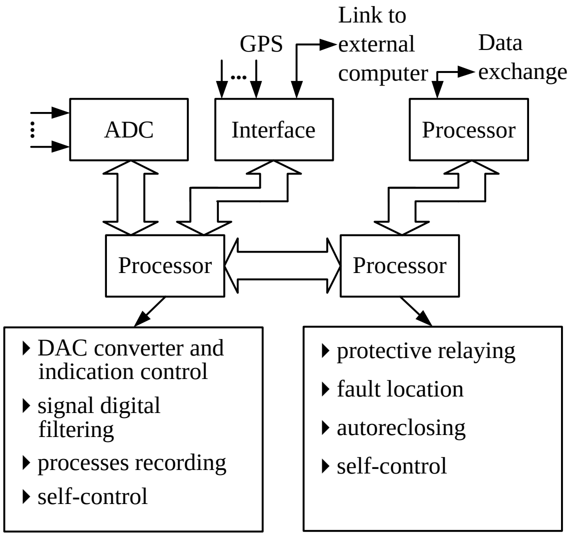

Fig. 6. Hardware implementation and basic functions of the terminal

CONCLUSIONS

The data exchange between transmission line protective terminals accomplished by modern microprocessor-based hardware provides increased fault location accuracy and reliability as well as additional options for autoreclosing process, such as: capability of rational choice of the breaker switching sequence, improved algorithm of autoreclosing type – single-phase of three-phase and number choice.

Integrated implementation of the single-ended and double-ended methods ensures improved accuracy and reliability of the fault location.

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