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USE OF PHASOR MEASUREMENT FOR LINE PROTECTION

FĀZU VEKTORU MĒRĪJUMU IZMANTOŠANA ELEKTROPĀRVADES LĪNIJU AIZSARDZĪBAI

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Introduction

The first ideas of synchronized measurements used for various power systems applications have been introduced by Prof. Phadke and his research group at Virginia Tech in the end of 80-ties. However, it was not earlier than mid of 90-ties when the first installations of Phasor Measurement Units (PMU) appeared. Most of existing PMU installations are at the moment employed within so called Wide Area Monitoring (WAM) concept [1]:. This concept represents synchronized measurements data collection and evaluation by dedicated WAM systems.
Looking from a long-term perspective (e.g. 20 years), it is believed that the degree of penetration of transmission systems with PMUs will significantly increase due to many advantages, which synchronized phasor measurements offer [1]:.
Over the recent years, many hundreds of publications have been dedicated to the use of PMUs, which testifies to significant interest in their application.
The goal of the present paper is looking for ways of effective use of PMUs in local relay protection and automation systems of power transmission lines, which are dedicated to the following:
The use of PMUs in local relay protection and automation systems.
Synthesis of new algorithms of distance protections; fault location for power transmission lines, implementation of autoreclosing functions.
In the present paper, only algorithms based on using the harmonic components of the industrial frequency are analyzed. Not considered are algorithms for filtering the components of currents and voltages (it is assumed that one of the known parameters can be used, which allows to single out current and voltage vectors with sufficient accuracy).

PMU based protection and automation schemes for power transmission

Current differential protection finds widespread application as a zone protection providing ideal fault selectivity and capability of high-speed operation [1]:. 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.

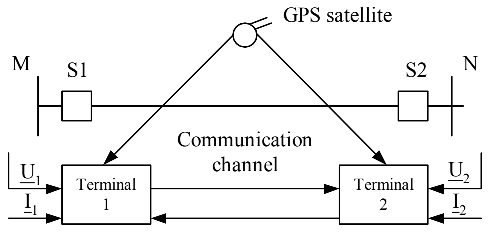

Figure 1. Diagram of the line protection

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, distance protection, 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 (Figure 1). This paper illustrates algorithms of realization of the described automation functions, on condition that communication channels are shared with the differential protection operation.

Distance protection and fault location

Below, we look at the algorithm for evaluating the distance to the fault location, which is based on using the following [2,3,4,5]:

1. A model of a line with R-L equivalent circuit, which allows to synthesize algorithms that are suitable for using on short lines;
2. Information received from the opposite end of the power transmission line.

The algorithm under consideration practically excludes the influence of the load currents, the power transmission line operation modes and the transient resistance at the place of short-circuits. The approach under consideration is suitable both for organizing fault location and for distance protection.

First, let us consider a faulted transmission line connecting two power systems (Fig. 2.).

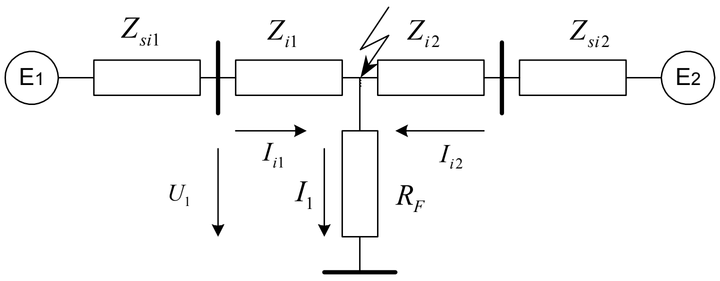

Figure 2. Diagram of the phase to ground faulted transmission line

Taking into consideration that in the fault point there is an equality of powers [2]:

$$U_1 I_1^* = -\left(U_2 I_2^* + U_0 I_0^*\right) \qquad (1)$$

where I^* is conjugate value of current I.

Proceeding with rearrangements, it is easy to obtain:

$$Im\left[\sum_{i=0}^{2} S_i\right] = Im\left[\sum_{i=0}^{2}\left(U_{iI}^{''} \cdot I_i^*\right)\right] = 0 \qquad (2)$$

where k_{il}^* is the conjugate value of the current distribution coefficient.

In case of current and voltage under the control (measuring) at the left end of high voltage line, let's define voltage U_i in positive sequence, negative sequence and zero sequence voltage order in the short-circuit point:

$$U_i = U_{i1} I_{i1} - I_{i1} Z_{i1} I_{i1} - R_F I_i \qquad (3)$$

Taking into account, that equation (1) is preserved in the short-circuit point, as well as conserning current Ii in the fault point, with help of measurements we get the following [6]:

$$\mathrm{Im}\left\{\sum_{i=0}^{2}\frac{U_{i1} I_{i1}^{\ *}}{K_i^*} - \sum_{i=0}^{2}\frac{\left|I_{i1}\right|^2 Z_{i1}}{K_i^*} - \frac{U_{11}\cdot I_L^{\ *}}{K_1^*} + \frac{I_1 I_L^{\ *} Z_{11}}{K_1^*}\right\} = 0 \qquad (4)$$

(2), (3) and (4) U_{il} and I_{il} – measured (calculated) voltage and current *i* – in such a sequence, *I** matched the volume of *I* current, I_L – rate of the current till accident, K_i – ratio of the current configuration:

$$K_i = \frac{I_{i1}}{Ii} \qquad (5)$$

but *Ki** – *Ki* conjugate values.

Impedance Z_{i1} and Z_{i2} depend on the distance till the fault point L_F is:

$$\left.\begin{aligned} Z_{i1} &= L_F Z_{iap} \\ Z_{i2} &= (L - L_F) Z_{iap} \end{aligned}\right\} \qquad (6)$$

It should be taken into account that phase-to-ground fault in the fault point have similar current, but on the basis of (4) more equations can be got concerning L_F [6]:

$$\mathrm{Im}\left\{\frac{\Delta U_{11} I_{01}^*}{K_0^*} + \frac{\Delta U_{21} I_{01}^*}{K_0^*} + \frac{\Delta U_{01} I_{01}^*}{K_0^*}\right\} = 0 \qquad (7)$$

$$\mathrm{Im}\left\{\frac{\Delta U_{11} I_{21}^*}{K_2^*} + \frac{\Delta U_{21} I_{21}^*}{K_2^*} + \right\} = 0 \qquad (8)$$

$$\mathrm{Im}\left\{\frac{\Delta U_{11} I_{21}^{*}}{K_2^{*}} + \frac{\Delta U_{21} I_{21}^{*}}{K_2^{*}} + \frac{\Delta U_{01} I_0^{*}}{K_0^{*}}\right\} = 0 \qquad (9)$$

In equations (7), (8) and (9):

$$\Delta U_{i1} = U_{i1} - I_{i1} \cdot Z_i \qquad (10)$$

Either of equations (4), (7), (8), (9) can be a basis both for defining the distance till the fault point, or for creating of algorithm of the first zone of the distance protection. However, the means of usage of these equations depends significantly on the form of the presentation of information, coming from the opposite of the line end. There are three ways of the presentation of such information:

1. By value of equivalent impedance of the negative or zero sequence Z_{s02} or Z_{s22};
2. By vectors of currents of the negative or zero sequence;
3. By vectors of voltage of the negative or zero sequence;

In the first case, if the equivalent impedance Z_{si2} is known, equations (4), (7), (8) and (9) in relation to the unknown distance L_F are quadratic equations and they can be considered to be the basis of the calculation [1]. The solution of the equations contains two roots. In case, both roots correspond to the length of high voltage line under the control, there appears problem of the choice of a real root. The problem can be solved with the help of additional calculations of R_F impedance, which after the defining of L_F value can be calculated with the help of the following equation:

$$U_F = \left(I_F + K \cdot I_{01}\right) Z_{1ap} L_F + \frac{3 R_F I_{01}}{K_0} \qquad (11)$$

The correct answer in relation to the unknown L_F, which can be got from (11) equation, can be only positive in relation to R_F value (taking into account the physical nature). In cases, when both R_F values are positive, the correct L_F is considered to be that, which corresponds to the farthest point calculating from the fault point.

In the second case, if the vector of the current of the reverse or zero sequence is known it is easy to calculate transfer current ratio K_o or K_2. In this case equations (4), (7), (8) and (9) become linear equations in relation to the unknown distance L_F. The problem of rejection of the false root and therefore the realization of calculations becomes easier.

In the third case, which can be used if there are any faults in the measuring circuits of the opposite end of the line protected on the basis of consideration of the substitution scheme Figure 2, we can write down:

$$-U_{i1} + I_{i1} Z_{i1} = -U_{i2} + I_{i2} Z_{i2} = -U_{i2} + I_{i2}(Z_{iL} - Z_{i2}), \qquad (12)$$

where:

$$I_{i2} = -U_{i2} + I_{i2} Z_{i2} + U_{i2} / (Z_{iL} - Z_{i2}) \qquad (13)$$

The last expression can be used for the defining of distribution current ratio, which allows defining L_F on the basis of equations (4), (6) or (7). Here, however, quadratic equation appears again.

Equations (4), (7), (8) and (9) ensure the equal calculation of L_F value. Here (7), (8) and (9) are easier in their realization, as they do not contain prefault conditions current value.

Results of Tests and Implementation

The described algorithms were tested and verified using faulted lines models of 330 kV transmission lines.

Figure 3 depict the results obtained applying the algorithms presented in this paper for 330 kV transmission line with the following parameters: L = 77.2 *km*, Z_{1ap} = 0.053 + j0.320, Z_{0ap} = 0.253 + j1.122, Z_{s02} = 3.8 + j23.54, $Z_{s12} = Z_{s22}$ = 1.98 + j16.18. Let us start by showing the basic properties of the algorithm under the hypothesis about uniform distribution of the measurement errors. The dependence of the accuracy of the power system E_2 equivalent impedance presentation when $R_F = 10\Omega$ is depicted in

Figure 3. The column 1 is obtained assuming that the angles of remote end measurements results are known precisely. With possible variation of remote end measurements results absolute value are within the limit ±5% (column 1) and ±75% (column 2, this case is real in case the connection channels with protection terminals are missed). Similarly, the columns 3 and 4 correspond to ±1 degree variation of the impedance Z_{s22} angle and variation of the impedance absolute value within the limit ±5% (column 3) and ±75% (column 4).

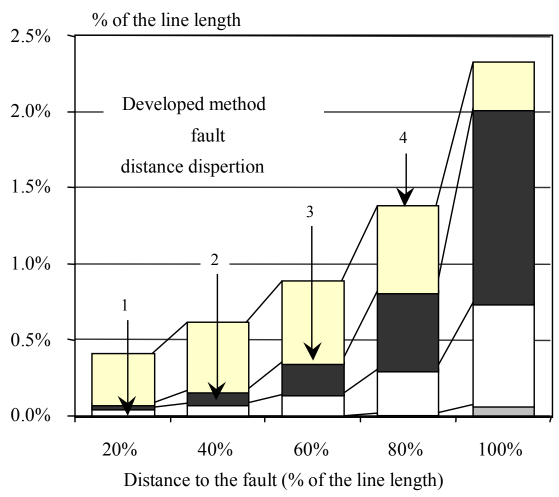

Figure 3. Dispersion as a function of the fault location at different accuracy presentations of the remote system parameters

Autoreclosing

If protection has tripped the faulted due to short circuit power transmission line, then, in a certain time interval, autoreclosing is performed.
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 Figure 4.
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.

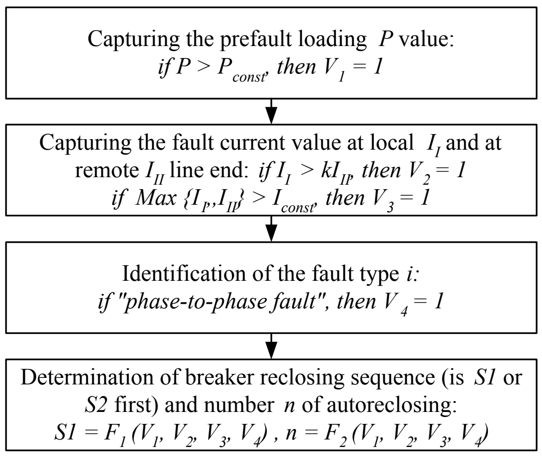

Figure 4. Breaker reclosing algorithm

Conclusion

It is planned that the possibility of applying a similar approach for synthesizing algorithms of the second and third zones of distance protection will be investigated (by using PMUs of neighbouring lines).
The task of using PMUs for increasing autoreclosing effectiveness appears to be interesting. Its solution may ensure an essential increase in the reliability of power transmission lines.

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Haļilova N., Kucajevs J., Sauhats A. Fāžu vektoru mērījumu izmantošana elektropārvades līniju aizsardzībai
Rakstā apskatītas fāžu strāvu un spriegumu vektoru mērījumu rezultātu izmantošanas iespējas augstsprieguma līniju releju aizsardzības un automātikas sistēmās. Mikroprocesoru un globālās pozicionēšanas sistēmas izmantošana dod iespēju paplašināt un pilnveidot automātikas funkcijas. Apskatīta bojāta līnija starp divām

energosistēmām. Analizēti algoritmi, kuru pamatā ir rūpniecības frekvences harmonikas komponentes. Apskatītais algoritms praktiski izslēdz slodzes strāvas ietekmi, energopārvades līnijas darbības režīmu un pārejas pretestību īsslēguma vietās. Aprakstītas fāžu strāvu un spriegumu vektoru mērījumu rezultātu izmantošanas iespējas distances aizsardzības, bojājumu vietas noteikšanas un atkārtotas ieslēgšanas automātikas algoritmos. Apskatīta bojāta augstsprieguma līnija starp divām energosistēmām, pierādītas dažu bojājuma vietas noteikšanas algoritmu izmantošanas iespējas. Lai mazinātu potenciālu, kas var būt atkarīgs no bojājuma vietas un pirmsavārijas stāvokļa, ir jāizvēlas slēdžu skaits un automātiskās atkārtotas ieslēgšanas secība. Apskatītais algoritms piedāvā plašas iespējas atkārtotas ieslēgšanas slēdžu skaita un secības uzstādīšanai. Tas var palielināt elektropārvades līnijas drošumu.

Haļilova N., Kucajevs J., Sauhats A., Use of phasor measurement for line protection
The goal of the present paper is looking for ways of effective use of PMUs in local relay protection and automation systems of power transmission lines. The general use of microprocessor devices allows extending functions of protection and automations, for creation complex and more comfortable in devices exploitation. Basic view and possibilities of the use of PMU are described, such as: distance protection, fault location and autoreclosing. A faulted transmission line connecting two power systems are presented in the paper. The algorithm under consideration practically excludes the influence of the load currents, the power transmission line operation modes and the transient resistance at the place of short-circuits. The support of the data transfer between two terminals provides means for implementation of the discussed algorithm that employs several techniques of current distribution coefficients determination. This paper illustrates algorithms of realization of the described automation functions, on condition that communication channels are shared with the differential protection operation. 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 described algorithm provides wide possibilities for setting optimal breakers' autoreclosing number and sequence.

Haļilova N., Kucajevs J., Sauhats A., Использование измерения фазовых векторов в защитах линий электропередач
Цель статьи- обзор возможностей эффективного использования устройств измерения векторов токов и напряжений фаз(PMU) в системах релейной защиты и автоматики линий электропередач. Повсеместное использование микропроцесорных технологий и глобальной позиционной системы позволяет расширить функции защит и автоматики для создания более комплексных и удобных в использовании устройств. Описаны основные виды и возможности использования измерения фазовых векторов в защитах линий электропередач в энергетике, такие как: дистанционная защита, определение места повреждения и автоматическое повторное включение. Рассмотрена поврежденная линия электропередач, соединяющая две энергосистемы. Рассмотренный алгоритм практически исключает влияние тока нагрузки. Представлен алгоритм, который использует несколько методик определения растояния до места повреждения. Чтобы снизить потенциал, который может зависеть от места повреждения и предаварийным состоянием, необходимо решить число выключателей и последовательность автоматического повторного включения.