THE IMPROVEMENT OF DISTANCE PROTECTION EFFECTIVENESS FOR THE TAPPED LINES

DISTANTAIZSARDZĪBU EFEKTIVITĀTES PAAUGSTINĀŠANA LĪNIJĀS AR ATZAROJUMU

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Introduction

Distance protection (DP) provides the basis for network protection in transmission systems and meshed distribution systems. At the same time the further developments of distance protection to the higher demands on protection systems, resulting from the growing complexity of the transmission and distribution networks and the increased utilization of the plant. The protection of complex transmission networks requires, as a rule, an individual consideration of each application case [1-2]. Further evolution of microprocessor technology enlarged the possibilities of the new principles and complex mathematical models creation in program protection algorithm.

The developed earth fault distance measuring unit DMU algorithms touch on the subject of the effectiveness increase for distance relay operation. There is considered the impedance-measuring problem, as the optimization problem, which is solved by the search methods of optimization. It is proposed the control bus voltage balance equations to use as the objective function of optimization. The voltage unbalance is defined as the difference between the measured voltage values and the bus voltage, which is calculated by monitoring currents and network parameters. For the search of the optimal solution it is used the Newton's optimization method. The advantage of Newton's method is in the rapid convergence of iterative process and method defects is in dependences on the initial data. This dependences problem is solved in the paper by using the maximally possible values for the initial vector of the unknown variables. It is help to avoid DP nonoperation during fault conditions.

The phase-to-earth faults on 330kV HVTL Viskali (Latvian EPS) - Shauly (Lithuanian EPS) in the presence the feeding in the zero-sequence system, when an earthed tap-transformer of Telshai terminal is connected to the line without generation behind it, and in the absence connections with Telshai terminal were performed. The operation estimations of the developed and classic earth fault DMU algorithms are shown. The using of the Newton's optimization method for the earth fault DMU increase the DP effectiveness at the single line and tapped line.

The Mathematical Fundamentals Of Algorithms

Distance relay operation is based on the evaluation of the entrance impedance, which is measured by the entrances voltages and currents. If the earth faults Distance relay uses the classical algorithm as follow:

$$\dot{Z}_{mer} = \frac{\dot{U}_{ph}}{\dot{I}_{ph} + \dot{K}_N \cdot \dot{I}_{EF}}, \qquad (1)$$

where $\dot{K}_N = \frac{\dot{Z}0_L - \dot{Z}1_L}{3 \cdot \dot{Z}1_L}$; $\dot{Z}1_L$, $\dot{Z}0_L$ are respectively positive and zero sequence impedance of the line per unit length; $\dot{U}_{ph}$ is phase voltage; $\dot{I}_{EF} = 3 \cdot \dot{I}0$; $\dot{I}_{ph}$, $\dot{I}0$ are respectively phase and zero sequence currents.

In the case of single line earth fault conditions without fault resistance the entrance impedance equals the positive sequence line impedance between the control bus and fault location.

But in the case of the earth fault conditions with fault resistance at the single line the bus voltage function is nonlinear relatively to the positive sequence impedance to fault location as follow from equation:

$$Urele = Irele * Z1_{fl} + I_{EF}(Z1_{fl}, R_F) * R_F,$$

Where $Z1_{fl}$ is the positive sequence impedance between the control bus and fault location; $I_{EF}(Z1_{fl}, R_F)$ is the earth current at the fault location, that is the nonlinear function of the positive sequence impedance $Z1_{fl}$ and fault resistance R_F.

It is not correct to use the classical algorithm (1) for the positive sequence impedance to fault location calculation. In common case for complex network configuration the bus voltage equation may be represented by the following function:

$$\dot{U}_{bus} = f(\overline{\Pi}_{mer}, \overline{\Pi}_{const}, \overline{\Pi}_{fl}),$$

Where $\overline{\Pi}_{mer}$ is the vector of DP measured parameters; $\overline{\Pi}_{const}$ is the vector of the constant network parameters; $\overline{\Pi}_{fl}$ is the vector of the unknown variables.

The problem of the unknown variables vector determination is considered as the optimization task. It is proposed to use the bus voltage balance equation as the objective function of optimization. The voltage unbalance between the control bus measured voltage and computed values of the bus voltage can be defined as follow:

$$\dot{U}_{nb}(\overline{\Pi}_{fl}) = \dot{U}_{mer} - \dot{U}_{bus} \qquad (2)$$

The zero conditions of the bus voltages unbalance is the criterion of optimization:

$$\dot{U}_{nb}(\overline{\Pi}_{fl}) = 0. \qquad (3)$$

The number of the unknown co-ordinates of $\overline{\Pi}_{fl}$ vector may be redused. Thus it is taken into account, that the zero sequence impedance may be expressed as the function of the positive sequence impedance:

$$\dot{Z}0_L = \dot{Z}1_L * (3 * \dot{K}_N - 1)$$

Furthermore, the real and the imaginary part of the positive sequence impedance are connected with the line angle by trigonometric function as follow:

$$\dot{Z}1_L = R1_L + jX1_L = ctg(\varphi_L) * X1_L + jX1_L . \tag{4}$$

Then the unknown vector $\overline{\Pi}_{fl}$ has two unknown parameters $X1_{fl}, R_F$. It is enough to have one bus voltage balance complex equation (3) for the receiving two single variables.
The task of the unknown variables calculation consists in the solution of the nonlinear equations system (3) relative to the impedance to fault location $X1_{fl}$ and fault resistance R_F. Dividing the imaginary and real parts of equation (3), it is obtained the equations system with the real elements in form:

$$\left. \begin{aligned} U_{nb}' &= Re\{\dot{U}_{nb}(\overline{\Pi}_{fl})\} = 0 \\ U_{nb}'' &= Im\{\dot{U}_{nb}(\overline{\Pi}_{fl})\} = 0 \end{aligned} \right\} \tag{5}$$

The nonlinear equations system (5) with the real elements is solved by the known iteration techniques. Newton's method is one of the most rapidly convergent iterative methods for solving the systems of non-linear equations. Newton's method defects are in dependences on the initial data. This dependences problem is solved in the paper by using the maximally possible values for the initial vector of the unknown variables.

The Model Of The Protective Network

The phase-to-earth faults on 330kV HVTL between Viskali (Latvian EPS) and Shauly (Lithuanian EPS) substations in the presence the feeding in the zero-sequence system, when an earthed tap-transformer of Telshai terminal is connected to the line without generation behind it, and in the absence connections with Telshai terminal were performed.
Fig. 1. shows 330kV HVTL in the absence connections with Telshai terminal.

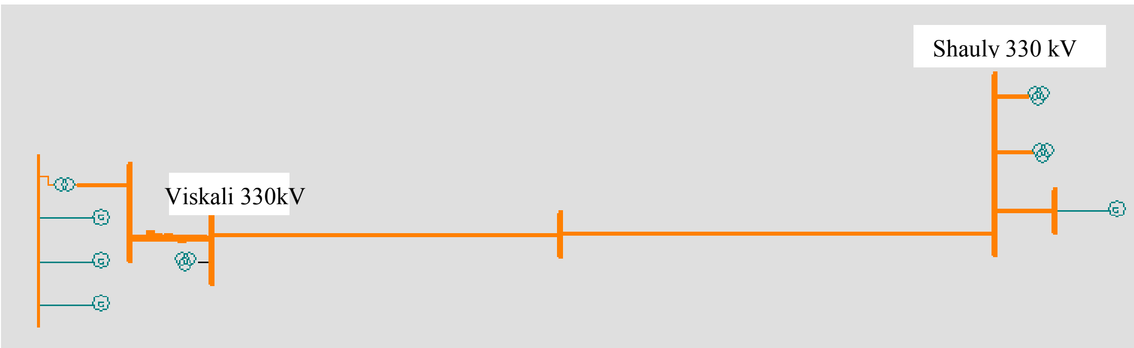

Fig. 1. HVTL model without taps.

So for the study system of Fig.1 the bus voltages balance equation for the earth faults with fault resistance may be calculated according to the expression:

$$\dot{U}_{nb}(\overline{\Pi}_{fl}) = \dot{U}_{ph,mer} - [\dot{Z}1_{fl} * (\dot{I}_{ph,mer} + \dot{K}_N \cdot \dot{I}0_{mer}) + \dot{I}_{EF} \cdot R_F] \tag{6}$$

where $\dot{U}_{ph,mer}$, $\dot{I}_{ph,mer}$, $\dot{I}0_{mer}$ are the phase voltage, phase current and zero sequence current measured by DP; $\dot{I}_{EF} = 3 \cdot \dot{I}0_F$, $\dot{I}0_F$ is zero sequence fault location current.
So for the study system of Fig.2 the bus voltages balance equation for the earth faults with fault resistance may be calculated according to the expression:

$$\dot{U}_{nb}(\overline{\Pi}_{fl}) = \dot{U}_{ph,mer} - [\dot{Z}1_{fl} * (\dot{I}_{ph,mer} + \dot{K}_N \cdot \dot{I}0_{mer}) + \dot{Z}1_{T-F} * \dot{I}_{EF} * \dot{K}_{cur}(\dot{Z}1_{fl}) + \dot{I}_{EF} \cdot R_F] \quad (7)$$

$\dot{Z}1_{T-F}$ is the positive sequence line impedance between tap and fault location;
$\dot{K}_{cur}(\dot{Z}1_{fl})$ is the current distribution coefficient, which depend on the network configuration to fault location. $Z1_{fl}$ is the positive sequence impedance between the control bus and fault location.

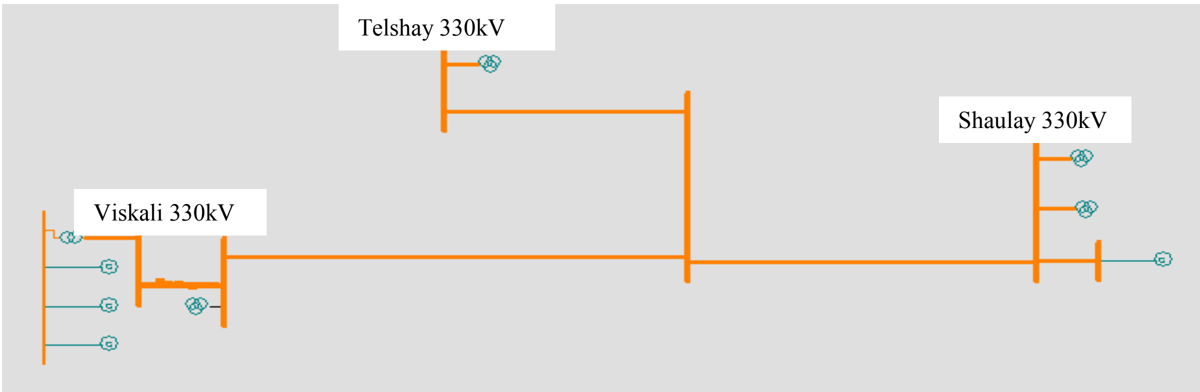

Fig. 2. HVTL model with taps.

Study Results

The earth fault DMU operation on Viskali 330kV substation was examined. Contemporary digital terminals of the line protection have the capability to install different settings groups of DP for each mode of the network configuration and to indicate the DMU operation algorithm. It is considered two regimes of network configurations.

- Regime 1. The single line without the tap (Fig.1.)

In this case the phase-to-earth faults located on the line from the controlled bus to the end of the protection first zone. Two algorithms were analysed:

1. The classic earth fault DMU algorithm, which use the equation (1);
2. The earth fault DMU algorithm, which is based on Newton's optimisation method and the objective function of the bus voltages balance equation (6).

The estimations of two DMU algorithms operation during the phase-to-earth faults with the variable fault resistance till 40Ω are shown at Fig.3, 4, correspondingly.
Fig.3 shows the tripping characteristics on the complex plane of the positive sequence impedance and the estimations of the classical earth fault DMU algorithm operation. There is correct operation only during the earth faults without fault resistances. In another earth fault conditions it is possible, that the distance relay out of operation. The fact is that the measured vector includes not only impedance to fault location, but also fault resistance. The expansion

of the tripping characteristic zone along the real axis is not always permissible, because it is possible to get to the load resistance region.
Fig.4 shows the tripping characteristics on the complex plane of the positive sequence impedance and the estimations of the earth fault DMU algorithm, which is based on Newton's method and the bus voltage balance equation (10). In this case the effectiveness of the DMU algorithm operation is very high in all conditions. The mathematical expectation of the work error is smaller then 0.1% in all cases. This fact allows to set a narrow tripping characteristic zone along the resistance axes for increasing the effectiveness of operation for distance relay during abnormal regime, for example in out of step conditions.

- Regime 2. The single line with the tap-transformer (Fig.2.).

Special requirements on the selectivity of relay operation are derected to the end of the protected zone. Therefore in this case the phase-to-earth faults located at the end of the DP first zone for the protected line. Two DMU algorithms were analysed:

1. The classical earth fault DMU algorithm, which use the equation (1).
2. The earth fault DMU algorithm, which is based on Newton's optimisation method and the objective function of the bus voltages balance equation (7).

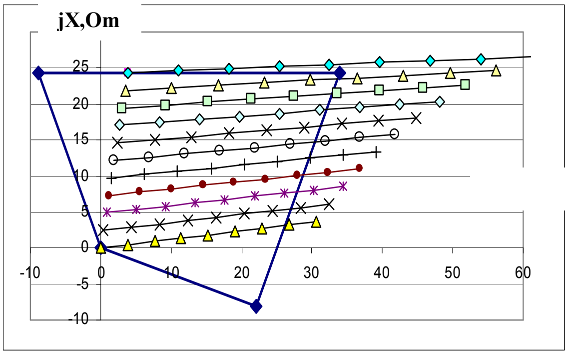

Fig.3. The estimations of DMU algorithms (1) during phase-to-ground faults

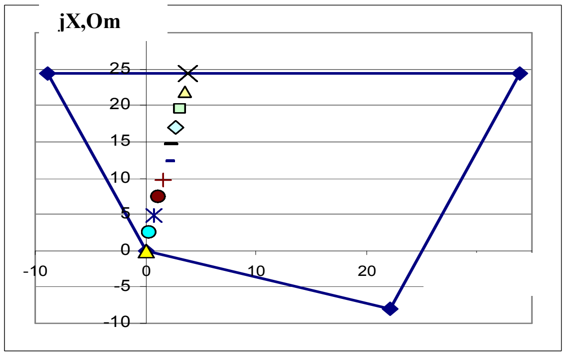

Fig.4. The estimations of DMU algorithms (6) during phase-to-ground faults

Fig.5 shows the tripping characteristics on the complex plane of the positive sequence impedance and the effectiveness estimations of two earth fault DMU algorithms. In this case the effectiveness of the developed DMU algorithm operation is higher in all conditions. The fault resistance do not influence on new algorithm operation. The mathematical expectations of the impedance measuring error for new DMU algorithms were calculated for the earth fault conditions with the fault resistance $R_F = 0 - 40, Om$ and it is 2.1% for the developed earth fault DMU algorithm (7) and 12.4% for the DMU classic algorithm (1). It may be considered that the developed earth fault DMU algorithms are more effective.

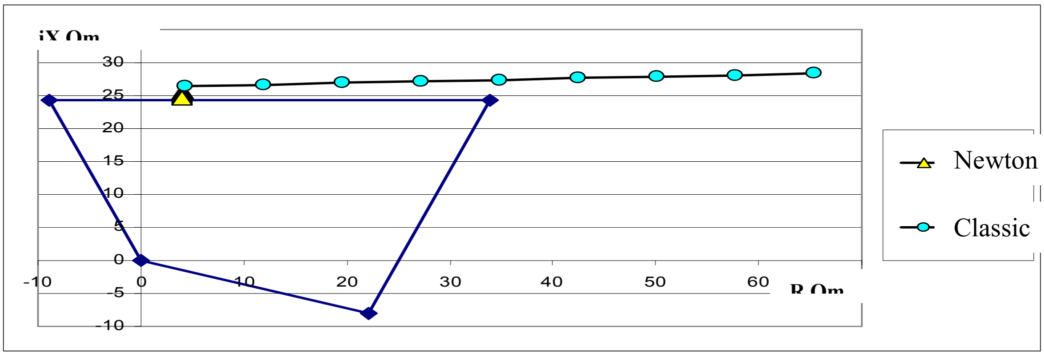

Fig.5. The estimations of DMU algorithms (1) and (7)
during single phase-to-ground faults at the end of the line protection zone

Conclusions

The developed new earth-fault distance relay algorithm gives the following advantages:

- It has high accuracy of the impedance to fault location calculation and therefore it is are more effective then the earth fault DMU classical algorithm in different earth faults.
- The vector of the measured impedance always coincides with the line impedance vector. This fact allows to set a narrow tripping characteristic for increasing the effectiveness of distance relay during abnormal regime, for example, during out of step conditions.
- The algorithm does not require information from the opposite end of the line along the communication channels that guarantees stability with turning off the communication channels.
- The developed earth fault DMU algorithms are especially effective for the use on the strongly loading high voltage transmission lines, where it is necessary to install the narrow operation characteristic of distance relay.

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Belugina V., Lomane T. Distantaizsardzību efektivitātes paaugstināšana līnijās ar atzarojumu.
Tīklos ar sazemēto neitrāli 110-500kV plaši izmanto elektropārvades līniju ar transformatoru uz atzarojuma. Nulles secības strāvas no transformatora sazemētas neitrāles pasliktina distances mērīšanas elementu darbību, it īpaši zemesslēguma ar lielu pārvades pretestību gadījumos. Šis darbs ir veltīts distances aizsardzības mērīšanas elementu darbības efektivitātes palielināšanai zemesslēguma gadījumos līnijās ar transformatora atzarojumu. Izstrādātā algoritma pamatā tika ņemta aizsargājamā objekta matemātiskā modeļa adaptācija pie tīkla konfigurācijas un Ņūtona optimizācijas metode īsslēguma vietas noteikšanai. Algoritmu darbības iegūtie rezultāti Latvijas ES tīklos uzrādīja, ka, pielietojot izstrādāto algoritmu, distances aizsardzības mērīšanas orgānu darbība zemesslēguma gadījumos līnijās ar transformatora atzarojumu ir daudz efektīvāka, nekā klasiskajā algoritmā. Turklāt algoritmam ir šādas priekšrocības: nav vajadzīga informācija par parametriem no pretējas līnijas puses; tiek nodrošināta droša aizsardzības darbība īsslēguma gadījumos ar lielu pretestību un selektivitāte ārējā īsslēguma gadījumos, pateicoties tam, ka aprēķinātais pretestības vektors sakrīt ar līnijas pretestības vektoru.

Belugina V., Lomane T., The improvement of distance protection effectiveness for the tapped lines.
In 110-500kV networks with a dead grounded neutral, high-voltage transmission lines (HVTLs) with tap-transformers are widely used. The zero-sequence currents from the grounded neutral of the transformer disturb the operation of the distance measuring elements, especially at the earth faults through the high contact resistance. The work is dedicated to the efficiency improvement of the distance measuring elements during earth faults on single lines and the lines with tap-transformers. The authors have developed the algorithm based on the adaptation of mathematical model of the protected object to the network configuration and on Newton's optimization method for effective solution of the fault location problem. The estimation of algorithms applied to the 330kV lines of the Latvian Power System has shown that the proposed algorithm is more effective than classical ones. Furthermore, the algorithm has the following advantages: the information about the parameters from the opposite side of a line is not required; the reliable protection operation at earth faults with a high resistance is achieved; the selectivity during external faults is provided owing to the fact that the measured impedance vector lies on the vector of line impedance.

Белугина В., Ломане Т., Повышение эффективности дистанционной защиты линий.
В сетях с глухо заземленной нейтралью 110-500кВ широко используются ЛЭП с трансформатором на ответвлении. Токи нулевой последовательности от заземленной нейтрали трансформатора ухудшают работу дистанционных измерительных органов, особенно, при коротких замыканиях на землю через большие переходные сопротивления. Данная работа посвящена повышению эффективности работы дистанционных измерительных органов защиты от коротких замыканиях на землю в линиях с трансформаторной отпайкой. Разработанный алгоритм основан на адаптации математической модели защищаемого объекта к конфигурации сети и применении метода оптимизации Ньютона для эффективного решения задачи определения мест коротких замыканий. Полученные оценки работы алгоритмов в сетях 330kV Латвийской ЭС показали, что работа дистанционных измерительных органов по разработанному алгоритму более эффективна, чем по классическому алгоритму. Кроме того алгоритм имеет следующие преимущества: не требуется информация о параметрах с противоположной стороны линии; обеспечивается надежная работа защиты при коротких замыканиях через большое сопротивление и селективность при внешних коротких замыканиях благодаря тому, что расчетный вектор сопротивления лежит на векторе сопротивления линии