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Misoperation of the Differential Protection During the Dynamic Processes of Faults in the Secondary Protection Circuit. Differential Protection Modeling with MATLAB Software and Fault Simulation

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Abstract: - The effect of faults in secondary current circuits in differential relay operation is presented in this work. It is found that faults in secondary circuits cause misoperation of differential protection, particularly from short circuits outside the normal zone of operation. If a short circuit occurs in secondary circuits, then the differential current will be increased up to a considerable value. Current value depends on the fault location and power of circuit loop and relay protection. This differential current is not sufficient for the relay to operate, if in normal circumstances, there are no dynamic processes in the power system. Therefore, this case corresponds to the situation when a short circuit occurs in secondary circuits, where neutral point of the transformer is grounded. General case is analyzed by modeling the differential protection in MATLAB. As a model, a numerical relay of the type "MICOM" (ALSTOM) is used. Faults using the MATLAB software are simulated, i.e, a short circuit in the secondary circuit, and the protection operations are achieved.

Key-words: - Differential protection, short circuit in secondary circuit, Matlab simulation

I. Introduction

Transformer differential protection is based on the principle of comparison of measured variables, i.e the instantaneous values of the phase currents of all ends are compared with one another.

Figure.1 shows a typical differential relay connection diagram for one phase. Before the phase currents of the individual windings or ends can be compared, they must first be matched with respect to the absolute value transformations resulting from the rated transformation ratios of the transformer and the main current transformer. Since the phase of the measured variables is also included in the current comparison, the phase relations of the amplitude-matched phase currents of the ends in questions must also be matched in accordance with respective vector group.

Only an internal fault in the protection zone of the differential protection will generate a phasor sum of end currents that differs from zero, namely the differential current I_d . The magnitude of the differential current can be used as the criterion for detecting an internal fault. However, in some cases, and CTs saturate or their ratios are not matched perfectly. This causes the differential signal to become considerably large even though there is no internal fault. In order to prevent false tripping in these cases, the threshold needs to be set at high value. However this would limit the relay's sensitivity. Therefore the practical solution is to use the second current namely the Restrain current I_r . The restrain current created by relay is equal to the sum of the currents (magnitudes) at all the terminals of protected elements. The restrain current is much higher during external faults than during internal faults. The function Id=f(Ir) is represented as tripping characteristic in the Id-Ir plane shown in fig.1

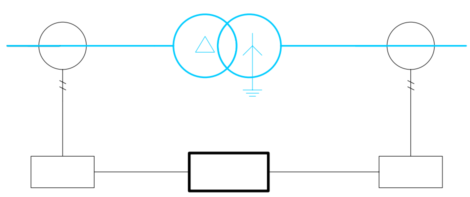


Fig. am

The formation of the restraining variables differs between two and three-winding protection. The following equations are valid for uniformly defined current arrows relative to the protected equipment, that is the current arrows of all windings point either towards the protected object or away from it.

The differential and restraining currents for two winding protection is of the following form

$$I_d = |\underline{i}_1+\underline{i}_2| \quad (1)$$

$$I_R = \frac{1}{2}\left(|\underline{i}_1| + |\underline{i}_2|\right) \quad (2)$$

And for the three- winding protection:

$$I_d = |\underline{i}_1+\underline{i}_2+\underline{i}_3| \quad (3)$$

$$I_R = \frac{1}{2}\left(|\underline{i}_1| + |\underline{i}_2| + |\underline{i}_3|\right) \quad (4)$$

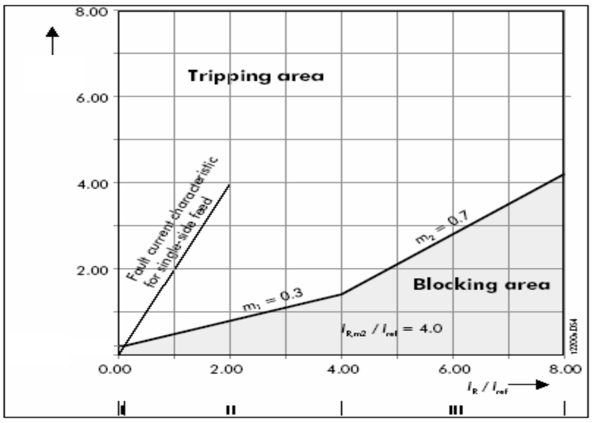


Fig.2 Tripping characteristic of differential protection

As we show the tripping characteristic of the differential protection has two knees. The characteristic equations for the three different ranges are given below.

Characteristic equation for the range $0 \leq I_R < 0.5I_{d1}$:

$$\frac{I_d}{I_{ref}} > \frac{I_{d1}}{I_{ref}} \quad (5)$$

Characteristic equation for the range $0.5I_{d1} \leq I_R < I_{R2}$:

$$\frac{I_d}{I_{ref}} > m_1\frac{I_r}{I_{ref}} + \frac{I_{d1}}{I_{ref}}(1-0.5m_1) \quad (6)$$

Characteristic equation for the range $I_R > I_{R2}$:

$$\frac{I_d}{I_{ref}} > m_2\frac{I_r}{I_{ref}} + \frac{I_{d1}}{I_{ref}}(1-0.5m_1) + 4(m_1 - m_2) \quad (7)$$

The model of differential protection in Matlab-Simulink is represented by (1), (2), (3), (4), (5), (6) and (7).

2. Misoperation of the unit differential protection during the dynamic processes in the power system

The aim of this analysis is to show the differential protection misoperation during the external dynamic processes (outside the zone monitored and protected by the relay). Misoperation of the differential protection in the case of the generator transformer unit of a Thermo Power Plant , i.e., the differential protection operation outside the protection zone, occurs as a result of dynamic phenomena in the power systems, such as single-phase and multi-phase in lines of the power system. This kind of faults results in misoperation whenever faults occur in the power system. Consequences of the fault operations of the protection are very large from the aspect of energetic and financial losses.

This analysis treats a practical example of fault operation of protection and is based on the measurements undertaken in the unit II of the “Kosova B” power plant, i.e., in the unit differential protection.

We describe below some general characteristics of the differential protection circuit. Differential protection, as shown in fig. 3, is provided with information from three parts of the circuit. Data are received from CT’s of the generator, from the CT’s in front of the transformer for auxiliary supply 2BT and from CT’s from the side of 400 kV voltage, i.e., from the secondary side of the main transformer of the network, 2AT. Therefore, this protection has a restricted operation zone inside the field covered by CT,s mentioned. Protection must operate against every electric fault inside this zone and must be nonresponsive to any electrical fault outside this zone.

From data gathered, we see that every temporary or permanent short circuit in overhead lines (OHL), resulted in an operation of the unit differential protection. It is obvious that the protection did not operate in normal working circumstances of the Transmission network.

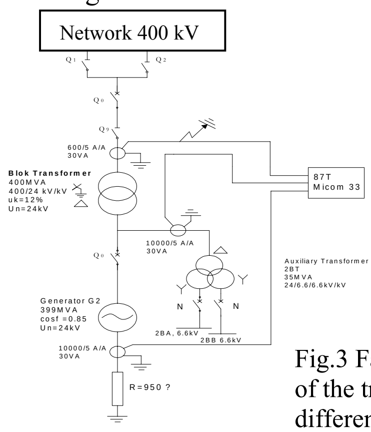
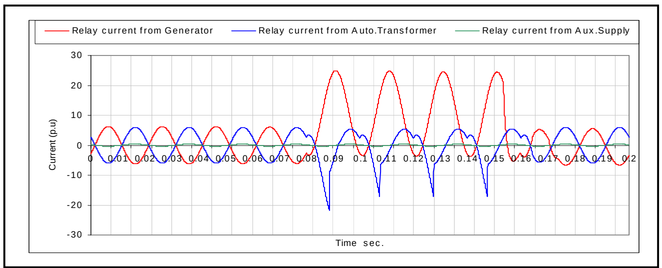


Fig.3 Faults in the secondary circuit of the transformer that supply the differential protection

If a short circuit occurs in secondary circuits, as shown in fig. 3, then differential current will be increased up to a considerable value around 20%, depending on normal circumstances in the system. The value of the current depends on the fault location and power of the relay circuit. This differential current is not sufficient for the relay to operate, if in normal circumstances there are no dynamic processes. Therefore, this case corresponds to the situation when a short circuit occurs in secondary circuits of the 400 kV zone, where neutral of the transformer is grounded. Misoperations of the relay occur during the faults outside the zone protected by the relay. This can be seen also from the graphical representation of the fault's wave shape current that flows in the relay (fig. 4). Therefore, we have different wave shapes currents increased considerably in amplitude. This effect normally causes the increase of differential current in relay. In fig. 5, the module of differential and restrain current is represented. Differential current corresponds to the case when a short circuit outside the zone protected by the relay occurs. Since there is also a permanent fault in secondary circuit toward CT's (current transformers) of the 400 kV side, then, normally, in these circumstances in the differential relay we find the value of differential current exceeding the operation limit of the relay (fig. 5).



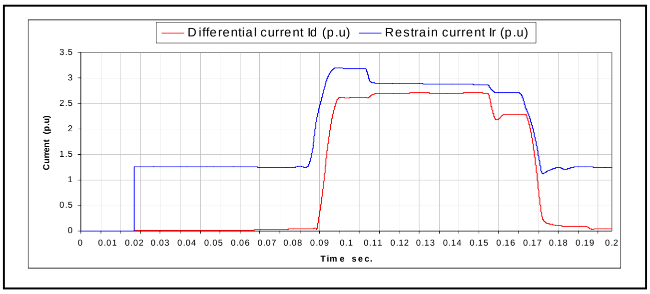


Fig.5. Differential and restrain currents in differential relay

Operation of the relay will occur in normal conditions as well, if the short circuit occurs in secondary circuits, on the side where there is no need for filters of zero sequency (generator zone – primary winding of transformer). This case occurs when the loading of generator is equal to the value of relay setting or higher. In our case the setting of the relay is 40%In (or >40%In). Therefore, we see that misoperation of the differential relay, depending on the location of the fault in secondary circuits.

During the regime of normal operation through the differential winding, a small current flows due to the current of magnetization of power transformers and errors of CT's(current transformers). This current has a small percentage in comparison with the nominal current. Differential protection must not operate during the short circuits outside the protection zone, i.e., short circuits in the network, during system voltage is applied to a transformer at a time when normal steady-state flux should be at a different value from that existing in the transformer, a current transient occurs, known as magnetizing inrush current. The differential relay must detect energization inrush current and inhibit operation. It is known that differential relays of transformers have a lower sensitivity, because the are supplied by current transformers of different types with different transforming coefficients. Differential protection must be disaccorded from the external short circuit, increase of voltage and turning on the transformers. For short circuits, current of disbalance with a large value can flow through the differential winding of the relay. This current appears due to errors of CT's. For example, if the Load Tap changer (LTC) of transformer is in the lowest position, for instance in 20% and when the current of short circuit in the network has the value $I_{lsh} = 10I_n$, then through the differential winding flows the current with a value of $\Delta I = 2xI_d$. In order to prevent the protection operation, the protection is disaccorded from these currents. This can be achieved by installation of the restrain winding on the relay.

Due to different reasons, in the network short-term over voltages might appear. For an increase of voltage by $(1.2\text{-}1.3)U_n$, current of magnetization is increased by $(10\text{-}100)I_{on}$, which results in increase of the current in the relay and misoperation of protection. In order to eliminate this, disaccordance of protection from the short-term increases of voltage in transformers must be carried out, using the fifth harmonic of the current of magnetization due to high induction in the magnetic core.

From the analysis above, it is seen that the differential current in phases where the fault in secondary circuits occurs, can be increased above the value $20\%I_n$. This current flows permanently through the differential relay of the unit. Differential relay for the studied case (relay type TMADT+TTA) is setting to operate with the differential current of $40\%I_n$, or as quoted above, with the value of 2 mA. It is known that any discrepancy of the net resulting in the increase of voltage or current of a short circuit, causes a differential current up to $20\%I_n$ in the differential relay. This is caused by errors of current transformers. When this value is superposed with the current flowing permanently through the fault phase due to a defect in

the secondary circuit, then the differential current reaches the value 40%I_n (>40%In) or 2 mA (or >2mA) which is sufficient for differential protection operation.
We have verified the above analysis by simulation in the applicative "MATLAB" software, version 6.5. Library SIMULINK is used.

3. Differential protection modeling by MATLAB software. Simulation of the short circuit in secondary circuits.

Now we present the simulation of the differential relay. Modeled differential relay is of MICOM 633 type with these characteristics:
nominal current: I_{nom} = 1A ose 5A
nominal power per phase: 0.7 VA
In order to analyze in detail the case of misoperation of the relay, the applicative MATLAB-R 6.5 software is used, which is appropriate enough, particularly for the analysis of transition processes.
Relay modeling is shown in fig. 6.
Filter of high harmonics for differential current is used in the model, as well as current amplitude equilizers, which replaced auxiliary transformers in old-type relays.
Tripp signal is a logic signal. If we have a logic output 1, then we have an Tripp signal which activates the final condition for Tripp the breaker. For modeling the zero sequence current filter, we have used a aux.transformer with ratio 1:1, which in the secondary side is realized in accordance with connection group D11 for the purpose of filtration of the zero sequence current Io and phase matching of the three currents of the same phase. Filter is set precisely for the currents that flow from the current transformers of the 400 kV side, where the transformer's neutral is grounded. In the primary side there is no need for filter of zero sequence currents, since the primary side is connected in a triangle. There is no need for filter of zero sequence of the current from the side of generator, as well.
Complete scheme of functioning is presented in fig.5.

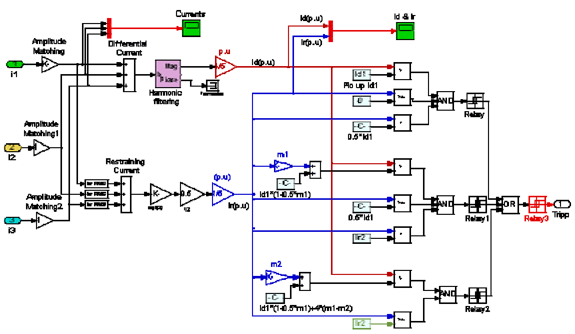


Fig.5. The functional model of e dual – slope percentage differential relay in Matlab - Simulink

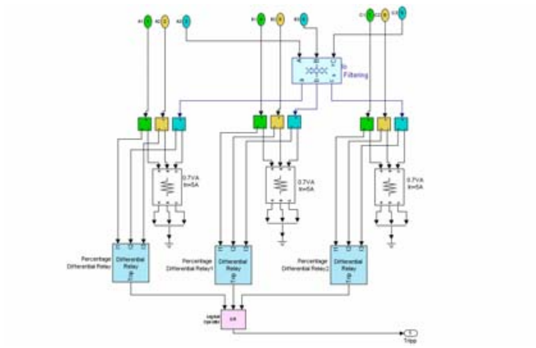


Fig.6, Three phase model of differential percentage relay

Simulations are carried out for different cases of short circuits. Following setting of the relay are taken: Differential current threshold Id1(p.u)=0.4, Lower slope m1=0.3, Restrain current threshold setting Ir2(p.u)=4, higher slope m2=0.7
First, we have carried out the simulation of the three phase short circuit in the protection zone of the generator, where we have simulated a short circuit in the fifth period after the start of simulation. We have simulated the termination of the short circuit in the 8^{th} period. Obtained results are presented in the diagrams below.

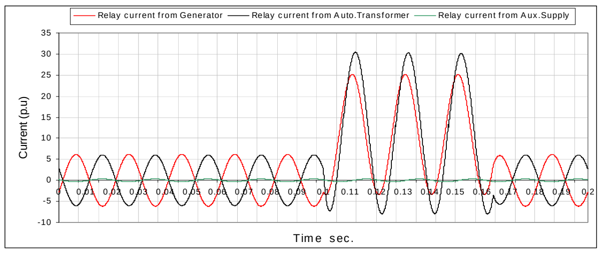


Fig. 7, Three phase relay currents during the internal fault.

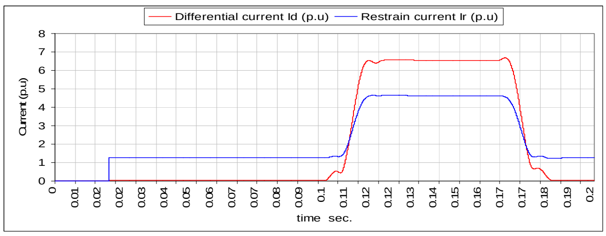


Fig.8, Differential and restrain currents during the internal fault

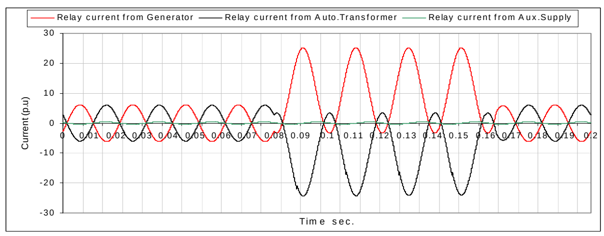


Fig.9 Three phase relay currents during the external fault.

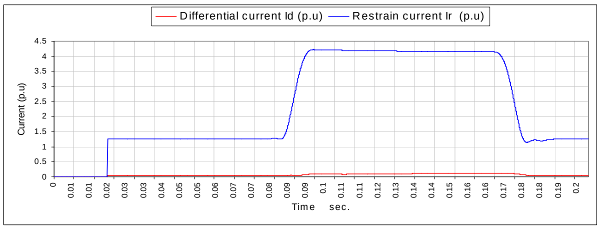


Fig.10, Differential and restrain currents during the external fault

In fig. 11, the case when we have a fault in secondary circuit (short circuit) is simulated. This corresponds to the part of the energetic circuit where the neutral of the energetic transformer is grounded directly.

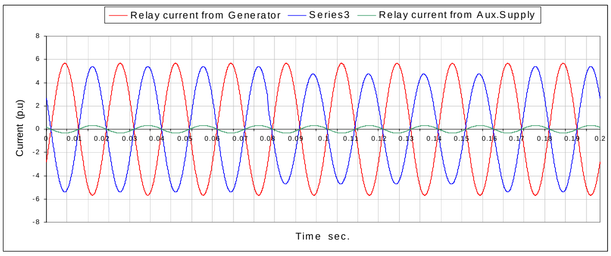


Fig.11 Wave shape current representation in relay, in case of fault in secindary circuits

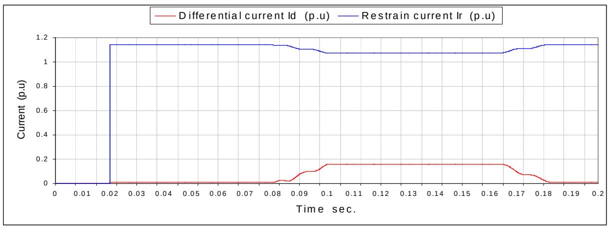


Fig.12 Differential and restrain current

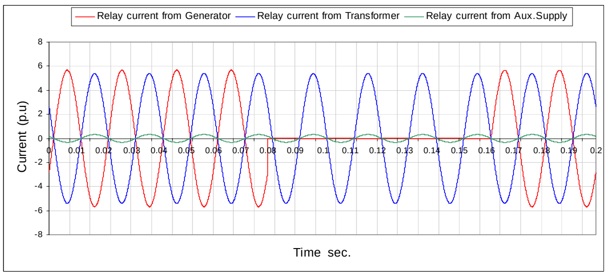


Fig.13. Wave shape current representation of the short circuit in the relay, when the short circuit occurs in the secondary circuit, in the energetic part toward generator

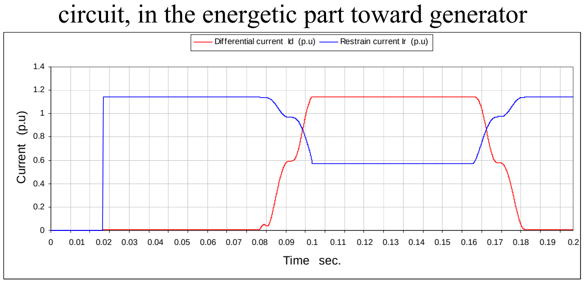


Fig.14 Differential and restrain current according fig.13

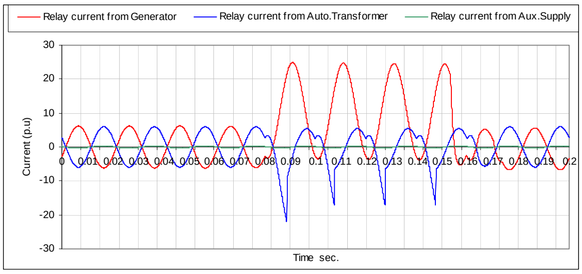


Fig.14. Wave shape current representation of the short circuit in the relay when the short circuit occurs in the secondary circuit. At the same time there is a short circuit in the electroenergetic system outside the protection zone of the relay

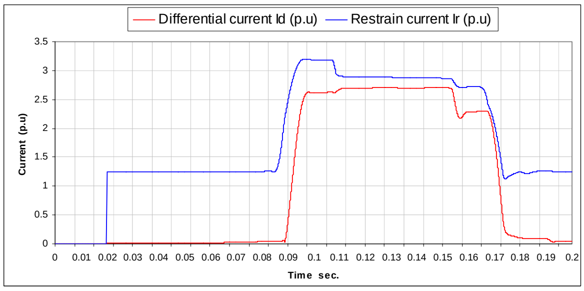


Fig.15, Differential and restrain current for case fig. 14

2.1. Case studies

Analysis is based on the measurements done in the unit II of the Thermo Power Plant "Kosova B", i.e., in the differential protection of the unit, when the generator was out of function, but the Unit transformer and the auxiliary power Transformer (2BT) were operating.

Characteristics of protection circuits for the analyzed case:

Generator:
U_n=24 kV, I_n=9650 A
Current transformers:
10000/5 A, 30VA , 5P15 , 4.82 A
Auxiliary transformer (TTA):
Ratio 1:1000, Regulation=0.96 ,
I_n=5 mA, connection Y-Y
Transformer 2AT:
24 kV/410 kV, I_{np}=9650 A, I_{ns}=560 A, connection DY5
Current transformers:
600/5 A, 30VA , 5P15 , 4.67 A
Aux transformers: (TTA):Ratio 1:1732 , regulat=0.94 ,
I_n=5 mA, connection Y-Δ
Transformer 2BT:24 /6.6/6.6 kV/kV/kV, I_{np}=9650 A, connection DYY
Current transformers:
10000/5 A, 30VA , 5P15 ,
Auxiliary transformer (TTA):
Ratio 1:1000 ,Regulation=0.96 ,
I_n=5 mA, connection Y-Y

Measurements from the CT,s toward the secondary side of transformer 2AT (400 kV), gave these values: I_R=15.8 mA, I_S=5.8 mA, I_T=4.3 mA, I_N=16.27 mA

Zero sequence current is a consequence of the unbalance of current intensities of the phases R, S, T.

The ratio of the transformer 2AT::

$N = I_p / I_S = 9650/560 = 17.232$

CT's ratio from the side of 400 kV:

$N_{TMRR} = 600/5 = 120$

Measured currents are:

$I'_R = 15.8mA,\ I'_S = 5.8mA,\ I'_T = 4.3mA$

If we transform them into the primary of the 2AT transformer, we have these currents:

$I_R = 1.896(A),\ I_S = 0.672(A),\ I_T = 0.516(A)$

Since these currents are small, for the sake of analysis we will increase them 100 times, so that we obtain currents in the secondary of the 2AT transformer (400 kV):

$I_R = 189.6A,\ I_S = 67.2A,\ I_T = 51.6A$

If we reduce these currents in the secondary from the side of 400 kV, we obtain these current values:

$I'_R = 1.576(A),\ I'_S = 0.56(A),\ I'_T = 0.43(A)$

The ratio of transformation of the aux. Transformer TTA:

$N_{TN} = 1/1732 \cdot 0.94$

Current at the input of the differential relay TMADT is:

$I''_{nR(rele)} = 1.676mA,\ I''_{nS(rele)} = 0.596mA$

$I''_{nT(relay)} = 0.457mA$

The ratio of the transformation of the current transformers is:

$N_{TMRR} = 10000/5 = 2000$

Transformed currents in the primary of "2AT" or "2BT", are:

$I_{R400kV} = 189.6A$

$I_{R24kV} = 189.6 \cdot 17.232 = 3267.187(A)$

Since CT's of the 2BT transformer did not have any defects, they have reduced normal currents with same intensities. This have been proved by measurements:

$I_{R24kV} = I_{R2BT(24kV)} = 3267.187(A)$

$I_{S24kV} = I_{S2BT(24kV)} = 3267.187(A)$

$I_{T24kV} = I_{T2BT(24kV)} = 3267.187(A)$

Reduced currents at the output of the CT's are:

$I'_R = 1.633594(A),\ I'_S = 1.633594(A)$

$I'_T = 1.633594(A)$

Currents after the aux. transformers (TTA) are:

$I''_{nR(relay)} = 1.70166mA,\ I''_{nS(relay)} = 1.70166mA$

$I''_{nT(relay)} = 1.70166mA$

Now we make a comparison of each phase that supplies the differential protection from the side of 400 kV and 24 kV voltages.

Differential current that flows through the relay TMADT in phases R, S, T, are:

$\Delta I_R = 0.02566mA,\ \Delta I_S = 1.10566mA$

$\Delta I_T = 1.24466mA$

If we take the ratios of currents for each phase and nominal current in the relay, which is I_n=5mA, we have:

$\Delta I_R = 0.612\% \cdot I_{nR}$

$\Delta I_S = 22.11\% \cdot I_{nS}$

$\Delta I_T = 24.9\% \cdot I_{nT}$

This current is due to the defect in the secondary circuit of the current gauge transformer.

Conclusion:

The paper describes the effects of damages in secondary circuits and the influence on misoperation of differential protection of transformer or unit generator–transformer. Therefore, this case corresponds to the situation when a short circuit occurs in secondary circuits of the 400 kV zones, where neutral of the transformer is grounded. This differential current is not sufficient for the relay to operate, in normal circumstances there are no dynamic processes.

$I''_{nR(relay)} = \sqrt{3} I''_{nR} = 1.676mA$

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