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Earth-Fault Detection Using Fuzzy Logic in Electrical Distribution Networks

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Abstract: *The optimal functioning of electrical distribution networks is to maintain the voltage to acceptable limits in order not to affect the insulation of the electric lines. During a nominal regime the voltage variation is not so big due to the several voltage regulation methods, but during a fault regime, usually during earth-faults can occur overvoltages that affect the line insulation. That is why earth-fault must identified and eliminated as quickly as possible.*

In the present medium voltage networks, the earth-fault detection is made using the admittance and current injection method. That means that in the normal regime, the system measures the reference homopolar admittances of every electric line that is supplied from the substation busbar after each tunning cycle for the Petersen Coil. By injecting a current in the coil it can discover the line with the biggest asymmetry in a 20-30ms time interval, which is the earth-faulted line. This method is perfectly functional when is precisely known the homopolar current and the capacitive current of the grid. There are projects where the Holmgreen filter is chosen with a big nominal current and the measuring of the homopolar current is done with errors because of the small earth-fault current in the medium voltage networks with Petersen coil and this way the earth-fault detection can function with errors. The classic method needs precise data in order to have good results.

The article is researching the possibility of detecting the earth-faults with fuzzy logic. The fuzzy logic uses artificial intelligence and allows earth-fault detection even if the input data is not so accurate because of the errors given by the instrument transformers. So using several logic rules, the phase and the circuit with earth fault can be successfully identified even if the input data is not so precise.

The expert fuzzy systems can be successfully used in earth-fault detection and also in detecting any kind of fault with superior results to the classical method because using the data with errors can obtain good results using the logic small, normal, and big for currents and voltages in the system can take decisions similar to the human operator.

1. INTRODUCTION

The main cause of earth-faults in an overhead distribution line is the failure or puncture of the insulator. The insulators are used in overhead transmission lines to provide insulation between the live conductor and metallic towers that are already connected with the earth's surface.

The main cause of earth-faults in cable distribution networks is damaging the insulation of the cables during work for another utility or the aging of the cable insulation.

During a fault earth-faults regime the overvoltages can affect the line insulation. That is why earth-faults must identified and eliminated as quickly as possible with maintenance techniques.

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Modern maintenance techniques become a competitive major advantage thanks to the fault detection early before the line insulation needs a major repair.

Remote monitoring technologies and on-site diagnosis on the maintenance using artificial intelligence can maximize the continuity of electrical energy delivery and reduce costs caused by energy delivery shutdown.

Integrating smart monitoring systems - using artificial intelligence - performs tracking in real-time of the condition of a distribution electrical network, and of the performances of its critical components. Preventive maintenance is the combination of activities consisting of monitoring and regular inspections. Its purpose is to avoid any possible replacement of the faulty line - as an expensive interventional corrective solution. This level of maintenance is the most efficient solution and a necessary solution to implement.

2. EARTH-FAULT CURRENTS IN MEDIUM VOLTAGE ELECTRICAL DISTRIBUTION NETWORKS

2.1. Earth-fault current in a neutral insulated system

The neutral insulated system is used mostly in medium voltage networks with short lengths. That means the using of this kind of neutral treatment is for networks with low capacitive currents, usually below 10A.

Figure 1 represents the equivalent diagram for a balanced triphasic system with insulated neutral and the electrical parameters used in it. There are represented the phasor diagram in normal and earth-fault regimes.

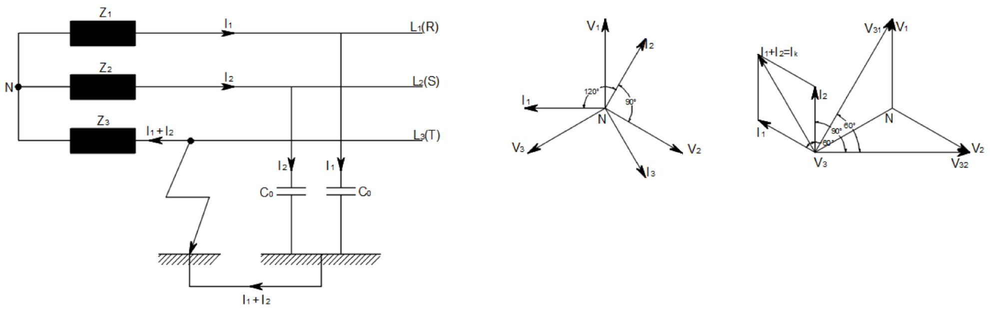

Figure 1. Diagram for earth-fault detection in a neutral insulated system

Source: Own calculations

During an earth-fault the neutral potential changes from the earth potential to the potential of the faulted phase ($V_3 = V_N$). In this way, the potentials of the good phases will rise $\sqrt{3}$, and the angle between them will be changed from 120° to 60°. The earth-fault current I_k is defined as a sum of the capacitive currents that flow on the good phases according to Wadhwa (2012) and Schlabbach and Rofalski (2008).

$$I_k = I_1 + I_2 \quad (1)$$

If this method is used in networks with big capacitive current, during an earth-fault the voltage on the good phases could be 4 times bigger than the phase voltage according to Weedy et al. (2012).

2.2. Earth-Fault Current in Distribution Networks Treated with Resistance

Figure 2 represents the equivalent diagram for a balanced triphasic system with neutral treated by resistance and the electrical parameters used in it. There are represented the phasor diagram in normal and earth-fault regimes.

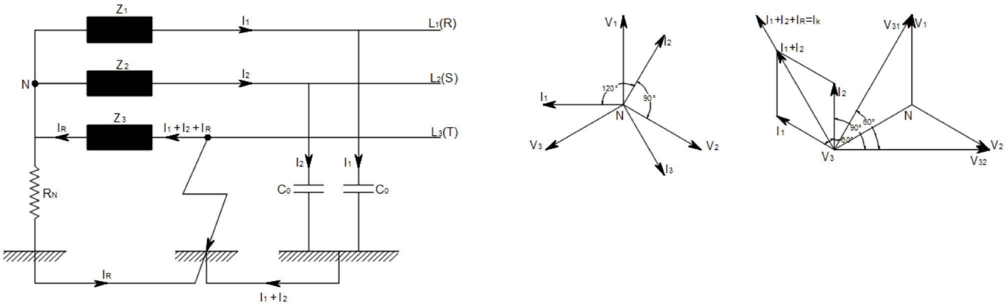

Figure 2. Diagram for earth-fault detection in distribution networks treated with resistance
Source: Own calculations

During an earth-fault the neutral potential changes from the earth potential to the potential of the faulted phase ($V_3 = V_N$). In this way, the potentials of the good phases will rise $\sqrt{3}$, and the angle between them will be changed from 120° to 60°. The earth-fault current I_k is defined as a sum of the capacitive currents that flow on the good phases. The earth potential V_f will be different from the neutral potential and through the resistance will flow a current in the same sense as the earth-fault current related to the resistance according to Wadhwa (2012) and Schlabbach and Rofalski (2008).

$$I_R = V_f / R_N \tag{2}$$

So, the compensated earth-fault current will be:

$$I_f = I_k + I_R \tag{3}$$

That means that any earth-fault current is boosted with the current flowing through the resistance in the faulted regime and in this way can be easily detected.

This method is used in small cable networks or in big networks where the capacitive currents are very high and another method is expensive. Because of the big currents that are flowing through the earth during an earth-fault, the entire network must have good earthing, which in the case of long overhead lines is very expensive.

2.3. Earth-Fault Current in Distribution Networks Treated with Petersen Coil

Figure 3 represents the equivalent diagram for a balanced triphasic system with neutral treated by Petersen Coil and the electrical parameters used in it. There are represented the phasor diagram in normal and earth-fault regimes.

During an earth-fault the neutral potential changes from the earth potential to the potential of the faulted phase ($V_3 = V_N$). In this way, the potentials of the good phases will rise $\sqrt{3}$, and the angle between them will be changed from 120° to 60°. The earth-fault current I_K is defined as a sum of the capacitive currents that flow on the good phases. However, the earth potential V_f. will be different than the neutral potential and through the Petersen coil will flow a current on the opposite side with the earth-fault current related to the coil impedance according to Wadhwa (2012) and Schlabbach and Rofalski (2008).

$$I_L = I_L \cdot V_f / (\omega L) \quad (4)$$

So, the compensated earth-fault current will be:

$$I_f = I_k - I_L \quad (5)$$

The condition for the resonance point of the coil is:

$$I_k = I_L \quad (6)$$

This method is used in most distribution networks because of its advantages. The earth-fault current is very small so the electric arc at the place of the fault turns itself off. However, if the capacitive current is very high, this method could be very expensive.

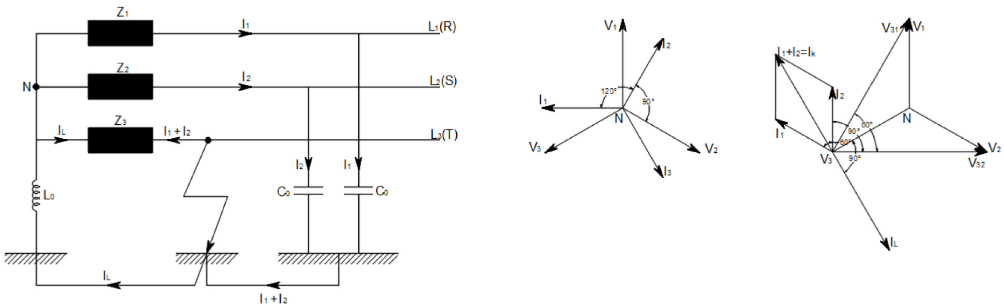

Figure 3. Diagram for earth-fault detection in distribution networks treated with Petersen Coil

Source: Own calculations

3. EARTH-FAULT DETECTION IN MEDIUM VOLTAGE ELECTRICAL DISTRIBUTION NETWORKS

The easy earth-fault detection is done in the networks treated with resistance and insulated because of the high current that flows during the fault. In the networks treated with Petersen Coil the earth-fault current is very small because of the coil current that opposes the capacitive current of the good phases and the detection of earth-faults is hard to do with precision.

The common method to detect earth-faults in electrical distribution networks is the admittance and current injection method. It detects the earth-faults by making a current injection after each setpoint of the Petersen Coil, for measuring the homopolar admitances of the lines connected to the busbar. The measured values are compared with the reference admittances. The line with the biggest asymmetry is the faulted line and can be detected in a period of 20-30 ms according to Trench Austria GMBH (2003) and Vasilievici et al. (2003).

Figure 4 is an example of a medium-voltage busbar with different types of electric lines. Two lines are with loading and two lines are functioning but not loaded.

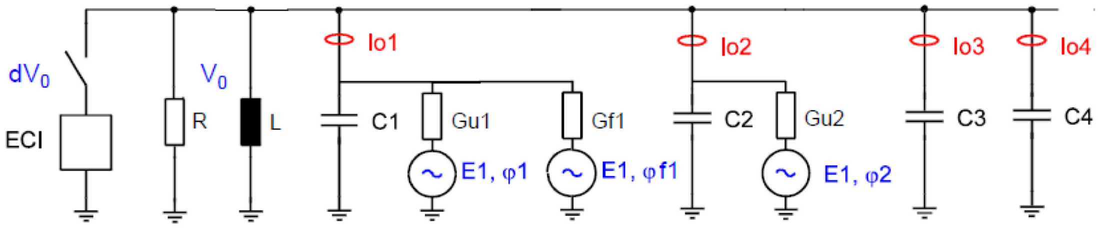

Figure 4. Diagram for earth-fault detection using the admittance method [6]

Source: Trench Austria GMBH, 2003

However, this method needs high-precision measurements in order to give good results. If the homopolar current is measured with errors, the detection of the faulted line is not done properly. To solve this problem we can use artificial intelligence in order to detect not only the earth-fault of a line but any kind of fault. The next chapter describes the fuzzy logic solution in order to detect faults on a line.

4. EARTH-FAULT DETECTION IN MEDIUM VOLTAGE ELECTRICAL DISTRIBUTION NETWORKS USING THE FUZZY LOGIC

The expert system will use fuzzy logic in order to detect the faults on the electric lines. The inputs for the system will be the current on each phase, the homopolar current, the voltages on each phase, and the homopolar voltage.

In the fuzzy system, the variables can take values between 0 and 1, and using the rules we can detect the outputs using approximate values for inputs according to Takagi and Sugeno (1985) and Zadeh (1989).

For each input, we set 3 levels: "L" – Low; "N"- Normal, and "H"- High for approximation and building of the logical rules in the table below.

Table 1. The Inputs and Outputs of The Fuzzy System

Rules	Input variables								Output Variables
	I_1	I_2	I_3	I_0	V_1	V_2	V_3	V_0	State
1.	N	N	N	N	N	N	N	N	No Fault
2.	H	N	N	H	L	H	H	H	L1-G
3.	N	H	N	H	H	L	H	H	L2-G
4.	N	N	H	H	H	H	L	H	L3-G
5.	H	H	N	H	L	L	H	H	L1,2-G
6.	H	N	H	H	L	H	L	H	L1,3-G
7.	N	H	H	H	H	L	L	H	L2,3-G
8.	H	H	N	H	L	L	N	H	L1,2
9.	H	N	H	H	L	N	L	H	L1,3
10.	N	H	H	H	N	L	L	H	L2,3
11.	H	H	H	H	L	L	L	L	L1,2,3

Source: Own research

Where: N – Normal, L – Low, H – High, I_1 – Phase L1 Current, I_2 – Phase L2 Current, I_3 – Phase L3 Current, I_0 – Homopolar Current, V_1 – Phase Voltage L1, V_2 – Phase Voltage L2, V_3 – Phase Voltage L3, V_0 – Homopolar Voltage, L1-G–Eartfault L1, L2-G–Eartfault L2, L3-G–Eartfault L3, L1,2-G–Eartfault L1, L2, L1,3-G–Eartfault L1, L3, L2,3-G–Eartfault L2-L3, L1,2–Biphasic Fault L1-L2, L1,3–Biphasic Fault L1-L3, L2,3–Biphasic Fault L2, L3, L1,2,3 – Triphasic Fault.

The simulation of this system was done using the program Matlab/Simulink. The defining of the membership function for input variables is done with the Mamdani Method, each input will be defined on a certain interval: L – Low – [-0,5 0 0,5], N – Normal – [0 0,5 1], H – High – [0,5 1 1,5]

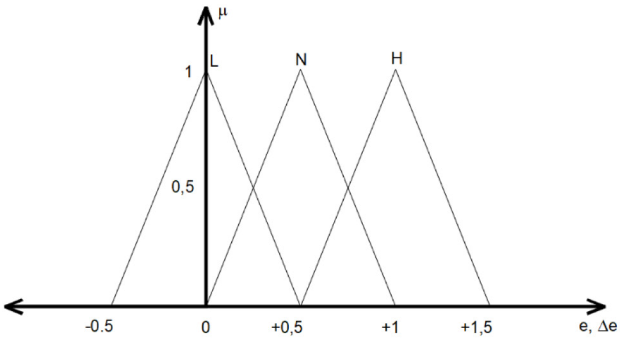

Figure 5. The membership functions for inputs
Source: Own research

Also, we define the membership for output variables:

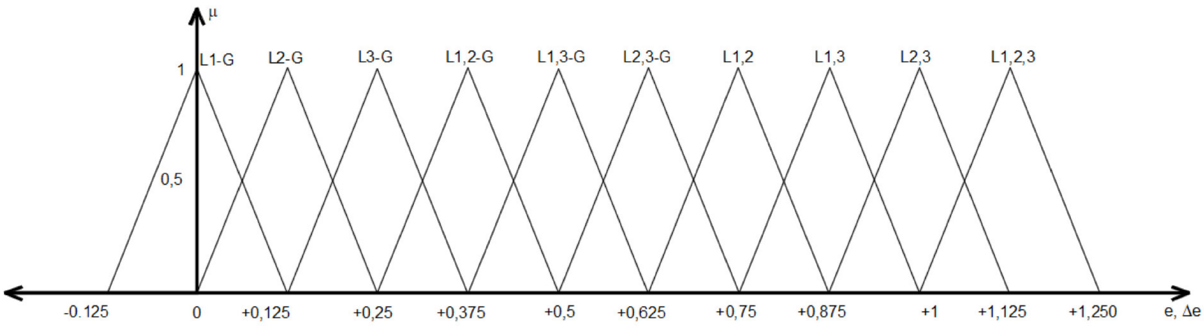

Figure 6. The membership functions for outputs
Source: Own research

If we try to simulate the earth-fault for L2, that means we will use rule 2 from Table 1 to obtain the results in the below figure.

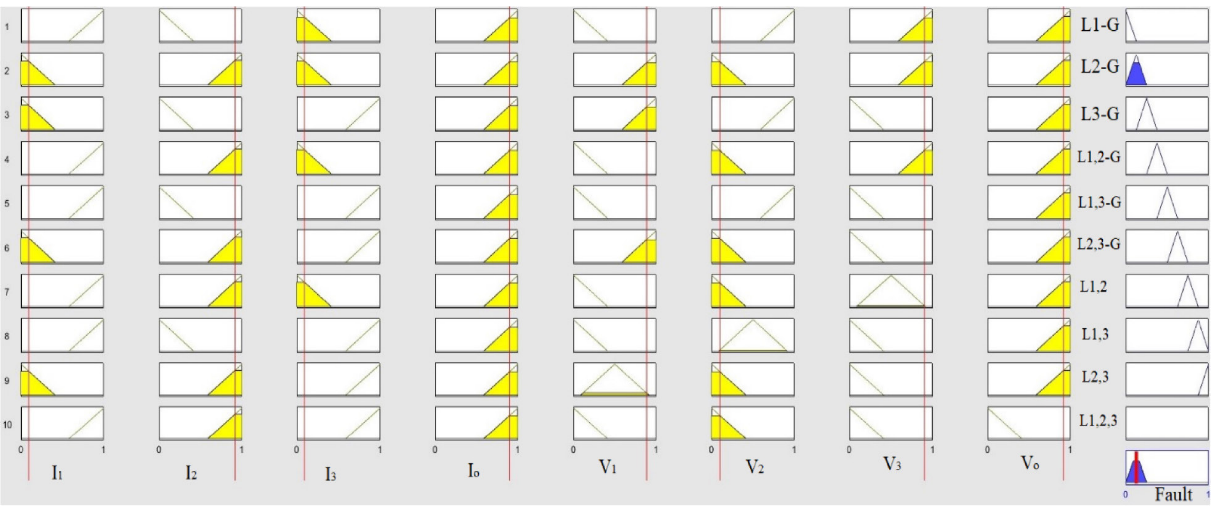

Figure 7. Results for simulation earth-fault on phase L2
Source: Own research

5. CONCLUSION

The admittance and injection current method in detecting earth-faults has good results as long as the input data is measured with very high accuracy. If the data is not accurate, the detection method can lead to bad functioning of the system because the relay will not have the exact information as in reality.

Here we have the improvement with the fuzzy system which in this article was simulated for one electrical line, but it can be adapted for any substation, with one fuzzy regulator for each line. The admittance method usually is used to detect earth-faults in the networks treated with Petersen coil, but this fuzzy system can detect earth-faults in any electrical network no matter how the neutral is treated.

The fuzzy system for detecting earth-faults can be successfully used in substations, it doesn't need accurate measurements because the output is related to some logic rules and is calculated based on the same percentage of incertitude as the inputs have. With a smaller rate of fault in detecting the earth-fault, the fuzzy system can save money because any earth-fault detected and eliminated in time protects the electric line insulation and ensures that the other consumers in the substation are supplied with electricity in parameters.

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Additional reading

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