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SAKARYA ÜNİVERSİTESİ

Determination of Relay Opening Current Information and Coordination of Distribution Network of Sakarya Province, Yazlık Region

Volkan ULUTAŞ*[1] Uğur ARİFOĞLU[1] Halime HIZARCI[1]

Abstract

Electricity is delivered to end users through generation, transmission, and distribution phases. The most important issues during energy journey is to provide selective, rapid, and safe protection to ensure energy continuity. In this context, when the operating conditions defined in the protection systems are exceeded, an effective protection system and coordination are required to provide that as few consumers as possible are affected by the energy outage and reliably isolate the fault. If the short circuit is not separate from the network quickly after a short circuit occurs, network equipment and electrical devices may be damaged because of overcurrent that occurs. In this study, the coordination of overcurrent protection relay at 34.5 kV voltage level of the distribution network in Sakarya Province, Serdivan District, Yazlık region is made and MATLAB/Simulink is used in the modeling of the system. All data of inspected distribution network is embedded to MATLAB/Simulink file and then optimum protection is provided on relay coordination settings by performing power flow analysis and short circuit calculations.

Keywords: Overcurrent, protection relays, circuit modeling, distribution network

1. INTRODUCTION

Dependency on electric energy is increasing in parallel with technological developments in the world day by day. Electric energy generated in power plants is transmitted at voltage level of 380 kV and is generally distributed at voltage level of 34.5 kV, and it is demanded to reach residences at voltage level 380~400 V. While going through whole these processes, it is undoubtedly very important to minimize technical losses, provide clean and reliable energy as well as uninterrupted energy [1]. Though the issues such as using a new equipment in the network, maintenance of the existing ones and wisely selection of the devices that will be used while designing reduce the possibility of fault emerging, they do not completely eliminate it. Circuit breakers are designed to open under load and especially during short circuit. But they cannot break/open by themselves. For this they must be supported with

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proper relay equipment that will continuously monitor the network and generate break signal when the fault occurs [2].

Relay coordination should be done very well taking into account the principle of selectivity in order to eliminate the fault as quickly as possible and to ensure that the minimum number of subscribers are affected by the interruption, to prevent loss of life/injuries, to avoid the power system equipment from becoming unusable and short service life [3]. The process of delaying relay the opening times of the relays positioned as they move from the short circuit point occurring at a point of the power system to the source supplying this short circuit is called relay coordination [4].

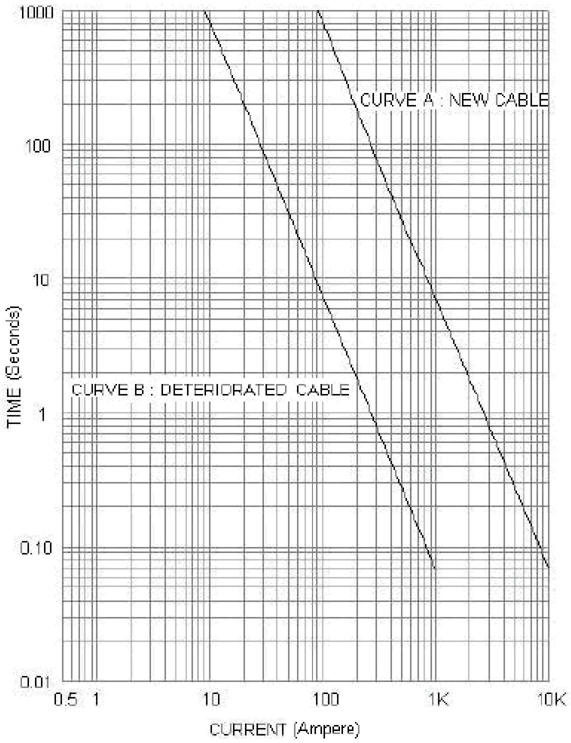

Figure 1 Comparison curves of a new cable and thermally damaged

It is always preferable to use of equipment placed in the network for many years and to have the least possible number of faults. It is essential to keep aging rate at the lowest level to prolong the life of network equipment. For this purpose, as well as maintenance made without delay, it is necessary to prevent the thermal and dynamic effects generated by electrical stresses in the network. Consequently, the life of network equipment can be extended only achieving effective relay coordination. A new cable and damaged cable are compared in Figure 1 [5].

In this study, firstly operation principles of overcurrent relay which are of great importance on power systems protection and how their coordination is achieved of these equipment is dwelled on, then relay coordination of an example electric distribution network at voltage level 34.5 kV is performed for better understanding of the issue. The example distribution network was first modeled in MATLAB/Simulink environment [6], then the power flow and short circuit analysis were realized [7], values related with relay coordination were calculated according to the results obtained from these analyses. As a result, relay coordination is realized to ensure the safest operation of the network without giving an opportunity to occurrence of any risk in the region examined with the outputs of this study.

2. METHOD

Overcurrent relays detect the amplitude of the fault current occurred in the network for any reason and send an opening command to contacts responsible for opening according to the preset current-time characteristic. These relays are divided into two groups as electromechanical and electronic [8]. The operating current that overcurrent relays are set is called starting current and it is indicated by I_s.

Overcurrent relays have definite time and/or inverse time operation characteristics. When fault current (I) exceeds the setting starting current (I_s) in the definite time operating order, the relay contacts change positions after waiting for the set time. On the other hand, in the inverse time operation, time delay of protection relay in the opening process is not fixed and this value changes depending on I/I_s ratio and time factor. Relays are generally arranged to have inverse time operating characteristic in phase-phase and three phase short circuits, and definite time characteristic in phase-earth short circuits [9].

Inverse time relay characteristics according to IEC 60255-3, "Electrical relays-Part3: Single input energizing quantity measuring relays with dependent or independent time" standard is defined as short time inverse (STI), standard inverse (SI), very inverse (VI), extremely inverse (EI) and longtime inverse (LTI) curve. General equation of opening time for inverse time curve is given in Equation (1).

$$t = \left[\frac{A}{\left(\frac{I}{I_s}\right)^{\alpha} - 1} + B\right] \times TMS \qquad (1)$$

Variables used in Equation (1) listed below:

t: opening time (s)

A ve B: constant for characteristic (s)

I: instantaneous current value (A)

I_s: setting current threshold value (A)

α: constant for characteristic (-)

TMS: time multiplier setting (-)

The values of all constants in Equation (1) are specified in IEC 60255-151 standards. IEC 60255-151 inverse time protection curves when TMS=1 are given in Figure 2. TMS multiplier adjustment range for all curves is (0.025-3.2) [10].

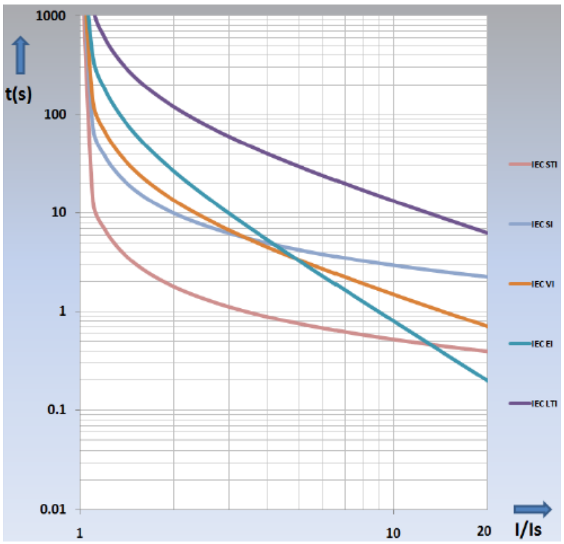

Figure 2 IEC inverse time protection curves when TMS=1

Relay coordination will be done with standard inverse curves in this study. In IEC 60255 standard, Equation (2) is obtained when the values of A=0.14, B=0 and α = 0.02 are replaced in Equation (1).

$$t = \left[\frac{0.14\ s}{\left(\frac{I}{I_s}\right)^{0.02} - 1}\right] \times TMS \qquad (2)$$

The values such as TMS, A, B and α used in inverse time curves are not valid for definite time curves. Graphs related with definite time curves are as in Figure 3 [10].

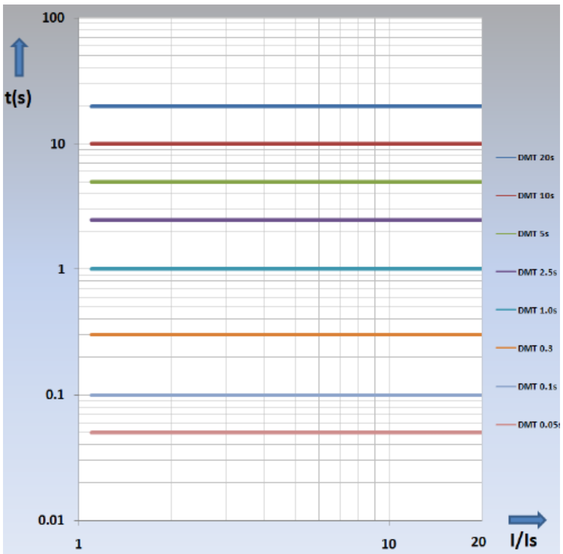

Figure 3 Definite time graphs at various time and current values

Single line diagram of the region in this study is given in Figure 4. A double circuit copper (Cu) XLPE (cross-linked polyethylene) line comes from Sakarya TM to DM1TR1 distribution center, and energy of Yazlık Region to be examined is supplied from Feeder 1 under normal operating conditions. Neutral resistance of Sakarya TM is established as 20 Ω and thus earth fault current is limited to 1000 A.

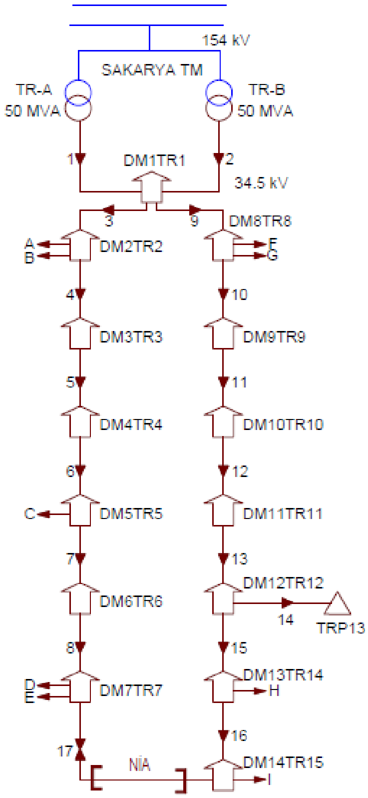

Figure 4 Single line diagram of modeled network

Under normal operating condition, each cabin is connected radially to the grid. In the case of any fault, energy continuity in the region may be maintained by activating ring system. Line data of the network given single line diagram and current transformer (CT) ratio of the breakers protecting this line are given in Table 1.

Table 1 Data of modeled network

Feeder number	Section	Length (m)	CT (A)
1	3(1x240/25 XLPE-Cu)	7582	600/5
2	3(1x240/25 XLPE-Cu)	7556	600/5
3	3(1x240/25 XLPE-Cu)	645	600/5
4	3(1x185/25 XLPE-Al)	707	300/5
5	3(1x185/25 XLPE-Al)	492	300/5
6	3(1x185/25 XLPE-Al)	956	300/5
7	3(1x185/25 XLPE-Al)	508	300/5
8	3(1x185/25 XLPE-Al)	853	300/5
9	3(1x240/25 XLPE-Cu)	1357	600/5
10	3(1x185/25 XLPE-Al)	821	300/5
11	3(1x185/25 XLPE-Al)	718	300/5
12	3(1x185/25 XLPE-Al)	524	300/5
13	3(1x185/25 XLPE-Al)	835	300/5
14	3xSwl	907	100/5
15	3(1x185/25 XLPE-Al)	587	300/5
16	3(1x185/25 XLPE-Al)	850	300/5
17	3(1x185/25 XLPE-Al)	708	300/5

3. SHORT CIRCUIT ANALYSIS

Short circuit analysis results are important in many stages such as establishment and operation of network. Generally, 5% of short circuits occurred in electric distribution network are three phase short circuit, 70% phase to earth short circuit, 15% phase-phase short circuit and 10% two phase-earth short circuit [11].

For the protection relays to open in case of fault, the setting starting current value must be below the value of short circuit current value. Short circuit analysis should be done at the network point that cause maximum current flow through the relay [12]. In the study, line numbers are shown in Figure , and according to the case of short circuit at the end of the line, the current value that will pass through the protection relay of this line is considered in the relay coordination [13].

In this study, MATLAB/Simulink model of the distribution network is given in Figure 5. The model of Adapazarı TM, which is not shown in the single line diagram in Figure 4. Because if the distribution system encounters a network fault, Adapazarı TM can feed the system. So while the system normal working, relay coordination is not necessary from Adapazarı TM. Cabinets, line 1, line 2, transformer centers and measuring blocks were defined as subsystem model and complexities in the modelling file are eliminated. The real data of all the equipment used in the modeling file. Test reports of transformers, disconnectors and breakers were examined and the laboratory results obtained were included in the analysis [14]. Disconnectors and breakers have 16 kA withstand current. The relay current circuit thermal resistance is 4 I_n (20A) (continuous) [10].

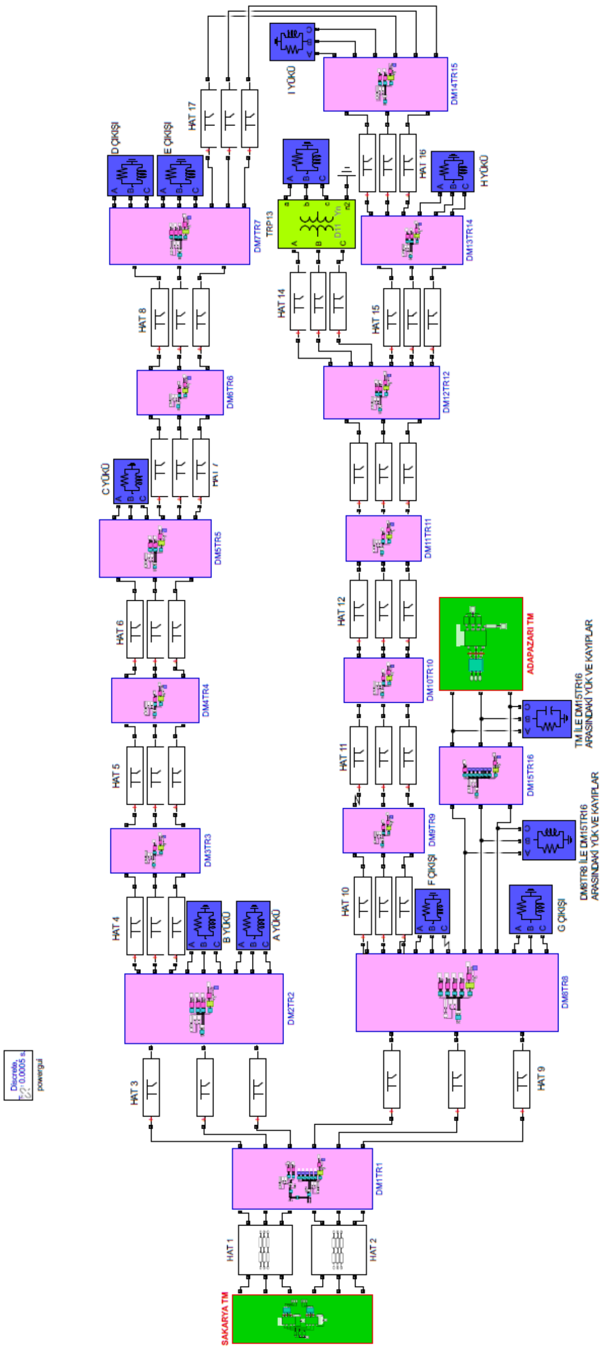

Figure 5 MATLAB/Simulink model of the network

In order to protection relays to open in case of failure, the adjusted starting current value must be below the short circuit current value. Short circuit analysis should be done at network points that cause maximum current flow through the relay [13]. Short circuit currents of system modeled in MATLAB/Simulink program are shown in Table 2.

Table 2 Results of short circuit analysis

Feeder number	Short circuit current (kA)		
	3-Phase	Phase-Phase	Phase-Earth
1	4.87	4.24	0.88
3	4.74	4.13	0.87
4	4.61	4.01	0.87
5	4.53	3.94	0.86
6	4.34	3.78	0.85
7	4.25	3.7	0.85
8	4	3.57	0.84
9	4.66	4.05	0.87
10	4.51	3.92	0.86
11	4.37	3.8	0.86
12	4.28	3.72	0.85
13	4.15	3.61	0.84
15	4.07	3.54	0.84
14	3.368	2.93016	-
16	3.94	3.42	0.83

Power flow analysis is of great importance especially for the actions to be taken in future planning of a system. Power flow solutions play a determinant role in studies to be made for voltage drop, transformer power, line capacity, active-reactive powers and even harmonics [15]. While specifying the current setting value in relay coordination, inrush current value of the system (the highest current drawn at the time of first energizing the system) should also be taken into consideration. In the study, the power flow analysis of the system will be used for determination of the inrush current.

According to IEC SI, the first relay which is in the transformer center, overcurrent relay setting time must be <=0.4e [16].

Inverse time curve will be studied for the first threshold (I>) values of the relays. Inverse time curves are a function of both current and time, the opening times change according to current. There is an inversely proportional relationship between current and time. This allows for large short circuit current to cut the energy instantaneously and not to cut the energy in the short-term inrush current. The first threshold value for the relay at the substation output is determined according to the line capacity value and the TMS factor is set to the range 0.3-0.4 [16]. In this study, the analysis was carried out by decreasing the factor of 0.05 for each cabin. The starting current values are set to 600 A for the transformer station and DM1TR1, and 300 A for afterwards (excluding the cabin outputs except the ring). Inverse time relay coordination is given in Table 3.

Table 3 First threshold setting of relays

Relay	Is (A)	TMS
Sakarya TM (1)	600	0.35
DM1TR1 (3)	600	0.3
DM2TR2 (A)	100	0.05
DM2TR2 (B)	100	0.05
DM2TR2 (4)	300	0.25
DM3TR3 (5)	300	0.2
DM4TR4 (6)	300	0.15
DM5TR5 (C)	100	0.05
DM5TR5 (7)	300	0.1
DM6TR6 (8)	300	0.05
DM7TR7 (D)	100	0.05
DM7TR7 (E)	100	0.05
DM1TR1 (9)	600	0.3
DM8TR8 (F)	100	0.05
DM8TR8 (G)	100	0.05
DM8TR8 (10)	300	0.25
DM9TR9 (11)	300	0.2
DM10TR10 (12)	300	0.15
DM11TR11 (13)	300	0.1
DM12TR12 (14)	100	0.05
DM12TR12 (15)	300	0.05
DM13TR14(16)	∞	0
DM14TR15 (I)	100	0.05

Graphs of the values in Table 3 are given in Figure 6Figure for Sakarya TM (1) and DM1TR1 (3)(9) and in Figure 7 for other cabins.

Calculations were made with Equations (3) - (6) in order to test the compatibility of the first threshold inverse time coordination setting to the system and to determine how long the relays will send interrupt commands. The short circuit current of 2 kA in Feeder 5 at the DM3TR3 output is taken as reference in these calculations.

DM3TR3 (Feeder 5):

TMS=0.2, I_s=300 A

$$t = \left[\frac{0.14}{\left(\frac{2000}{300}\right)^{0.02} - 1}\right] \times 0.2 = 0.724\ s \quad (3)$$

DM2TR2 (Feeder 4):

TMS=0.25, I_s=300 A

$$t = \left[\frac{0.14}{\left(\frac{2000}{300}\right)^{0.02} - 1}\right] \times 0.25 = 0.9051\ s \quad (4)$$

DM1TR1 (Feeder 3):

TMS=0.3, I_s=600 A

$$t = \left[\frac{0.14}{\left(\frac{2000}{600}\right)^{0.02} - 1}\right] \times 0.3 = 1.723\ s \quad (5)$$

TM Output (Feeder 1):

TMS=0.35, I_s=600 A

$$t = \left[\frac{0.14}{\left(\frac{2000}{600}\right)^{0.02} - 1}\right] \times 0.35 = 2.0105\ s \quad (6)$$

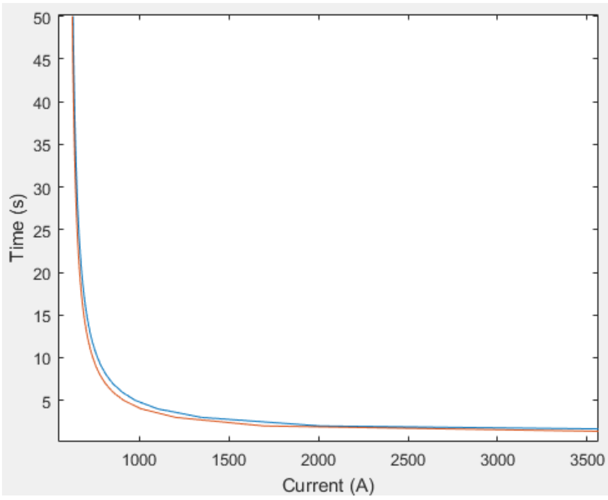

Figure 6 I > inverse time curve for TM output relay and main distribution center (DM1TR1)

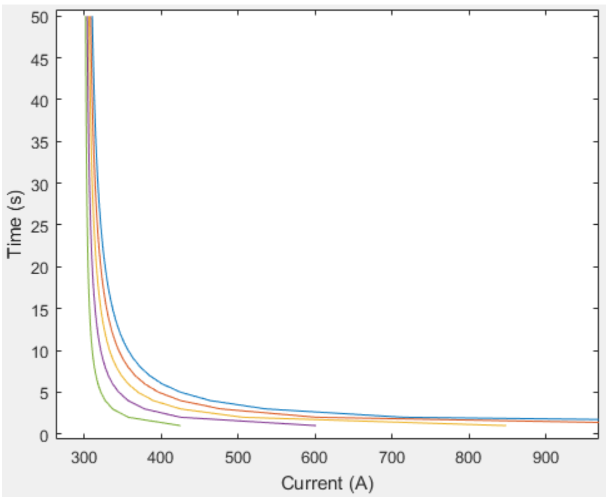

Figure 7 I> inverse time curve for other relays

The definite time curve will be studied for the second threshold values (I >>) of the relays. This setting is taken as 1.1 times the short circuit current in the second or third cabinet for the relays at the substation outputs and time value is are selected in the range of 0-0.3 s [16]. After this adjustment, time value t=0.15 s was chosen at the DM1TR1 main distribution center which is the first cabin.

Since the next cabins are very close to each other, the short circuit current values obtained at the end of the calculations are very close to each other. Hence, to ensure the most effective relay coordination, the second threshold values of some cabins have been made passive so that the least number consumer are affected by the load density and interruption. It was decided that the relay coordination values for the second threshold should be as in Table 4 in this study.

Table 4
Second threshold setting of relays

Relay	I >> (kA)	t >> (s)
Sakarya TM (1)	4.8	0.3
DM1TR1 (3)	4.8	0.15
DM2TR2 (A)	∞	0
DM2TR2 (B)	∞	0
DM2TR2 (4)	∞	0
DM3TR3 (5)	∞	0
DM4TR4 (6)	3.8	instantaneous
DM5TR5 (C)	∞	0
DM5TR5 (7)	∞	0
DM6TR6 (8)	3.5	instantaneous
DM7TR7 (D)	∞	0
DM7TR7 (E)	∞	0
DM1TR1 (9)	4.8	0.15
DM8TR8 (F)	∞	0
DM8TR8 (G)	∞	0
DM8TR8 (10)	∞	0
DM9TR9 (11)	∞	0
DM10TR10 (12)	3.8	instantaneous
DM11TR11 (13)	∞	0
DM12TR12 (14)	∞	0
DM12TR12 (15)	3.6	instantaneous
DM13TR14(16)	∞	0
DM14TR15 (I)	∞	0

The constant time curve will be studied for the third threshold values (I >>>) of the relays. Due to the first and second threshold values, mostly there is no need to the third threshold. However, in terms of the soundness of the application, the third threshold value was used for the substation and the main distribution center (DM1TR1) in this study. The third threshold value for the relays at the substation output is set as 1.1 times the short circuit current in the first cabinet and the time value has been selected in the range of 0-0.15 s [16]. The third threshold value for the substation output is designed as 5.2 kA instantaneous time and for DM1TR1 as 5 kA instantaneous time.

Table 5 Earth settings of relays

Relay	I_o > (A)	t (s)
Sakarya TM (1)	60	1.2
DM1TR1 (3)	60	1.05
DM2TR2 (A)	60	0.03
DM2TR2 (B)	60	0.03
DM2TR2 (4)	60	0.9
DM3TR3 (5)	60	0.75
DM4TR4 (6)	60	0.6
DM5TR5 (C)	60	0.03
DM5TR5 (7)	60	0.45
DM6TR6 (8)	60	0.3
DM7TR7 (D)	60	0.03
DM7TR7 (E)	60	0.03
DM1TR1 (9)	60	1.05
DM8TR8 (F)	60	0.03
DM8TR8 (G)	60	0.03
DM8TR8 (10)	60	0.9
DM9TR9 (11)	60	0.75
DM10TR10 (12)	60	0.6
DM11TR11 (13)	60	0.45
DM12TR12 (14)	60	0.03
DM12TR12 (15)	60	0.3
DM13TR14(16)	60	0.15
DM14TR15 (I)	60	0.03

In this study, the definite time curve is used for the relays to protect the network against earth faults. Earth protection setting for the relays at the substation output is set to 30-120 A and <= 1.4 s [16]. In the study, t is 1.2 in the substation, and the time values in relay coordination are adjusted so that they start from the closest cabinet to the point where the fault occurred and decrease towards the last cabinet farthest from the fault. Coordination parameters obtained under these conditions are shown in Table 5, and graphs are given in Figure 8.

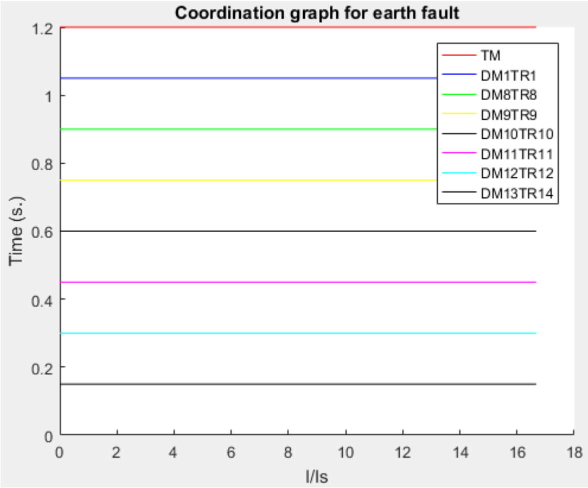

Figure 8 Coordination graph for earth fault

Relay detecting the fault and generating an opening signal and opening the circuit breaker, a time such as 300 ms is required. In this case, one relay should be configured with a time delay of 300 ms in coordination with the other relay behind it. In places where the distance between the two cabinets is very short, such as in the selected region in this thesis, short circuit currents are very close to each other. It is possible to reduce it to 150 ms according to experiences. However, the normally accepted and required time is considered to be 300 ms.

4. CONCLUSIONS

While conducting relay coordination in a power system, analyses are made by considering many factors. Short circuit and power flow analysis are the primary come first among these. In this study, firstly, these two analyses of the investigated network were made with the help of MATLAB/Simulink program, and information about the general condition of the power system was obtained. In the light of this information, starting currents for relay coordination were determined and time factors were calculated. Although the relay coordination has been done virtually, a study has been presented in the network studied so far, blended with the previous experiences. For the coordination of the relays different scenarios can be defined according to the operating scheme of the network. In this study, only the first scenario (between DM7TR7 and DM14TR15 is open in normal operating condition) is studied. If desired, this study can be expanded for new and different scenarios, which also consider factors such as various fault states, load densities and subscriber numbers.

Before implementing a project at the design stage in the field, usage of simulation studies is very important in terms of detecting some mistakes made during the project stage and reaching the correct values. Various projects such as renewal of the network, additional facility work and addition of new loads to the network can be analyzed in a simulation environment and the potential impacts of the project on the field can be examined in a realistic way from various aspects. In this study, the data entry required for the network examined by considering the real operating conditions was provided by using the simulation program.

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The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

V.U: Conceptualization, methodology, writing, simulation studies, investigation, original draft.

U.A: Review, editing, supervision.

H.H: Review, editing.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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