Protection Coordination Practices for Industrial Ring Distribution Network

Case Study of Organized Industrial Zone (GEBZE, Turkey)

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Abstract-The traditional distribution networks are mostly radial. Radial networks are easy to implement and operate, but it introduces a great challenge concerning electricity supply reliability. In organized industrial zones, the unplanned energy interruptions can cost a lot, as industrial loads are always working. Consequently, distribution networks are mostly implemented as a ring network. The ring distribution network improves the electricity supply reliability. However, compared to the radial networks, the application of ring network introduces its own technical challenges such as increased short circuit current during the fault, difficulty in protection coordination, increased rating capacity of each equipment and increased investment cost. In this paper, the protection coordination technique that is used in an organized industrial zone will be discussed. In the ring distribution network, differential relays, which rely on communication between the protection relays, are used for the underground cable protection. To guarantee cable protection when communication is failed, an auxiliary protection by using directional overcurrent relays is used. In this paper, the protection coordination study for the GEBZE organized industrial zone, which is available in Istanbul, Turkey, is conducted by using state of the art methods. The results of the study are verified by applying to ABB relays, which are available on the organized industrial zone's site under study.

Keywords: Differential protection; earth fault protection; organized industrial zones; overcurrent protection; radial networks; ring networks.

I. INTRODUCTION

In the electrical power system, the protection coordination is a very crucial for quality, reliability, and security of power supply, as well as for the safety of life and property [1], [2]. Protection coordination is the about organizing (coordinating) of the protection relays during overcurrent, short circuit and other fault conditions, intended to isolate only the faulty sections of the power system. In power systems, the protection system plays a critical role in keeping the reliability and operability of the system at the highest levels [3]. The proper selection of protection relays and their coordination plays an important role in order to clear the faults that occur during abnormal system conditions. When a fault occurs, only the faulty section has to be disconnected from the rest of the system in the shortest possible time [4], [5]. If the fault current cannot be cleared, the prolonged short circuit current will damage the power system equipment. Therefore, in order to reduce the damage on the equipment, at least there must be a method to limit fault current if clearing the fault is impossible. In addition, the protection system has to be designed in such a way that it cannot result in any unnecessary disconnections of the un-faulted systems. Furthermore, alternative operation scenarios have to be considered for the continuity of the supply during the fault [6].

In order to achieve good coordination between protection relays, short circuit fault analysis has to be conducted. The analysis has to include determination of the maximum and minimum fault currents at the relaying points for which the protection setting has to be determined. For the protection relay that is to be coordinated in a series, the pickup values like for example operation current and the operating time has to be determined in such a way that it provides maximum protection with minimum possible energy interruption. In the event of a fault, the relay near to the fault has to operate first. If the relay near to the fault is unable to operate, for example, cannot send the trip signal to the circuit breaker due to an internal fault, the next backup relay should send the trip signal to its own circuit breaker in order to localize the fault.

Providing coordination in the ring network is not an easy task as the energy flows in two directions [7]. In addition, the short-circuit current of the system increases compared with the radial system.

The challenging issue in the protection coordination of distribution network is the time restriction from the network operators. Due to the time restrictions, the numbers of overcurrent relays that are to be coordinated in the ring will be limited to a few. This makes the coordination of overcurrent protection relays to become more difficult for the ring networks. In this study, the state of the art method for the protection of the

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industrial ring distribution network will be discussed. The study is supported by practical work for the protection coordination of Gebze organized industrial zone distribution network.

In the distribution network under consideration, the protection for the underground cables is provided by differential and directional overcurrent relays. The customer feeders are protected by non-directional overcurrent relays. Electrical Power System Analysis and Operation Software (ETAP) is used for modeling and analysis of the ring network.

II. SYSTEM MODELING AND SHORT CIRCUIT ANALYSIS

The organized industrial zone (GEBZE) is supplied from 100 MV, 154/34.5 KV substation, which is available nearby the organized industrial zone. The industrialized zone contains distribution substation (designated as DM) that provide energy to the industrial customers. For the site under study, there are seven DMs connected in a closed ring and the connections among the DMs is shown in Fig. 1.

To analyze the system short circuit analysis is conducted by using ETAP-software. For the protection coordination, short circuit analysis is conducted for three conditions of the network. These are when the network is operated as a closed ring, opened from the left side (radial, opened at ADM_A of Fig. 1.), and opened from the right side (radial, opened at ADM_B of Fig. 1.). This helps to identify the exact maximum and minimum short circuit currents for different operating conditions. As the current transformers are placed in the incoming and outgoing feeder of the ring network, the maximum short circuit current flowing through the relaying point is measured when the fault is applied while the ring network is operated in radial condition. For each DMs in the ring, the maximum short circuit current values calculated at each DM's bus bar and summarized in Table 1. The results show that, the short circuit currents are increasing towards the source from both sides of the ring network.

Similarly, the minimum short circuit current values for the system under study are given in Table 2. From the analysis, it is observed that the minimum short-circuit current flowing in the incoming and outgoing feeders of the ring occurs when the fault occurs while the network is operated in a closed ring. This is because the fault current is divided into two branches of the ring network towards the fault point (left and right). In addition, the minimum short circuit current flowing towards the bus and the cable have different values.

TABLE 1. MAXIMUM SHORT CIRCUIT CURRENT WHEN THE RING OPENS FROM THE RIGHT AND LEFT

ADM_A-DM1 SIDE OPEN (Right)		**ADM_B-DM3 SIDE OPEN (Left)**	
Group- 1 DMs	Iscmax (A)	Group-2 DMs	Iscmax (A)
DM1_A A01	7900	DM3_B A14	8220
DM2_A A01	8136	DM6_A A01	8707
DM4_A A01	8999	DM5_A A01	9324
DM5_B A13	9236	DM4_B A14	9577
DM6_B A12	9927	DM2_B A11	10764
DM3_B A14	10639	DM1_B A09	11188
ADM_B A12	11479	ADM_A A02	11479

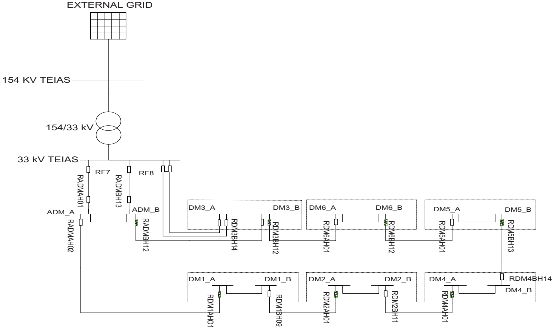


Fig.1. Ring distribution network of the organized industrial zone

TABLE 2. SUMMARY OF MINIMUM SHORT CIRCUIT CURRENT

Group-1 DMs	**Iscmin (A)**		**Group-2 DMs**	**Iscmin (A)**	
	Towards the Bus	Towards the Cable		Towards the Bus	Towards the Bus
DM1-A H01	594	9442	DM3-B A14	1786	8712
DM2-A H01	1489	9101	DM6-A A01	3353	6794
DM4_A H01	4210	5844	DM5-A A01	5122	4877
DM5_B H13	4877	5150	DM4-B A14	5815	4237
DM6_B H12	6763	3380	DM2-B A11	9064	1517
DM3_B H12	8712	1786	DM1-B A09	9431	624
ADM_B H12	9669	15	ADM-A A02	9669	15

III. CUSTOMER FEEDERS' PROTECTION

The customer feeders are protected by overcurrent relays with inrush blocking capability. The relays that are used are ABB REF 615 series [8]. An inverse time overcurrent protection is used to protect the customer feeder from overcurrent situation. In the inverse time overcurrent protection, the operating time is inversely proportional to the magnitude of the fault current. There are many standard curves defining the time-current characteristics. For example, Table 3 shows the IEC 60255 characteristics curves.

In this study, the standard inverse characteristic curve is used for the relays. The pickup current of the inverse time overcurrent relay is selected to start at 1.1 times primary currents of the current transformer. The primary currents of the current transformers are selected by considering the maximum load currents. For the time multiplier setting, the value of 0.2 is selected for the IEC normal inverse characteristic curve. The inrush multiplier is set to 10 so that if the inrush current is detected, especially during transformer starting, the pickup setting will change from 1.1 to 11.

TABLE 3. IEC 60255 STANDARD CHARACTERISTIC [4]

Relay Characteristics	**Equations (IEC 60255)**
Standard inverse (SI)	$t = TMS * \frac{0.14}{(I_r)^{0.02} - 1}$
Very inverse (VI)	$t = TMS * \frac{13.5}{I_r - 1}$
Extremely inverse (EI)	$t = TMS * \frac{80}{I_r^{\,2} - 1}$
Long time stand by earth fault	$t = TMS * \frac{120}{I_r - 1}$

Where: Ir = I/Is, I= Measured current, Is=Relay setting current, TMS=Time Multiplier Setting

The short circuit fault protection is provided by the definite time overcurrent function. The pickup current of the instantaneous element is set to 5 times the primary current of the current transformer. However, when inrush is detected it is multiplied by 3 and the pickup is raised to 15 times the primary current. The operating delay setting for the instantaneous element is 50 ms.

Definite time overcurrent function provides the ground fault protection. The ground fault pickup current has to be set above the maximum unbalance current on the feeder. For this study, 20 percent of the primary current value of current transformer is selected.

The inrush current setting is used to coordinate transformer inrush situations in distribution networks. The inrush detector element evaluates the ratio of second harmonic current to the fundamental frequency current. If the ratio exceeds the setting value, it will block the operation of the other protection functions like time overcurrent or instantaneous element. In this project, the setting value of 15% is selected for the inrush detector.

IV. INCOMING AND OUT GOING FEEDERS PROTECTION

The most selective and fast power system protection is the unit protection [9], [10]. In unit protections, the protection zones are established for each component of the power system like a generator, cable, motor, transformer, and the bus bar. The most commonly implemented unit protection is differential protection.

Differential protection is used as a main protection to protect the cable in the ring network. The detailed discussion on the principle of the differential relay is available in [4]. The percentage differential curve used by RED 615 relay is also shown in the Fig. 2 and the differential protection setting parameters are summarized in Table 4.

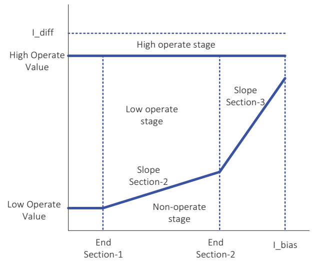


Fig. 2. Operating characteristics of the differential protection [8]

TABLE 4. THE PARAMETERS FOR RED 615

Parameter	**Value**
High Operate Value (%Ir)	1000
Low Operate Value (%Ir)	20
Slope Section-1 (%)	30
End of Section-1 (%)	150
Slope of Section-3 (%)	60
Start Value 2.H	15
Start Value 5.H	35

Although the fault in the cable is cleared instantaneously by the differential protection, inverse time overcurrent protection is provided to protect the cables from the overcurrent and short circuit faults as the backup protection. Directionality is also included to selectively coordinate the operation of the relay. The directionality of the relay is achieved by using voltage transformer with the current transformer.

To determine the direction of the fault, there are many polarizing methods like cross polarization, positive sequence polarization, negative sequence polarization and self-polarization [4], [11], [12]. In this study, cross polarization is used. In a cross-polarization, the voltage of healthy phases is used as a reference to determine the direction of the fault current. In Fig. 3, the vector diagram of commonly used 90^{o}-45^{o} connection cross-polarizing technique - is shown (fault occurred on phase-A). The maximum torque angle (MTA) is rotated by 45^{o} to provide maximum sensitivity (Fig. 3).

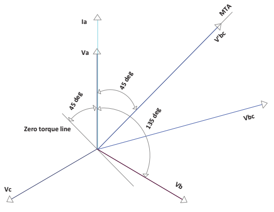
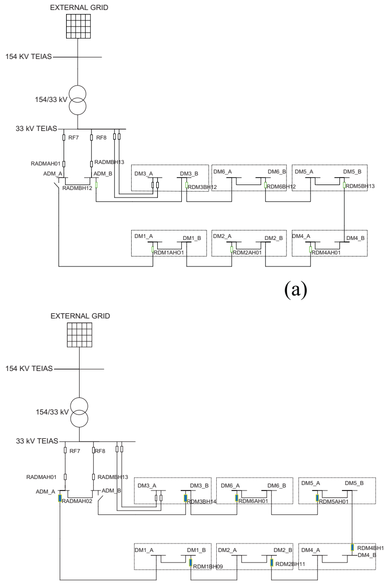


Fig. 3. Vector Diagram for the 90°-45° Connection (Phase-A element).

In the medium voltage feeder of the utility's substation (in this case GEBZE substation), the operating time for the inverse time overcurrent (at the maximum short circuit current) and the instantaneous ground fault protection is set to 1 second. Consequently, the protection coordination has to be done by considering this constraint. In modern relays, the grading margin between relays is about 200 ms. For example; we can only coordinate only five relays in series for an earth fault instantaneous overcurrent relay from the customer feeder to the utility's feeder. Consequently, if the ring distribution network has more than five DMs in series, to provide the coordination, grouping some of the DMs by compromising reliability is an inescapable.

The coordination in the ring network using overcurrent relay is done by opening the ring on one end first (for example right end as shown in the Fig. 4 (a)) and coordinating it as if it is a radial network. This means protection relay will be coordinated in a counterclockwise direction when the ring is open on the side of DM1-H01 (Fig. 4 (a)). This group includes RDM1AH01, RDM2AH01, RDM4AH01, RDM5BH13, RDM6BH12, RDM3BH12 and RADMAH12. The designations, for example, RDM3BH14 is shown in Table 5. In a similar manner, the clockwise coordination is done when the ring is open on the side of DM3-H14 (Fig. 4(b)). This group includes RDM3BH14, RDM6AH01, RDM5AH01, RDM4BH14, RDM2BH11, RDM1BH09 and RADMAH02.



(a)

(b)

Fig. 4. The ring network opened from the right (b) The ring network opened from the left

TABLE 5. MEANING OF DESIGNATION RDM3BH14

R	DM	3	B	H14
Relay	Distribution Substation	3rd	B-group	14th Cubicle

If the tn and TMSn are downstream relay's operating time and time multiplier settings respectively, by using the IEC normal inverse curve, the operating time (tn) can be calculated as:

$$t_n = TMS_n * \frac{0.14}{\left(\frac{I_n}{I_{p_n}}\right)^{0.02} - 1} \quad (1)$$

A fixed grading margin, which is about 200 ms for the modern relays, is selected for the coordination among the protection relays that are in series. Then, the time multiplier setting of the immediate upstream relay can be calculated as follows:

$$TMS_{n+1} = \frac{t_n + 0.2}{\frac{0.14}{\left(\frac{I_n}{I_{p\_n+1}}\right)^{0.02} - 1}} \quad (2)$$

Where: In is the fault current for the downstream relay; In+1 is the fault current for the immediate upstream relay. Ip_n+1 the pickup current to the upstream relay; TMSn+1 is the time multiplier setting for the upstream relay. The operating time for the upstream relay is calculated as follows:

$$t_{n+1} = TMS_{n+1} * \frac{0.14}{\left(\frac{I_{n+1}}{I_{p_{n+1}}}\right)^{0.02} - 1} \quad (3)$$

The time coordination must take into account that the relay near to the source network must not exceed the time limit set by the network operator. By using equations (1)-(3) the time multiplier setting for each relay in the ring under study is determined. In this case, the network operator's time multiplier setting restriction is 0.3, which corresponds to 1 second at maximum short circuit current. In order for the relay to be coordinated under this level, a grading margin, which is less than 200 ms, has to be used. However, this may compromise the supply reliability by causing some distribution substations to operate together for the fault at the other substation. The coordination curve showing the coordination characteristics is shown in Fig. 5 and Fig. 6 for the case when the ring is opened from the side of DM1-H01 and DM3-H14 respectively.

Directional definite time overcurrent protection provides short circuit fault protection in the ring distribution network (for the cable and the bus bars protection). The pickup currents are determined based on the minimum fault currents. The protection for the cable protection is coordinated in a similar fashion as for the time inverse protection discussed.

Directional earth-fault protection is used for selective operation during occurrence of earth fault in the ring network. The directionality is achieved by using the residual voltage (it can be measured or calculated) or the negative sequence component as the polarizing quantity. In this study, the residual voltage is used as polarizing quantity. The torque angle used in this project for the REF 615 relay is 45° (Fig. 3). The grading is provided by using different time settings at each relay points (the current setting is the same, but the time setting differs). In this case, since there are more than five

DMs in the ring network, some of the DMs are grouped together.

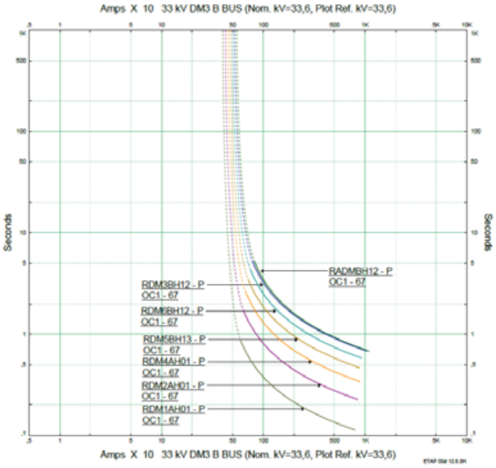


Fig. 5. The inverse time coordination characteristic curve when the DM1-H01 side is open.

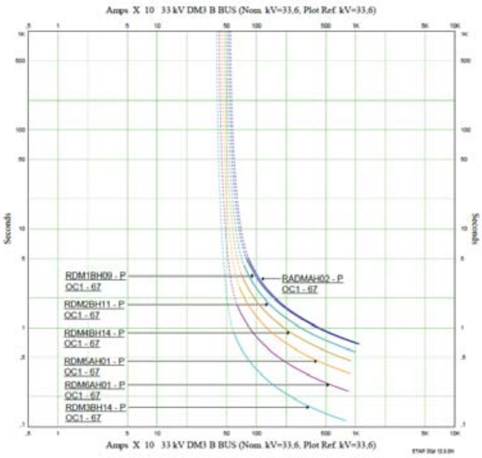


Fig. 6. The inverse time coordination characteristic curve when the DM3-H14 side is open

V. CONCLUSION

Organized industrial zones' distribution networks must be supplied with electricity continuously. Considering the radial distribution network, a fault on the network affects all the downstream feeders. Due to this fact, the ring distribution network is commonly implemented in the organized industrial zones. The challenging aspect is the protection coordination of the ring distribution network. The customer feeders can be protected by overcurrent relays. The underground cables are protected by differential relays. In addition, auxiliary protections are implemented by using overcurrent relays for the case the differential protection is not working properly. The overcurrent protection must be directional for the selective operation as the current flows in the ring network from two directions. The coordination is done by considering as if the ring network is radial from two sides. The auxiliary protection can also provide Busbar protection. In this work, all the necessary protection coordination for the ring distribution networks are discussed by using organized industrial zone as a case study. The results from this study are implemented to the industrialized zone and it is working properly.

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