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Coordination Tool for Overcurrent and Earth-Fault Relays at A 33/11 KV Power Distribution Substation in Basrah City

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Abstract
The coordination of overcurrent relay protection in the power framework is crucial for preserving electrical distribution systems. It ensures that both primary and backup protection are provided to the system. It is essential to maintain a minimal level of coordination between these relays in order to reduce the overall running time and guarantee that power outages and damage are kept to a minimum under fault conditions. Proper coordination between the primary and back-up relays can minimize the operation duration of overcurrent with instantaneous and earth fault relays by selecting the optimum TMS (Time Multiplier Setting) and PS (Plug Setting). The present study investigates the difficulty associated with determining the TMS and PS values of earth-fault and overcurrent relays at the 33/11 kV power distribution substation in Basra using the instantaneous setting element. Overcurrent and earth fault relays were simulated in two scenarios: one with a time delay setting and one with an immediate setting. This procedure was carried out to generate Time Current Characteristics (TCC) curves for each Circuit Breaker (CB) relay took place in the Nathran substation, which has a capacity of 2×31.5 MVA and operates at a voltage level of 33/11 kV. The substation is a part of the Basrah distribution network. The short circuit current is estimated at each circuit breaker (CB), followed by the simulation of protection coordination for the Nathran substation using the DIgSILENT Power Factory software. This research is based on real data collection, and the setting considers the short-circuit current at the farthest point of the longest feeders. The results show the effectiveness of the proposed coordination scheme, which reduced trip operation time by 20% compared to the presented case study while maintaining coordination between primary and backup protection.

Keywords
Relay coordination, instantaneous relay, earth relay, Inverse Definite Minimum Time relays

I. INTRODUCTION

Under the normal operational conditions of grid-connected power systems, load flow is in safe mode if it is within the limits of the connected loads. If the current flow is constant and there is no high heat, then the operation status is stable and normal. However, electrical hazards are possible due to sudden, unavoidable overloads or short circuits [1].

Protection devices in transmission or distribution systems handle this challenge by continuously monitoring the power system to detect faulty lines. These lines are subsequently isolated to guarantee continued supply to the remaining area. Protective relays are the main devices utilized for this purpose. Distance protection relays are very common in transmission networks due to their sufficient speed and sensitivity [2]. However, overcurrent (OC) and earth fault (EF) devices primarily perform protective functions in distribution systems as a pri-

mary and backup protection [3].

The phase and neutral current are measured continuously and then compared to the required current levels. Suppose the measured value exceeds the minimum current. In that case, the relays start executing a regular sequence of commands by the circuit breakers in the order of their positions to isolate the faulty lines after a pre-determined time delay. For the process to be effective in solving the fault problem, there must be coordination between adjacent relays, and this coordination is represented by the priority of operating the relays and the timings between them. The appropriate sequence of phases and predefining optimal timings in advance ensures optimal isolation of faulty power lines and overcoming problems with the least possible losses [4].

Optimal values of relay settings, such as current setting and time setting, play prominent roles in overcoming the coordination challenge of relays, so minimizing the operation time. There are several methods for achieving appropriate coordination of relays such as trial and error [3], [4], topology analysis [5], [6], and optimization methods. The first method provides a good relay setting but has drawbacks such as needing time and effort. In contrast, the second method depends on the deriving case study model, which leads to achieving the best results, while the third one is the best but depends on the second method, means the case study should be modeled first. Hence, the present study focuses on the selection of the 33/11 kV power distribution substation model in Basrah City as the case study. The primary objective is to develop a model of the substation and after that, evaluate it to determine the ideal values for relay settings.

Recently, a several researchers have begun examining the difficulties associated with overcurrent and earth-fault relays. Various approaches have been suggested to address these difficulties. However, we will concentrate on specific methods that closely align with the case study of this paper. For instance, Al-Nayli et al. [7] have put forward a technique that utilizes the phase overcurrent function as a backup protection for the local earth fault function within the same relay. The IEC Microgrid Benchmark was used to validate the format. Furthermore, Also, the overall running time is reduced by modifying the objective function. The results have been compared to ensure the proposed method's success and reliability. Andruszkiewicz et al. [8] proposed a multi-criteria protection algorithm to boost the performance of overcurrent relays in medium voltage networks for various two-phase faults, in which the performance is evaluated by DIgSILENT PowerFactory software. Furthermore, they stated that for small earth-fault current values, the coordination of protection settings identified by other protection relays is unnecessary.

Samadinasab et al. [9] proposed a combination of differential evolutionary and genetic algorithms to overcome the coordination problem of overcurrent and distance relays. A standard 8-bus power system network is utilized to validate this approach. Based on the results, the authors conclude that the proposed method can effectively optimize the coordination settings. Korashy et al. [10], introduced several methods to solve the challenges of the coordination issue involving directional overcurrent relays (DOCRs) and distance relays, which optimize the coordination format to enhance the performance of the coordination approach. This study includes an analysis and examines the 8-bus and IEEE 30-bus networks. Wang et al. [11] proposed the hybridization of PSO as a new method to optimize the Coordination of Directional Overcurrent Protection Relays (DOPR) for the IEEE bus system. This approach is utilized to test the IEEE 4-bus, 6-bus, and 8-bus systems. From the results, the authors conclude that the hybridization of the PSO algorithm and heuristic PSO algorithm can present a promising approach to optimize power system protection. Andruszkiewicz et al. [12] proposed a multi-criteria protection algorithm that may boost the effectiveness of power lines short-circuit overcurrent relays in medium voltage networks for different two-phase faults. The main contribution of this study is enhancing protection performance by analyzing the fault current symmetrical components and utilizing the negative and zero sequence currents as criteria for protecting the overcurrent line against faults. DIgSILENT PowerFactory software has been used to simulate the proposed approach, and the results show that the proposed method can be proved to increase the zone of effective operation twice compared to the traditional phase current-based solutions.

The protection plan in power systems must be structured in such a way that the protection relays disconnect the problematic component of the network as soon as feasible to avoid damage to the equipment and ensure minimum system downtime. Due to the thermal dynamic consequences generated by the short circuit, its absence can cause dangers in the electrical network infrastructure [13] since the energy system plays a crucial role in this [14]. Current builds up suddenly as a result of shunt faults in power systems. This amount of fault current can be used as a fault presence indicator. As a result, the most common method for protecting power systems is over-current protection [15], [16]. Inverse Definite Minimum Time (IDMT) relays have frequently been employed as a cost-effective substitute for primary or secondary protection of the power supply [17], [18], [19], [20].

Overcurrent relays are essential for distribution feeders and might be the only form of protection [21]. A relay needs sufficient opportunities to protect the area that is the focus of its primary defense. The back-up protection should only take over tripping if the primary protection cannot resolve the fault. Malfunction can happen if back-up relays are not synchronized properly. To preserve the electrical grid, OC relay

synchronization is a critical concern. The back-up protection should only start to trip if the primary protection cannot resolve the issue. The relays protecting the nearby equipment must be coordinated with each protective relay in the power system. As a result, the coordination of overall protection is extremely difficult [22]. The best coordination of OCRs was proposed using several optimization strategies [23], [24], [25].

The issue of figuring out the most suitable TMS and PS values for OC relays is presented in this study. With the quick growth of Basrah distribution networks, it is necessary to update the protective settings for medium voltage levels. This study aims to identify the most effective protective coordination strategy for the medium voltage system at the 33/11 kV Nathran substation inside the power distribution system of Basrah. IEC standards will be applied to the protective configurations of relays at the electrical grid substation and downstream circuit breakers of the selected grid substation to determine the coordination at the Medium Voltage level. Many accomplishments have been made in this effort, which are enumerated as follows:

1. Design a dependable and effective industrial coordination scheme according to IEC requirements for the medium voltage system using the collection of real technical data, principally from one of the substations in the center of Basrah city.

2. Because it works properly even in the worst-case scenarios, the proposed technique is immune to a variety of faults.

3. The proposed coordination technique has been actually carried out on an industrial numerical IDMT characteristics type relay (overcurrent and earth fault) of the 33 kV incoming feeder, main feeder 11 kV, and outgoing feeder 11 kV due to the results demonstrating the robust coordination method.

4. Comparing the results obtained from the real data of the Nathran substation and the ideal calculations for all the required parameters for the IDMT relays and earth fault relays for both duration delays and instantaneous time in the distribution system of the Nathran substation.

5. Explaining the risks of failing to coordinate all overcurrent IDMT and earth-fault relays in the Nathran substation's distribution system.

II. METHODOLOGY

This section describes the most effective protective coordination strategy for the medium voltage system at the 33/11 kV Nathran substation within the Basrah power distribution

system. The protective configurations of relays at the electrical grid substation and downstream circuit breakers will be determined by applying IEC standards to ensure effective coordination at the Medium Voltage level. The procedure under consideration is detailed as follows:

A. The significance of settings and coordination curves

Even the most advanced protection measures, meticulously planned, implemented, activated, and maintained, are completely useless if they are not properly configured. Because IDMT relays must cooperate with upstream and downstream relays, careful attention should be made to their settings. Moving the plug bridge in the horizontal direction adjusts the curve left or right and selects the current pick-up value when setting the IDMT relay. To select the operating time, turn the time multiplier or dial multiplier up or down in the vertical direction (see Fig. 1) [21].
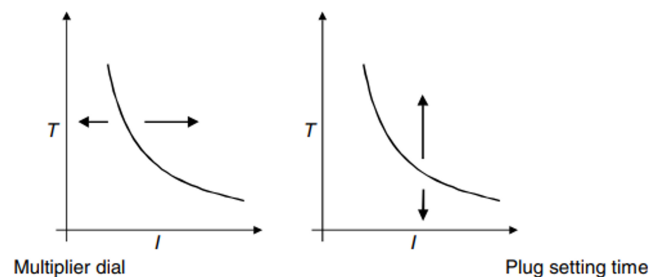

Fig. 1. Effect of settings.

Figure 2 demonstrates that two different combinations of plug setting and time multiplier can be used to produce the same setting. Observe the points at which the curves intersect. By selecting appropriate plug or time dial settings, it is possible for the curves to intersect, even if there is a time interval between them. Accordingly, Relay A operates prior to relay B for low fault currents, while relay B operates before relay A for high fault currents. Consequently, there is a loss of coordination. It is crucial to generate coordination curves after choosing relay settings to ensure that they do not intersect and are correctly aligned with each other, as seen in Fig. 3.

They must pick up the lowest fault level (minimum plant) and coordinate for the highest fault level (maximum plant), according to two basic guidelines. A final remark on a subject is rarely appreciated. The electrical network is, in reality, alive. It develops and evolves over time. Generation is added, load centers are developed, old plants are retired, and new plants are expanded, among other things. As a result, fault levels alter and invariably rise. It is necessary to regularly evaluate the settings of IDMT relays, especially when there are plans for extensions or modifications. Simultaneously, it is imperative to take advantage of the chance to update the security measures.
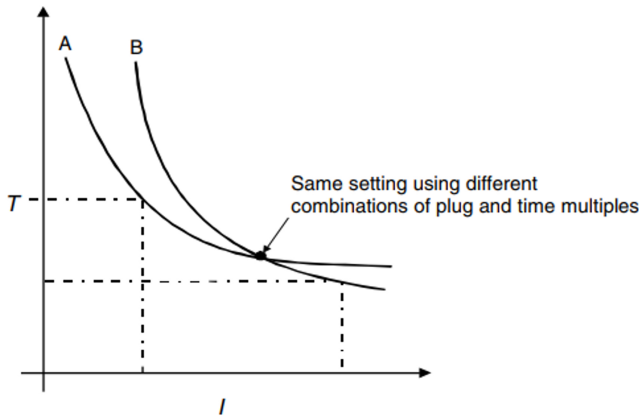
Fig. 2. Curves must not cross.

Fig. 3. Ideal coordination of setting curves.

Fig. 4. Earth fault current limited by NER.

B. Protection against sensitive earth faults

Several situations emerge where the load current necessitates high-ratio line current transformers, and the neutral current has been regulated to a low value for safety reasons by employing a remote high-impedance neutral earthing device. In this case, a normal IDMTL earth fault relay with a minimum setting of 10% would be unable to detect an earth fault state. Sensitive earth fault prevention should be addressed for such an application (see Fig. 4). Furthermore, high-resistance earth faults are possible on overhead rural distribution lines, particularly if a conductor breaks and falls on very dry ground with a high silica concentration. In certain cases, the first rush of fault current led the silica to create a glass envelope around the end of the damaged conductor, allowing a live conductor to go undetected after the auto-reclose shot [21].

C. Adjusting the time delay overcurrent relays' parameters

In order to avoid the premature tripping of an overcurrent relay prior to the installation of any additional protective mechanisms in close proximity to a fault, it is necessary to delay the operational duration of the relay. Figure 3 illustrates the curves of inverse-time overcurrent relays connected to three breakers on the same feeder in a standard system. This diagram shows the different operational characteristics of various relays when subjected to identical fault levels in order to meet the discrimination margin criteria. The two adjustable factors for definitive-time relays and inverse-time relays are the time dial or time multiplier setting and the pick-up or plug setting (tap setting). The pick-up setting, sometimes referred to as the plug setting, establishes the relay's pick-up current, and fault currents that it detects are expressed as multiples of this value. The plug setting multiplier (PSM), sometimes known as the plug setting multiplier (PSM), is the ratio of the secondary amp error current to the relay pick-up or plug setting. Plug or picking up configuration (tap setting) for phase relays is
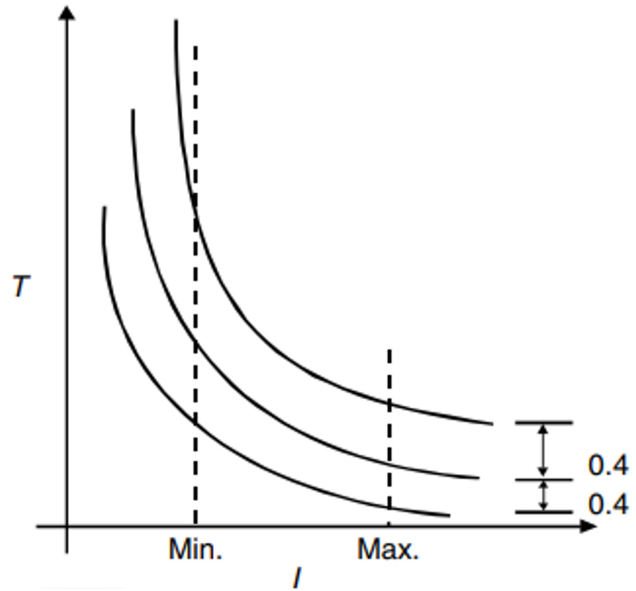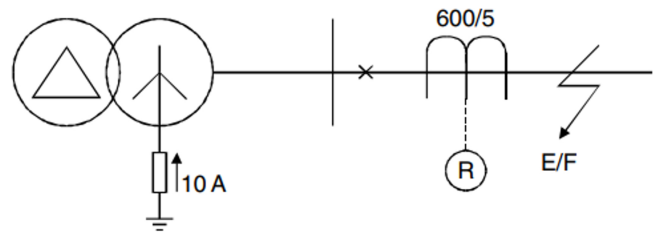
established by allowing an overload margin above the nominal current, as in the following expression:

$$\text{Pick} - \text{up setting} = (OLF \times I_{\text{nom}})/CTR \qquad (1)$$

Where: OLF = Overload factor that depends on the element being protected; I_{nom} = nominal circuit current rating. $CTR = CT$ ratio. The motor overload factor that is advised is 1.05. Normal ranges for lines, transformers, and generators are 1.25 to 1.5. The overload factor can be of the order of 2 in distribution systems where it is possible to raise the loading on feeders during emergency situations. I_{nom} must in all cases be less than the CT and the conductor's thermal capacity; otherwise, the pick-up setting must be determined using the least value. The pick-up setting for earth-fault relays is established by considering the maximum unbalance that would exist in the system under typical operating circumstances. Typically, an unbalance allowance of 20%, makes the equation in Equation 1 become

$$\text{Pick} - \text{up setting} = (0.2 \times I_{\text{nom}}) / CTR \qquad (2)$$

The imbalance allowed might drop to 10% for HV transmission lines, while it could increase to 30% for feeders used for rural distribution [14].

D. Time dial setting
The time delay before the relay operates is modified by the time dial setting when the fault current is equal to or exceeds the relay current setting. In electromechanical relays, reducing the time dial value results in shorter operational durations. This is often accomplished by adjusting the actual distance between the moving and fixed contacts. The time multiplier setting is synonymous with the time dial setting. The criteria and procedures for determining the time dial setting are considered to ensure the system is adequately protected and coordinated. While these conditions are also applicable to definite-time relays, they largely apply to inverse-time relays. The criteria and procedures for determining the time dial setting are as follows:

1. Using the lowest time dial setting and taking into account the fault level for which the instantaneous unit of this relay picks up, It can determine the required operating time $t_{primary-pro}$ of the primary protection relay that is farthest from the source. If the load is flowing when the circuit is reenergized after a large loss of supply (the cold load pick-up), or if it is essential to coordinate with devices installed downstream, such as fuses or recloses, then this time dial setting may need to be increased.

2. Calculate $t_{backup-pro} = t_{primary-pro} + CTI$, where CTI is the coordination time interval, and $t_{backup-pro}$ is the operating time of the back-up protection relay connected to the upstream relay, to find the operating time of the upstream relay. The calculation's fault level is the same as the fault level used to calculate the time $t_{primary-pro}$ of the relay connected to the prior breaker.

3. With the same fault current as in 1 and 2 above, and knowing t and the pickup value for upstream relay, calculate the time dial setting for the upstream relay. Use the closest available relay time dial setting whose characteristic is above the calculated value.

4. Beginning with stage two, continue the sequence. If the characteristic curves of the relays are considered to be scaled in seconds, then the described technique is adequate. To create the time dial setting, begin by applying the fastest multiplier to the time dial 1 curve for relays that specify time adjustment as a percentage of

the operating curve for one second. Most contemporary relays allow you to set the time in steps of 0.1 seconds, starting at numbers as low as 0.1 s.

E. Coordination time interval
Typically, a time discrimination margin or *CTI* of the order of 0.25 to 0.4 s should be employed between two sequential time or current characteristics. Due to one or more of the following, this value prevents selectivity loss: Breaker opening times, relay overrun times after a fault has been fixed, varying fault levels, departures characteristics, tolerance, and current transformer mistakes are all examples of timing issues. Since there is no overrun with numerical relays, the margin can be set as low as 0.2 seconds. On the delta side of a Dy transformer, single-phase defects are not visible. In order to significantly reduce the settings and thus the running times of earth-fault relays closer to the source infeed, earth-fault relays on the delta side might be adjusted using the lowest available time dial setting.

F. Relay properties are calculated mathematically
Using the technique for earth and phase units is simple whenever the functioning parameters of the relaying are known through computation instead of log-log paper curve. According to International Electrotechnical Commission (IEC) standards, the operational time can be described mathematically as [1], [3], [4].

$$t = \frac{k\beta}{\left(\frac{I}{Is}\right)^{\alpha}} + L \qquad (3)$$

where: t = the operating time of the relay in seconds. Is = chosen pick-up current I = the amp-level of the secondary fault current. K = the setting of time multiplier, or a time dial. L = constant.

The variables α and β were used to calculate the slope of the relay properties. The constants related with the L parameter in the IEC standard for overcurrent relays are provided in Table I.

TABLE I
IEC CHARACTERISTICS FOR CONVENTIONAL
OVERCURRENT RELAYS.

Curve description	α	β	L
Standard inverse	0.02	0.14	0
Very inverse	1	13.5	0
Extremely inverse	2	80	0

G. Relay coordination limitations
The restrictions of relay coordination are as follows [13], [14], [15]:

- Levels of minimal short circuit: It is crucial to check the lowest fault level at which the relay will function in the proper order.

- The pick-up values are as follows: critical situations involving the starting of motors and inrush current in transformers; critical evaluation of relay settings when other types of equipment in the system are energized; and inrush current in transformers, which is capacity dependent.

- Thermal limits: After defining the curves for the over-current relays, it is important to make sure that they are lower than the curves corresponding to the machines' and cables' assigned thermal capacities. The graphs provided by the conductor manufacturer show how long different diameters can tolerate varying short-circuit values. The maximum fault current that transformers can tolerate at any one time is limited by their impedance.

III. FLOW CHART OF THE PROPOSED COORDINATION SCHEME

The coordinating relay flowchart is divided into four parts. The first stage begins with the main protection for the longest feeder at 11 kV to calculate the time operation, and the second stage starts with the back-up protection to calculate the TDS and time operation. The third stage begins with the validation of the preceding stages, and if the difference between the time of operation for the primary and main protection is greater than or equal to CTI, the relays are set. If not, it must check the pick-up currents and restart the procedure, as illustrated in the diagram in Figure 5.

IV. SYSTEM MODELING USING DIGSILENT POWER FACTORY

Basrah distribution substations use simple protection methods that include feeder circuit overcurrent, and transformer protection via differential and overcurrent relays. The 2x31.5MVA, 33/11 kV Nathran substation's technical data was obtained and used for relay coordination modeling. The technical data in Table II was utilized to model the substation equipment. For both main and back-up protection in the outgoing feeders 11 kV, 33 kV transformer feeders, and 11 kV transformer feeders, the overcurrent and earth fault relays must be from the numerical inverse definite minimum time lag (I.D.M.T.L.), in line with IEC standards.

This work aims to acquire coordinating findings from various analyses and calculations performed on a section of the Basrah distribution network known as Nathran Substation (2 x 31.5 MVA, 33/11 kV), as illustrated in Figs. 6 and 7.
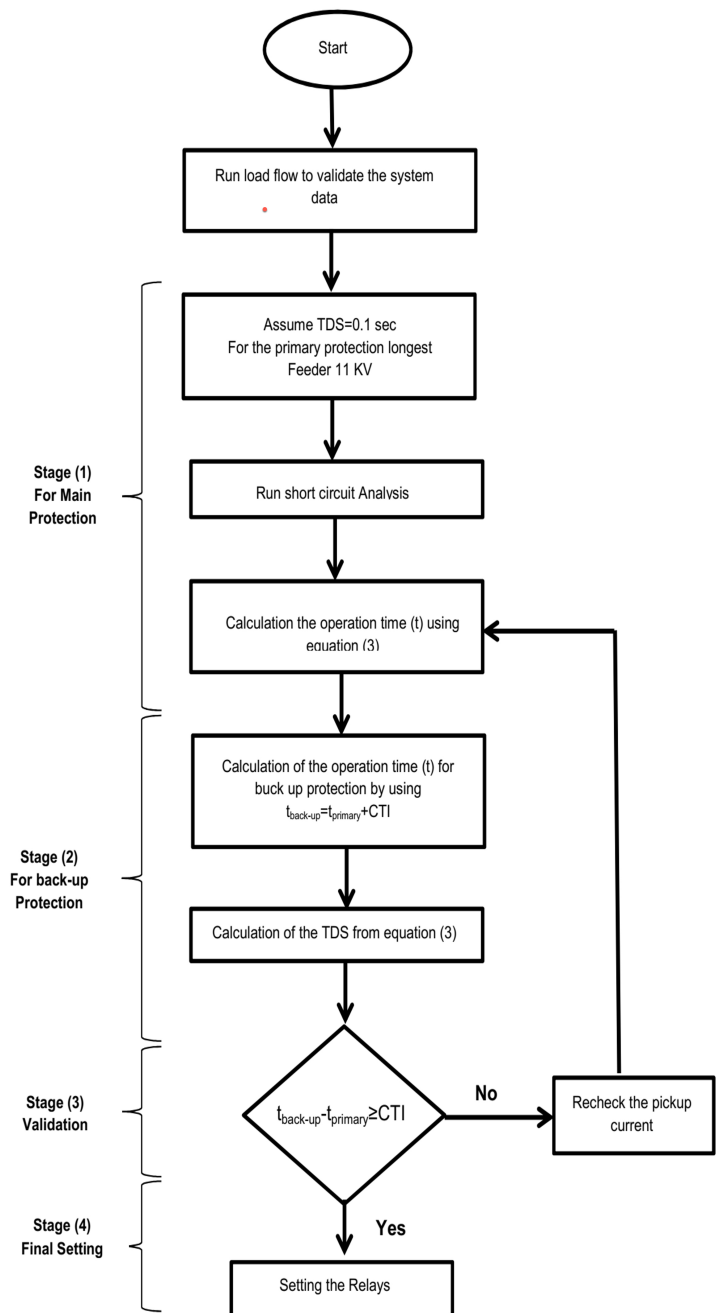

Fig. 5. Flow chart of the proposed coordination scheme.

TABLE II.
REAL DATA TO NATHRAN SUBSTATION

Devices	Parameters	Values
External grid	*MVAsc*	1428.9
Cable 1*400 mm^2, 33kV, 0.025 km	Positive sequence impedance	0.0984+ i0.084 Ω/km
	Zero sequence impedance	0.1192+ i0.0548 Ω/km
Cable 1*400 mm^2, 11kV, 0.035 km	Positive sequence impedance	0.036+ i0.0457 Ω/km
	Zero sequence impedance	0.054+ i0.0371 Ω/km
Power Transformer 33/11kV, 2*31.5MVA, Dyn11	Impedance Short Circuit Voltage	10.5%
Cable 3*150 mm^2,11kV, 1.25 km	Positive sequence impedance	0.1264+ i0.0932 Ω/km
	Zero sequence impedance	0.639+ i0.3088 Ω/km
Over-Head Transmission Line, ACSR, 120/20 mm^2,11kV, 1.5km	Positive sequence impedance	0.2422+ i0.3272 Ω/km
	Zero sequence impedance	0.3904+ i0.5894 Ω/km
Distribution Transformer (Number /13), 11/0.4 kV, 400KVA, Dyn11, 13	Impedance Short Circuit Voltage	4%
Distribution Transformer (Number /1), 11/0.4 kV, 1000KVA, Dyn11	Impedance Short Circuit Voltage	5%

This substation is described in detail in reference [17]. The DIgSILENT power factory software package version 15.1 is used to simulate this network.

Figures 8, 9, and 10 illustrate pictures of some real parts of the Nathran substation, Figure 8 shows the 33 kV Metal-Clad Switchgears and numerical type Relay, IDMT characteristic (Overcurrent and Earth fault) in feeder 33 kV. Figure 9 shows the power transformer 33/11.5 kV, 31.5MVA, and 11 kV Metal-Clad Switchgears. Figure 10 shows the 11kV longest outgoing switchgear(Al-khather) the feeder represented by the feeder1 in section1, and numerical type Relay, IDMT characteristic (Overcurrent and Earth fault) in feeder 11 kV.

V. PERFORMANCE EVALUATION

As illustrated in Fig. 7, multiple types of faults have been put into the suggested framework as a three-phase short circuit fault, a single-to-ground fault, and a double-phases-to-ground fault at the longest outgoing feeders (Feeder 1 and Feeder 8). Section 1 modeled all parameters in real data from the Nathran substation in Basrah city, whereas Section 2 modeled all parameters from the computation using a better coordination tool for overcurrent IDMT relays and earth fault relays. The longest feeder in the Nathran substation runs on sections 1 and 2, and the farthest point on each feeder has been used to calculate the short circuit current (feeder 1 in section 1 and feeder 8 in section 2).

A. *Parameter modeling for overcurrent relays with time delay*

To obtain the precise specifications for the symmetrical fault current at the 33/11 KV Nathran substation, the end of the
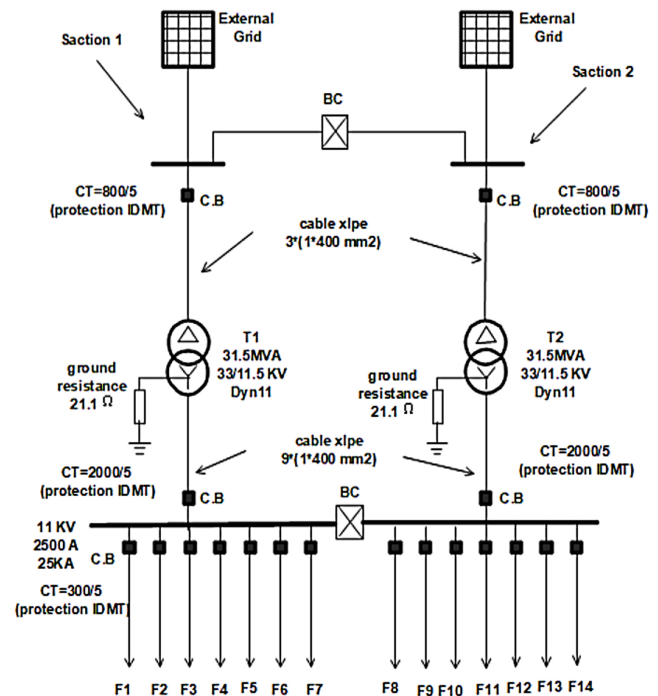

Fig. 6. The Basrah distribution network's Nathran substation (2×31.5 MVA, 33/11 kV) [18].
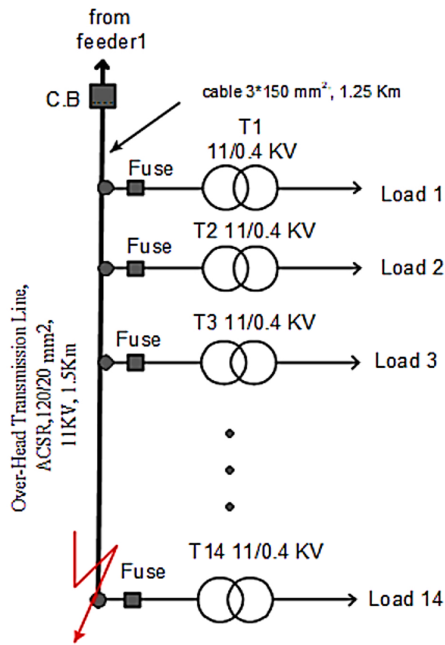
Fig. 7. longest outgoing feeders (Feeder 1 in section 1 or feeder 8 in section 2).

(a)

(b)

Fig. 8. (a) 33 kV Metal-Clad Switchgears. (b) Numerical type Relay, IDMT characteristic (Overcurrent and Earth fault) in Feeder 33 kV.

feeder is the worst-case scenario for the short circuit in practice. The positive sequence impedance for the power transformer has been identified, and it is being considered the grid because it will be the source of the fault. Considering that it is the longest feeder 11KV, feeder 1 from section 1 and feeder 8 from section 2 were chosen. Setting the time delay for overcurrent relay measurement is displayed in Table III by using section 1 from real data on the feeder's farthest point, and coordination is computed by using section 2 with the discrimination time set to 0.3 seconds, as shown in Table IV. The TCC curves generated by the DIgSELENT Power Factory software package utilizing a three-phase short circuit are shown in Fig. 7 (a) feeder 1, 11 kV in section 1 and Fig. 7 (b) feeder 8, 11 kV in section 2.

B. Modeling of overcurrent relay characteristics with instantaneous components

Feeder 1 and feeder 8 were chosen because they are the longest feeder according to sections 1 and 2, respectively. The calculation of the short circuit current at the farthest point on the feeder has yielded a value of 5627 A. Table V shows the instantaneous setting of overcurrent relays on the Nathran substation is measured by referring to section 1 for actual data, and to improve coordination between the relays, the instantaneous setting current for the relay was calculated at the 11 kV feeder by 50% of the fault current, and at the main feeder 11 kV by 125% of the fault current, while at the 33 kV

feeder by 150% of the fault current calculated at the furthest point from feeder 8 from section 2. As shown in Table VI, the discrimination time and coordination, as determined by referencing section 2, were determined to be 0.3 seconds.

C. Parameter modeling for earth fault relays with time delay.

Due to the power transformer's vector group being Dyn11, it can be observed that earth's fault calculations for outgoing feeders at 11 kV are not reliant on the short circuit current. As a result, the zero-sequence current in the power transformer's secondary side does not transfer to the main side and, hence does not pass to the substation's 11kV feeder. As a result, the largest line to ground short circuit current is 300 A, with the earthling resistance of 21.1 ■ connected to the secondary side of the power transformer Dyn11. As a result, it is advised that all incoming feeders have the same earth fault setting. The coordination could be determined by employing section 2 and a discrimination time of 0.3 seconds. Because the zero-sequence current on the power transformer's secondary side is not transferred to the main side, CB 33 kV in Nathran sub-

TABLE III.
SETTING OVERCURRENT RELAYS WITH A TIME DELAY BY USING SECTION 1 FROM ACTUAL DATA.

	Feeder 33 KV	Main feeder 11 KV (Incoming)	Feeder1 11 KV (Outgoing)
CTR	800/5	2000/5	300/5
Ipickup (Amp)	400	1200	300
TMS (sec)	0.15	0.15	0.15

TABLE IV.
SETTING WITH TIME DELAY FOR OVERCURRENT RELAYS DETERMINED ACCORDING TO SECTION 2,
BASED ON SHORT CIRCUIT CURRENT AT THE FARTHEST POINT ON THE FEEDER.

	Feeder 33 KV	Main feeder 11 KV (Incoming)	Feeder1 11 KV (Outgoing)
CTR	800/5	2000/5	300/5
Operating time + 0.3 sec	0.83	0.53	0.23
Ipickup (Amp)	480	1200	300
TMS (sec)	0.16	0.125	0.1

TABLE V.
THE INSTANTANEOUS SETTING OF OVERCURRENT RELAYS ON THE NATHRAN SUBSTATION
IS MEASURED BY REFERRING TO SECTION 1 FOR ACTUAL DATA.

	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
CTR	800/5	2000/5	300/5
Relay setting (Amp)	4 kA	10 kA	1500
Definite time (sec)	0.2	0.2	0.1

TABLE VI.
THE NATHRAN SUBSTATION'S INSTANTANEOUS OVERCURRENT RELAY SETTINGS WERE DETERMINED
BY REFERENCING SECTION 2.

	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
CTR	800/5	2000/5	300/5
Relay setting (Amp)	2803	7033	2812
Definite time (sec)	0.23	0.15	0.1
Operating time + 0.3 sec	0.9	0.6	0.3

(a)

(b)

Fig. 9. (a) Power Transformer 33/11.5 kV, 31.5MVA. (b) 11 kV Metal-Clad Switchgears.

(a)

(b)

Fig. 10. (a) 11kV longest outgoing switchgear (Al-khather). (b) Numerical type Relay, IDMT characteristic (Overcurrent and Earth fault) in Feeder 11 kV.

station section 1 and CB 33 kV for the feeder in section 2 are equivalent, as seen in Table VII. It shows how to configure earth fault relays with time delay measurement on the Nathran substation using actual data from section 1, and Table VIII depicts the component of earth fault relays with time delay calculated by referring to section 2 for Nathran substation after selecting Ipickup to 10% from the maximum earth fault at feeder 11 kV, 20% from the maximum earth fault at main feeder 11 kV, and 8% from the maximum earth fault at feeder 33 kV (considering the maximum fault current side of the 132 kV is 1000 A according to IEC standards, and this percentage of the earth fault also depends on the distance from the location of the grid 132 kV to the 33/11 kV substation).

D. *Modeling of earth fault relay characteristics with instantaneous components*

Table IX displays the actual value for the instantaneous component of earth fault relays on the Nathran substation, which is measured by referring to section 1 and to improve the co-ordination computed by the instantaneous element referring

to section 2, with the margin of indeterminate time set at 0.3 sec. As shown in Table X, the setting of 33 kV in Nathran substation is 24% from the maximum earth fault referred 33 kV (Considering that the maximum fault current side of the 132 kV is 1000 A according to IEC standards and that the percentage of the earth fault also relies on the distance from the grid 132 KV location to the 33/11 kV substation,), 70% from the maximum earth fault referred 11 kV to main feeder, and 50% from maximum earth fault referred 11 kV to feeder 11 kV.

VI. RESULTS AND DISCUSSION

Scenario one: Figure 11 illustrates the three phase short circuit at the feeder's farthest point, feeder 1 at section 1 and feeder 8 the short circuit current of which has been computed to be 5627 A. Figure 7 shows that section 1, which is based on the actual setting of the Nathran substation, does not work correctly because if the relay close to fault does not work for any technical reason (worse-case), the transformer feeder

TABLE VII.
SETTING EARTH FAULT RELAYS WITH TIME DELAY MEASUREMENT ON THE NATHRAN SUBSTATION
BY REFERRING TO SECTION 1 FOR ACTUAL DATA.

	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
CTR	800/5	2000/5	300/5
Ipickup (A)	80	200	30
TMS (sec)	0.15	0.15	0.1

TABLE VIII.
THE EARTH FAULT RELAY SETTINGS WITH TIME DELAYS ARE DETERMINED BY CONSULTING
THE NATHRAN SUBSTATION'S SECTION 2.

	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
CTR	800/5	2000/5	300/5
Ipickup (A)	80	60	30
Operating time + 0.3 sec	0.89	0.59	0.29
TMS (sec)	0.3	0.15	0.1

TABLE IX.
THE INSTANTANEOUS SETUP OF EARTH FAULT RELAYS ON THE NATHRAN SUBSTATION IS
MEASURED BY REFERRING TO SECTION 1 FOR REAL DATA.

	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
CTR	800/5	2000/5	300/5
Relay setting (Amp)	800	3 kA	240
TMS (sec)	0.2	0.2	0.1

TABLE X.
THE INSTANTANEOUS SETUP OF EARTH FAULT RELAYS FOR NATHRAN SUBSTATION IS DETERMINED BY
REFERRING TO SECTION 2.

	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
CTR	800/5	2000/5	300/5
Relay setting (Amp)	240	200	150
Operating time + 0.3sec	1.03	0.73	0.43
Definite time (sec)	0.16	0.13	0.1
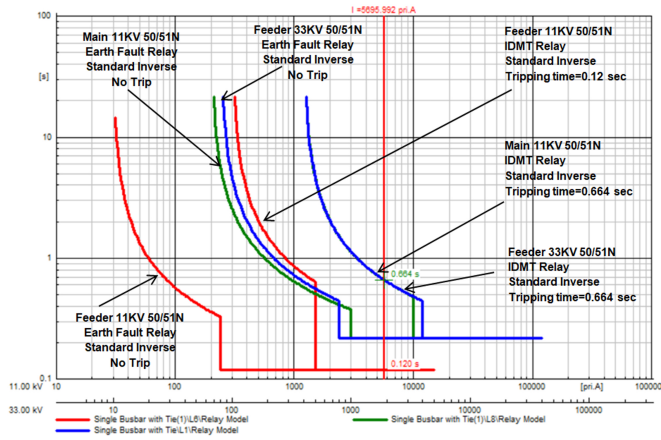
(a) section 1
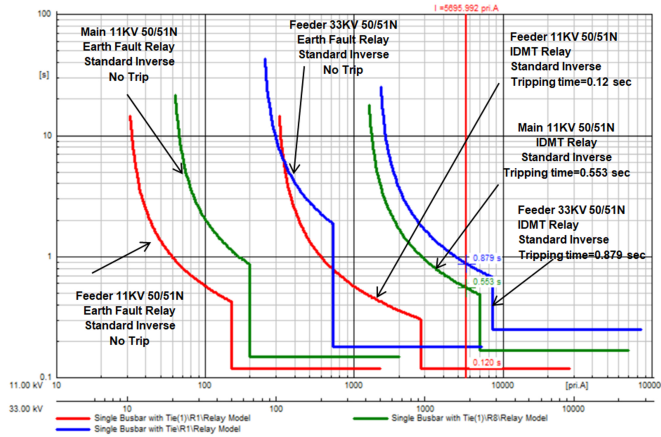
(b) section 2

Fig. 11. TCC curves produced by the DIgSILENT Power Factory software according to a three-phase short circuit fault at the farthest point of the longest feeders.

TABLE XI

MEASUREMENT TIME OPERATION BY USING DIgSILENT POWER FACTORY SOFTWARE ACCORDING TO A THREE-PHASE SHORT CIRCUIT FAULT AT THE FARTHEST POINT OF THE LONGEST FEEDERS IN FEEDER1 AT SECTION 1 AND FEEDER 8 AT SECTION 2

IDMT Relays	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
Operating time At section 1	0.664	0.664	0.12
Operating time At section 2	0.879	0.553	0.12

TABLE XII

MEASUREMENT TIME OPERATION BY USING DIgSILENT POWER FACTORY SOFTWARE ACCORDING TO SINGLE-PHASE TO GROUND SHORT CIRCUIT FAULT AT THE FARTHEST POINT OF THE LONGEST FEEDERS IN FEEDER1 AT SECTION 1 AND FEEDER 8 AT SECTION 2

Earth Fault Relays	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
Operating time At section 1	No Trip	2.251	0.12
Operating time At section 2	No Trip	0.15	0.12

sides 11 and 33 kV will trip at the same time due to the discoordination in the operation time between them and as a result, all of the loads, even the healthy feeders, will separate on this section, which may cause issues, especially if there are any critical loads, such as hospitals or water pumps. The IDMT relays utilized in section 2 operate in a coordinated and sequential way, based on the estimated values of the setting. Table XI illustrates this.

Scenario one: Figure 12 depicts a single phase to ground short circuit at the farthest points of the feeder, feeder 1 at section 1, and feeder 8 at section 2. It has been noted that when a single-phase fault occurs, the fault current flows through the earth fault relays. It has also been noted that the ground relays in section 1, which are set with real data of the Nathran substation, are not functioning properly because in the event that the relay close to the fault fails to work for any technical

reason (worse-case), the back-up protection will operate for 2.237 seconds, which is a long time to separate the fault and is dangerous to the equipment and human safety. As with the earth fault relays in section 2, the operating time for the relay closest to the fault is coordinated, and the fast time clearing the fault, as in the case assumed above, is 0.15 sec. As back-up protection, and this represents the strengthening of the proposed coordination, as illustrated in Table XII .

Scenario three: Figure 13 depicts a double-phase to ground short circuit at the farthest points of the feeder, feeder 1 at section 1, and feeder 8 at section 2. A double-phase to-ground fault will have an effect on the IDMT relays for the overcurrent as well as the earth fault relays, as shown in Tables XIII and XIV. According to the order and results of the operating time in section 1 based on real-time data from the Nathran distribution substation, it has been noticed that there is a discoordination in the operating times for the back-up relays if the relay close to the fault does not function (worst-case). For phase element protection, the relay side 33 kV will operate before the main feeder 11 kV, and for ground element protection, the back-up protection will not operate, which is extremely dangerous for the equipment and the safety of humans. The earth fault relays do not function completely in Section 1. In section 2, the operating time results demonstrate the effectiveness of the data calculations for all IDMT and earth fault

relays.

An example of a Nathran substation application is radial distribution networks, where each feeder typically contains an ANSI/IEEE code 50/51 overcurrent relay that must be coordinated with all relays installed on the feeder, as seen in test cases in consumer substation relays. The feeder relay must be coordinated with upstream protection and so on in accordance with the protection philosophy specified by the electrical engineer.
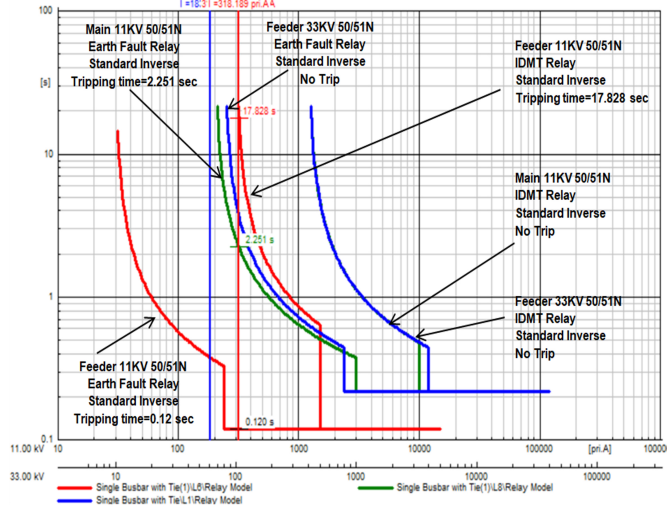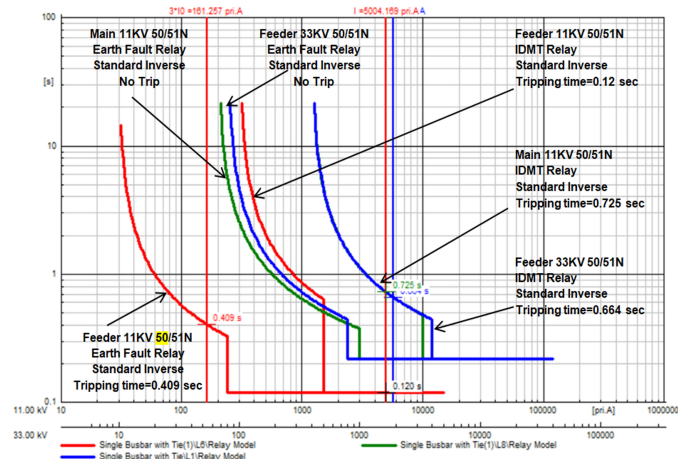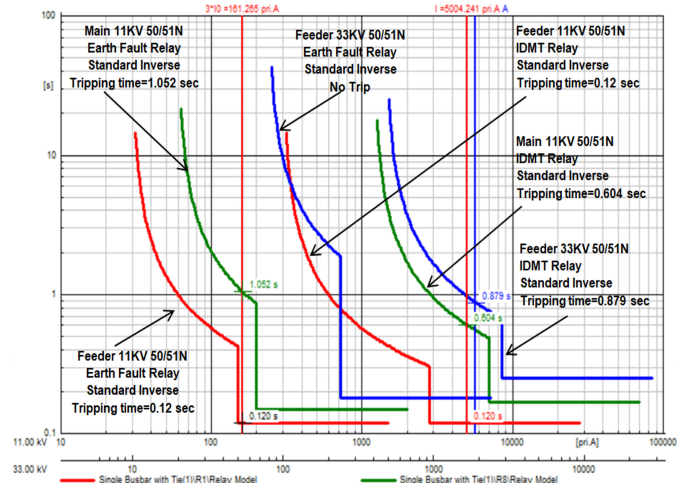

(a) section 1
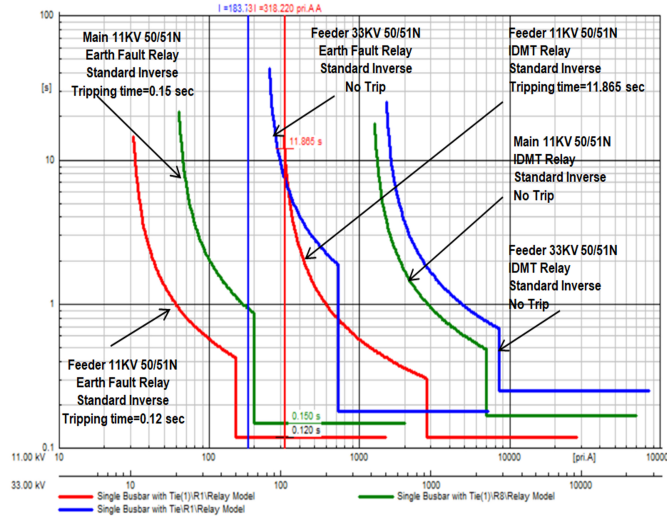
(b) section 2

Fig. 12. TCC curves produced by the DIgSILENT Power Factory software according to single-phase to ground fault at the farthest point of the longest feeders.

(a) section 1

(b) section 2

Fig. 13. TCC curves obtained using DIgSILENT Power Factory software according to two-phase to Ground fault at farthest point of the longest feeders.

VII. CONCLUSION

This study provides a comprehensive analysis of variety of faults to demonstrate the existing miscoordination of one of

TABLE XIII

MEASUREMENT TIME OPERATION BY USING DIGSILENT POWER FACTORY SOFTWARE ACCORDING TO TWO-PHASE TO GROUND SHORT CIRCUIT FAULT AT THE FARTHEST POINTS OF THE LONGEST FEEDERS IN FEEDER1 AT SECTION 1 AND FEEDER 8 AT SECTION 2

IDMT Relays	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
Operating time At section 1	0.664	0.725	0.12
Operating time At section 2	0.879	0.604	0.12

TABLE XIV

MEASUREMENT TIME OPERATION BY USING DIGSILENT POWER FACTORY SOFTWARE ACCORDING TO TWO-PHASE TO GROUND SHORT CIRCUIT FAULT AT THE FARTHEST POINTS OF THE LONGEST FEEDERS IN FEEDER1 AT SECTION 1 AND FEEDER 8 AT SECTION 2

Earth Fault Relays	Feeder 33 kV	Main feeder 11 kV (Incoming)	Feeder1 11 kV (Outgoing)
Operating time At section 1	No Trip	No Trip	0.409
Operating time At section 2	No Trip	1.052	0.12

the substations in the center of Basrah. Therefore, a reliable and efficient industrial coordination technique for the medium voltage system is proposed. This method utilizes actual technical data collection to provide primary and back-up protection for the relays' down and up streams. The coordination is based on the symmetrical short circuit that takes place at the farthest points of the longest feeder. Moreover, the proposed coordination technique has been tested on an industrial numerical IDMT characteristics type relay (overcurrent and earth fault) of the 33 kV incoming feeder, the main feeder 11 kV, and the outgoing feeder 11 kV. The results of the simulation demonstrate that the new scheme is robust to different types of faults because it works properly even in the worst-case scenarios.

CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

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