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Protection Coordination of 33/11 kV Power Distribution Substation in Iraq

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K E Y W O R D S

Protection coordination, power, overcurrent protection, relays setting, CYMDist software.

A B S T R A C T

The coordination between protective devices is the process of determining the most appropriate timing of power interruption during abnormal conditions in the power system. The aim of this work is to coordinate the protection of the 33/11 kV power distribution substation in Iraq using the CYME 7.1 software package. In this paper overcurrent and earth fault relays are simulated in two cases, with time delay setting and instantaneous setting, to obtain the Time Current Characteristics (TCC) curves for each Circuit Breaker (CB) relay of Al-Karama substation (2×31.5 MVA, 33/11 kV) in Babil distribution network. The short circuit current at each CB is calculated and accordingly, the protection coordination for Al-Karama substation has been simulated. The TCC curves have been obtained in two cases for overcurrent and earth fault relays; in a case with time delay setting and in the case with the instantaneous setting. The setting takes into consideration the short circuit current at the furthest point of the longest outgoing feeder and the shortest outgoing feeder.

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1. Introduction

Appropriate protection schemes with proper protection coordination are necessary to maintain the power system reliability and avoid damage to very costly equipment such as power transformers. The correct operation of protective relays and Auto-Reclosers during transient faults will minimize permanent tripping in the distribution network. Therefore, coordination of protective relays at grid substation and downstream Auto-Reclosers are very much essential to maintain the high reliability in Medium Voltage distribution network.

There is a requirement of revising the existing protection settings of Medium Voltage level with the rapid development of distribution networks in Iraq. The objective of the study is to determine the best protection co-ordination of the Medium Voltage system of AL-Krama substation 33/11 kV in the Babil power distribution network. Protection settings of relays at grid substation and downstream Auto-Reclosers of the selected grid substation will be analyzed according to IEC standards to determine the coordination in Medium Voltage level.

2. Setting of overcurrent relays

Overcurrent relays are usually supplied with a time delay element and an instant element in the same unit. A three-phase overcurrent unit and an earth-fault unit are the most modernistic microprocessor protection has within the same case. Overcurrent protection relay settings include choosing the time\current characteristic parameters of both instantaneous and time delay units; firstly, for the phase overcurrent protection relays and secondly for the earth fault protection relays. The phase-to-earth fault current is used for setting the earth fault relays, while the three-phase short circuit current is used for setting the phase relays [1, 2, 3].

I. Instantaneous unit setting

The instantaneous unit can be set by multiplying six to ten times the maximum current rating or 50 percent of the maximum short-circuits current at the point of connection of the Current Transformer (CT) supplying the relay:

$$\text{Setting of instantaneous elements} = \frac{0.5\ I_{SC}}{CTR} \quad (1)$$

where:

I_{SC} is the maximum short-circuit current

CTR is the current transformer ratio

II. Inverse Definite Minimum Time (IDMT) unit setting

Inverse definite minimum time protection relays can be modified by choosing two parameters; the plug setting (tap setting) and the time dial setting.

1. Plug Setting Multiplier (PSM): is the ratio of the fault current in secondary amps to pick-up of the relay:

$$\text{PSM} = \frac{\text{Relay (or secondary)fault current}}{\text{Relay pick−up setting current}} \quad (2)$$

- Pick-up setting for phase relays is specified toward permitting a margin higher than the nominal current in overload cases,

$$\text{Relay pick} - \text{up setting current} = \frac{OLF \times I_{nom}}{CTR} \quad (3)$$

where:

OLF = the overload factor which depends on the part being protected. It ranges between (50% and 200% in 25% steps). For generators, lines, and transformers it is recommended in the range of 1.25 to 1.5 while in case of emergency conditions to increment the load on feeders, such as in distribution systems, OLF could be up to the order of 2.

I_{nom} = nominal circuit current rating.

CTR = current transformer ratio

- Pick-up setting for earth fault relays, the pick-up setting is determined taking account of the maximum to unbalance that would exist in the system under normal operating conditions. A typical unbalance allowance is 20 percent so that:

$$\text{Earth fault relay pick up setting current} = \frac{0.2 \times I_{nom}}{CTR} \quad (4)$$

In high voltage transmission lines, the unbalance allowance could go down to 10 percent, while in rural distribution feeders the value could be as high as 30 percent.

2. Time Multiplier Setting (TMS): When fault current arrives at a magnitude similar to or more than the setting of relay current before relay operates the time delay adjusted by time dial setting or Time Multiplier Setting (TMS) which range between (0.05-1 in 0.05 steps). The procedure for calculating (TMS), to find the convenient coordination and protection to the system are explained as follows:

Step1: Find the required operating time (t_1) of the remote relay from the supply source by utilizing the minimum TMS and depending on the fault level.

Step2: Find the relay operating time-related with the next substation breaker towards the source

$$t_{2a} = t_1 + t_d \tag{5}$$

where: t_{2a} is the back-up relay desired operating time.
t_1 is the operating time of the downstream relay.
t_d is the time discrimination margin for IDMT to IDMT relay.

$$t_d = 0.25t_1 + 0.25 \tag{6}$$

where: Relay Error Factor = $0.25t_1$.
Downstream breaker interrupting Time = 100 msec.
Relay Overshoot Time = 50 msec.
Safety Margin = 100 msec.

Step3: calculate the time dial setting for the back-up relay through the same current of the fault and find t_{2a} so as the pickup value.

$$TMS_{new} = \frac{\text{Desired operating time}}{\text{operating time at selected PSM and (TMS= 1.0)}} \tag{7}$$

Step4: Find the actual operating time (t_{2b}) of the back-up relay, but now using the fault level and pickup value where this relay is connected.

$$t_{2b} = \text{Operating time at selected PSM and (TMS=1.0)} \times TMS_{new} \tag{8}$$

Step5: Go on with the sequence, beginning from step 2 [1].

III. Time discrimination margin

A time discrimination margin between two successive time/current characteristics of the order of 0.25 to 0.4 s should be typically used [4]. This value avoids losing selectivity due to one or more of the following [1, 4]:

- Breaker opening time.
- Relay overrun time after the fault has been cleared.
- Variations in fault levels, deviations from the characteristic curves of the relays (for example, due to manufacturing tolerances), and errors in the current transformers. In numerical relays, there is no overrun, and therefore the margin could be chosen as low as 0.2 s.

IV. Mathematical calculation for the characteristics of the relay

The procedure for the earth and phase units can be readily utilized when the operating characteristics of the relays are known by a mathematical formula in lieu of log-log paper curves. The operating time can be defined mathematically according to IEC standards as [1, 2, 3]:

$$t = \frac{K\,\beta}{\left(\frac{I}{Is}\right)^{\alpha}} + L \qquad (9)$$

where:
t = operating time of relay in seconds.
I_s = selected pick-up current
I = secondary fault current level in amps.
k = time multiplier setting, or time dial.
L = constant.

The parameters α and β are to determine the relay characteristics slope. These constants with L to IEC standard of the overcurrent relays are given in Table I.

TABLE I: IEC constants for standard overcurrent relays

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

V. Constraints of relay coordination

The constraints of relay coordination are [1, 4, 5]:

- Minimum short-circuit levels: In the correct sequence, it is important to inspect the minimum fault levels the relay will operate.
- The pick-up values: Important inspection of the relay settings when other system types of equipment are energized, especially in critical situations for starting in motors and inrush current in the transformers depends on the transformer capacity.
- Thermal limits: Once the curves for the overcurrent relays have been defined, a check should be made to ensure that they lie below the curves for the designated thermal capacity of machines and cables. The conductors' manufacturer's graphs indicate the length of time that different sizes can withstand various short-circuit values. In transformers' case, the magnitude of the fault current that they can withstand during a given time is limited by their impedance.

3. System Modeling using CYMDist Software

Distribution substations in Iraq have simple protection schemes consisting of feeder circuit overcurrent, reclosing, and transformer protection, either with high-side fuses or differential and overcurrent relays. Each substation comprising the following:

- Indoor switchgear 33 kV.
- Two transformers 31.5 MVA, 33/11 kV.
- Indoor switchgear 11 kV.
- Feeder 11 kV cable, copper 1x400 mm^2, XLPE insulated, with pilot cables.
- Local SCADA with intelligent electronic devices for each panel of 33 & 11kV switchgear with a port to be connected to the regional control Centre.

This work is dedicated to obtaining coordination results from the different analyses and calculations applied to a part of Babil distribution network named Al-Karama Substation (2×31.5 MVA, 33/11 kV), as shown in Figure 1. Details of this substation are given in reference [6]. This network is simulated in CYMDist software package version 7.1 [7].

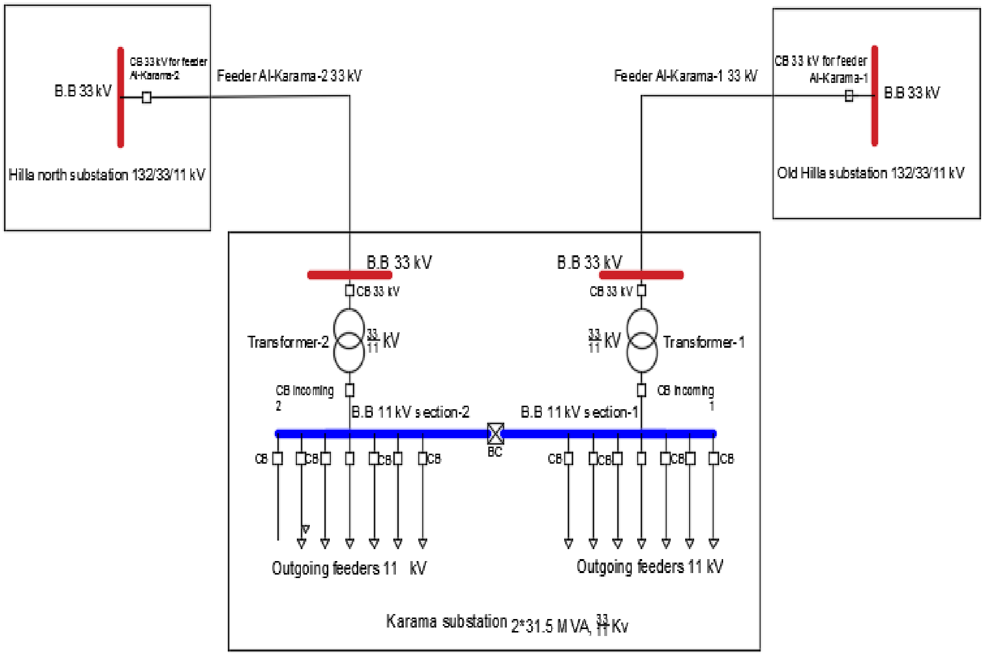


Figure 1: Al-Karama substation (2×31.5 MVA, 33/11 kV) in Babil distribution network [6]

4. Simulation of Protection Coordination

The short circuit current on busbar 132 kV for Hilla north substation is 15989.5 A according to the Ministry of Electricity (MoE). This short circuit current has been entered into the proposed model as the supply short circuit current to determine the short circuit current on the 11kV busbar in Al-Karama substation which is found to be 9493 A, as shown in Figure 2. Two feeders have been considered; the longest and shortest that operate on the same section in Karama substation. And the short circuit current has been calculated at the furthest point of each feeder (Hukam and Karama).

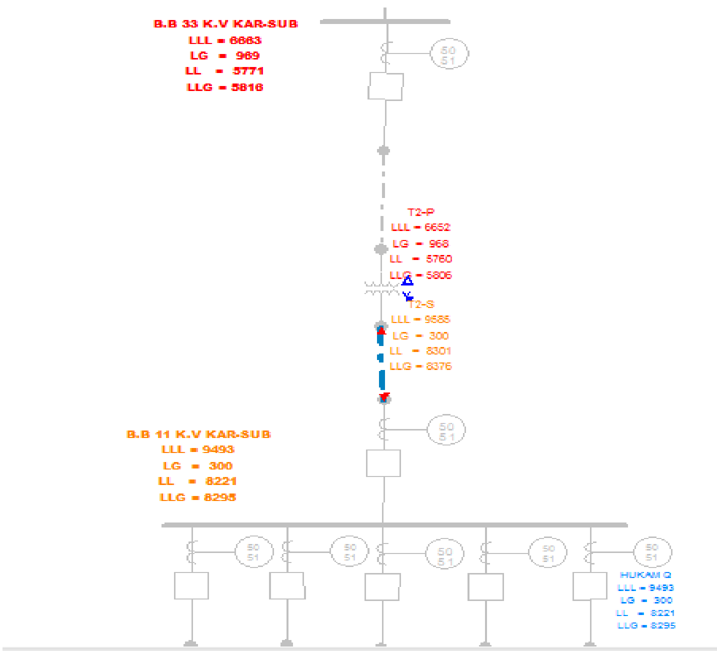


Figure 2: Short circuit current in Karama substation at busbars 33 kV and 11 kV and CB of an outgoing feeder of modeled system

I. Setting overcurrent relays with time delay

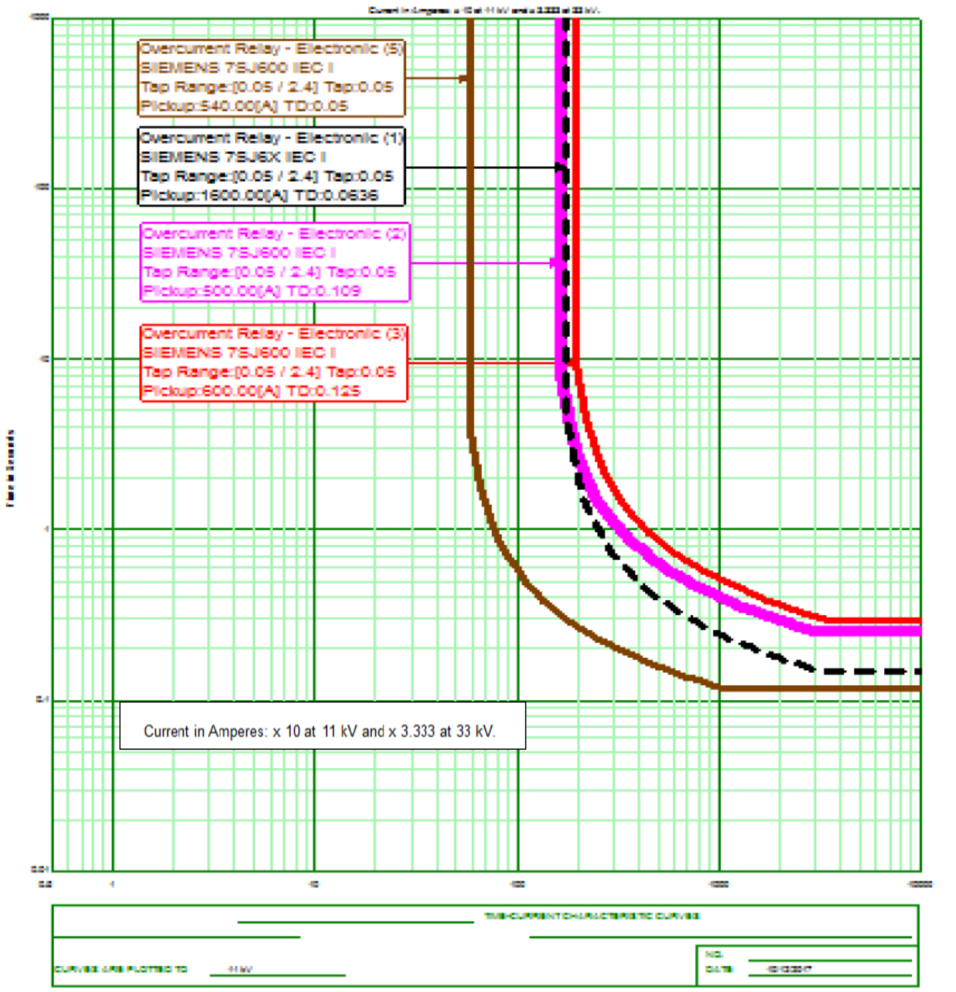
The feeder Hukam 11 kV has been chosen because it is the longest feeder. The short circuit current at the furthest point on the feeder has been calculated and it is found to be 4699 A, as shown in Figure 3. The coordination is calculated by referring to section 2, considering that the discrimination time is 0.25 sec, as given in Table II. And the TCC curves obtained using CYMDist are shown in Figure 4.

$$t = 0.05 \times \frac{0.14}{\left(\frac{4699}{540}\right)^{0.02} - 1} = 0.16$$

Figure 3: Short circuit current at the furthest point of Hukam feeder of modeled system

TABLE II: Setting with time delay for overcurrent relays calculated by referring to section 2 depending on short circuit current of Hukam feeder.

	CB 33 kV Hilla north - Sub	**CB 33 kV Karama -Sub**	**CB 11 kV Karama –Sub (Incoming)**	**CB 11 kV Karama –Sub (Outgoing)**
CTR	600/5	600/1	2000/1	300/1
Operating time +0.25 sec	0.91	0.66	0.41	0.16
PSM $=\frac{I\ setting}{In}$	2.61	3.132	2.93	8.7
Primary current (Amp)	600	500	1600	540
TMS	0.125	0.109	0.0636	0.05



— Over current relay for CB 33 kV of Hilla north,
— Over current relay for CB 33 kV of transformer-2 Karama substation,
… Over current relay for CB 11 kV of incoming Karama substation,
— Over current relay for CB 11 kV of the outgoing feeders Hukam.

Figure 4: TCC curves obtained using CYMDist software according to setting with a time delay of overcurrent relays for different CBs.

The feeder Karama 11 kV has been chosen because it is the shortest feeder. The short circuit current on the furthest point on the feeder has been calculated and it is found to be 7578 A, as shown in Figure 5. The coordination calculated by referring to section 2. The discrimination time is considered 0.25 sec, as given in Table III. And the TCC curves obtained using CYMDist software are shown in Figure 6.

$$t = 0.05 \times \frac{0.14}{\left(\frac{7578}{420}\right)^{0.02} - 1} = 0.1175$$

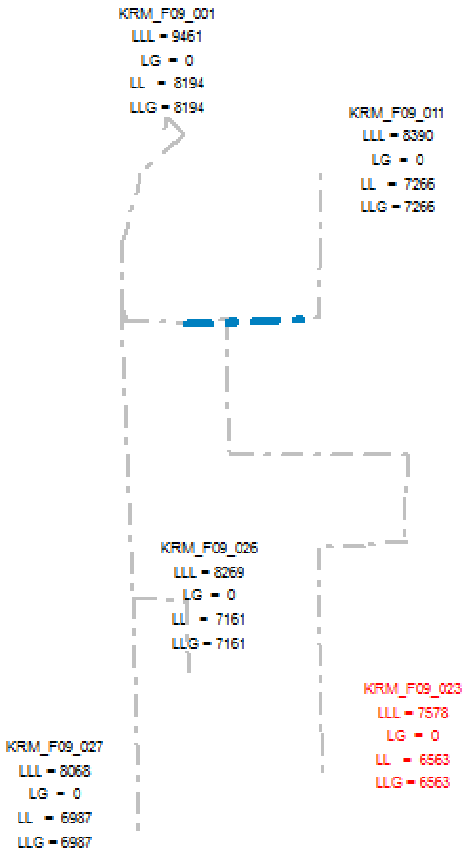
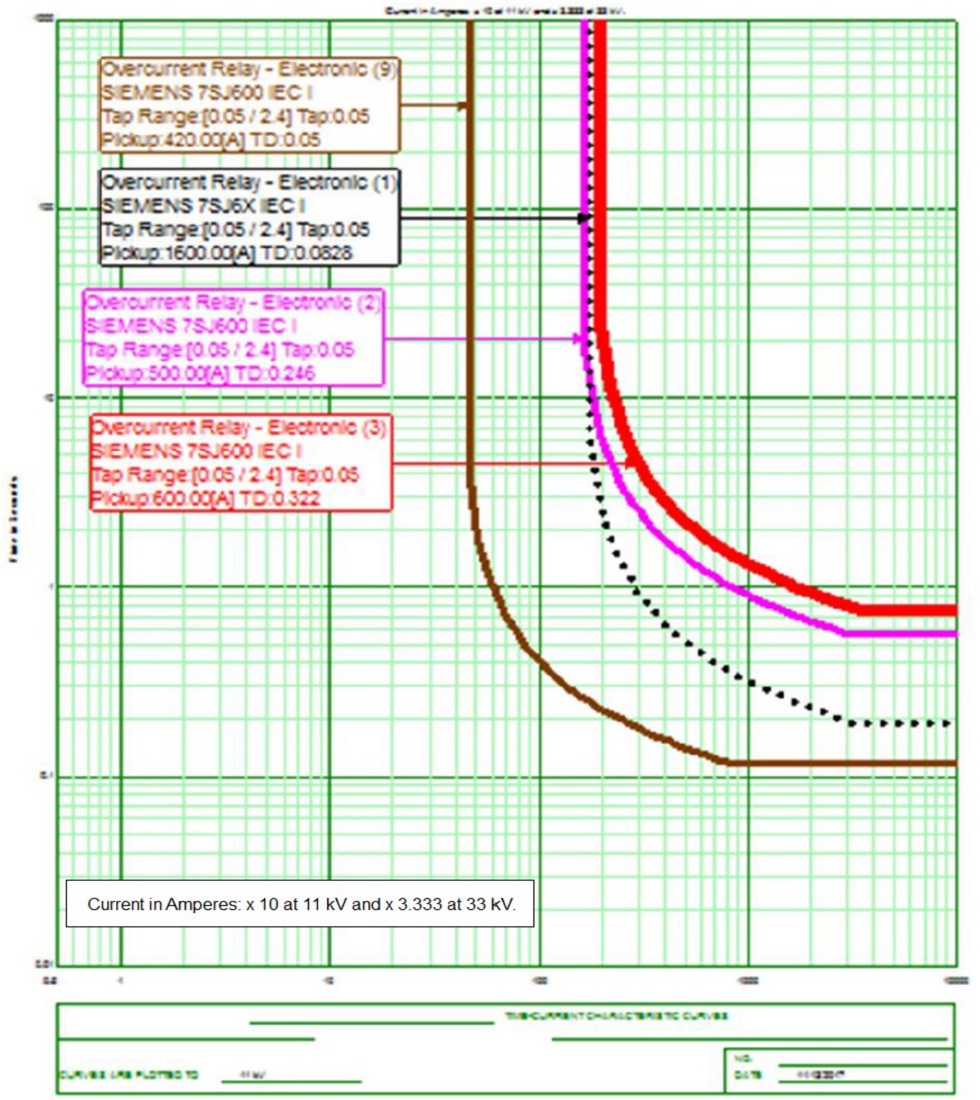


Figure 5: Short circuit current at the furthest point of Karama feeder of modeled

TABLE III: Setting with time delay for overcurrent relays calculated by referring to section 2 depending on short circuit current of Karama feeder.

	CB 33 kV Hilla north - Sub	CB 33 kV Karama -Sub	CB 11 kV Karama –Sub (Incoming)	CB 11 kV Karama –Sub (Outgoing)
CTR	600/5	600/1	2000/1	300/1
Operating time +0.25 sec	0.8675	0.6175	0.3675	0.1175
PSM=$\frac{I\ setting}{In}$	12.63	15.156	4.73	18
Primary current in Amp	600	500	1600	420
TMS	0.322	0.246	0.0828	0.05



— Over current relay for CB 33 kV of Hilla north,
— Over current relay for CB 33 kV of transformer-2 Karama substation,
… Over current relay for CB 11 kV of incoming Karama substation,
— Over current relay for CB 11 kV of the outgoing feeders Karama.

Figure 6: TCC curves obtained using CYMDist software according to setting with a time delay of overcurrent relays for different CBs.

The protection of bus section-2 for power transformer-2 in Karama substation includes; the incoming CB 11kV, the CB 33 kV Karama substation, and the CB 33kV Hilla-north substation, as shown in Figure 1. The TMS for bus section-2 relays should be chosen to guarantee that the coordination will work for the highest Plug Setting Multiplier (PSM) which is reversely proportional with the operating time, as given in Table IV. A load of feeders and/or size of CTR should be taken into consideration.

TABLE IV:Final TMS for section-2 of Karama substation.

	CB 33 kV Hilla north -Sub	CB 33 kV Karama -Sub	CB 11 kV Karama –Sub (Incoming)	CB 11 kV Karama –Sub (Outgoing)
TMS	0.32	0.25	0.1	0.05

II. Instantaneous setting of overcurrent relays

A. Using multi-zone [1, 8]

According to the calculation of short circuit current at each bus as given in figures (2, 3, and 5) and according to section 2 the instantaneous setting of overcurrent relays is calculated as given in Table V. When two relays see the same fault current the selectivity is achieved depending on the margin of 0.25 sec for a definite time. The margin between CB 11 kV for incoming feeder and CB 33 kV for Karama substation is 0.05sec since the setting of instantaneous relay for CB 33 kV for Karama substation will not associate in the same zone with the CB 11 kV incoming in all cases, as shown in Figure 7. The TCC curves as obtained using CYMDist software are shown in Figure 8.

TABLE V: Instantaneous setting of overcurrent relays calculated by referring to section 2 for Karama substation.

	CB 33 kV Hilla north - Sub	CB 33 kV Karama -Sub	CB 11 kV Karama–Sub (Incoming)	CB 11 kV Karama–Sub (Outgoing-Hukam)	CB 11 kV Karama–Sub (Outgoing-Karama)
CTR	600/5	600/1	2000/1	300/1	300/1
Short circuit current (Amp)	7673	6663	9493	4669	7578
Relay setting (Amp)	3837	3332	4747	2350	3789
Definite time (ms)	500	300	250	50	50

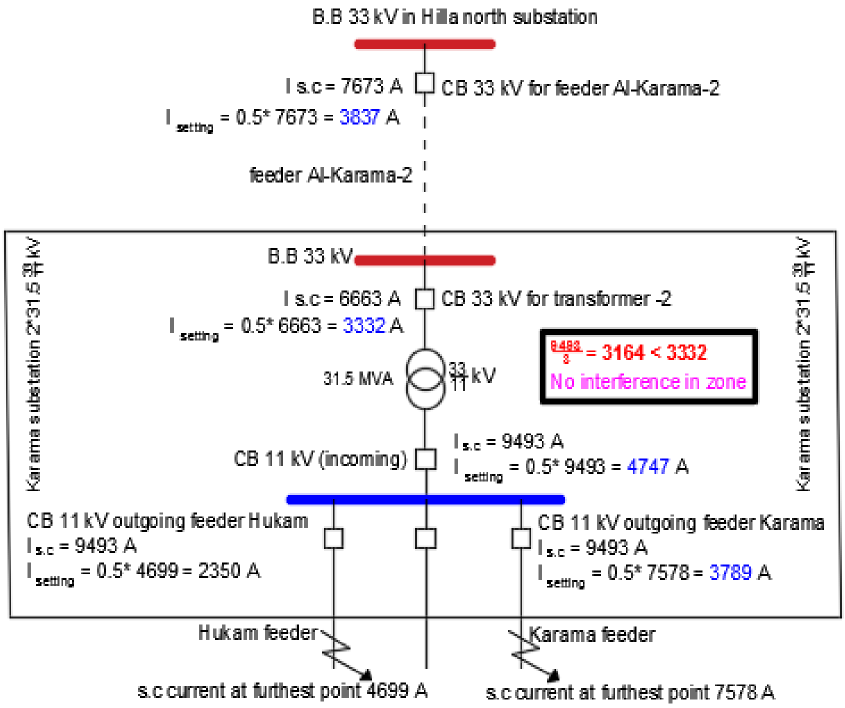
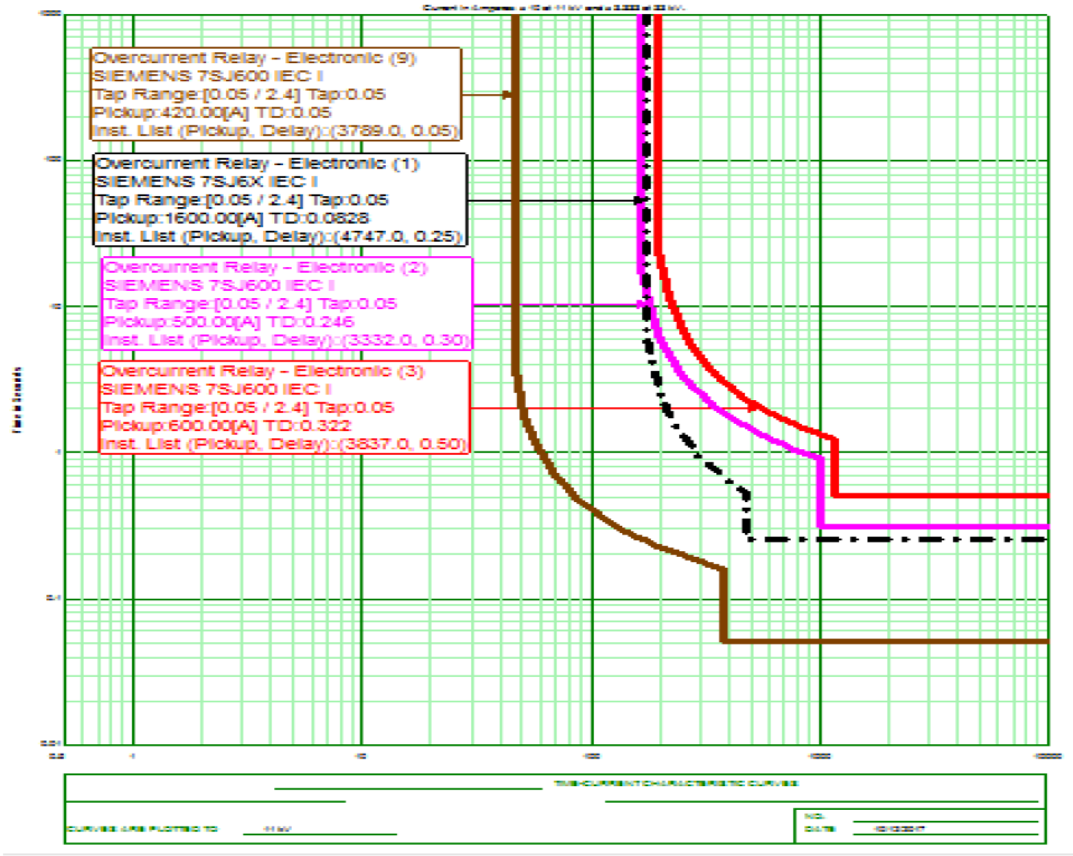


Figure 7: Instantaneous setting of overcurrent relays calculated referring to section 2 for Karama substation.



— Over current relay for CB 33 kV of Hilla north,
— Over current relay for CB 33 kV of transformer-2 Karama substation,
... Over current relay for CB 11 kV of incoming Karama substation,
— Over current relay for CB 11 kV of the outgoing feeders Karama.

Figure 8: TCC curves obtained using CYMDist software according to the instantaneous setting of overcurrent relays for different CBs.

B. Using one zone

This method is applied in the general directorate of energy transmission in middle AL-Furat / MOE. The minimum short circuit current in all feeders of the transformer section is calculated and using the upstream CB as aback up protection for downstream CB and according to section 2 depending on the time only to achieve the selectivity. The instantaneous setting of overcurrent relays is calculated in Table VI. Considering the furthest point for Karama feeder represent minimum short circuit current for all section-2 which is (7578 A), as shown in Figure 9. And the TCC curves are obtained using CYMDist software as shown in Figure 10.

TABLE VI:Instantaneous setting of overcurrent relays calculated according to general directorate of energy transmission/ MOE for Karama substation considering minimum fault current at Karama feeder.

	CB 33 kV Hilla north - Sub	CB 33 kV Karama-Sub	CB 11 kV Karama-Sub (Incoming)	CB 11 kV Karama-Sub (Outgoing)
CTR	600/5	600/1	2000/1	300/1
Short circuit current (Amp)	7673	6663	9493	7578
Relay setting (Amp)	3789	3789	3789	3789
Definite time (ms)	650	450	250	50

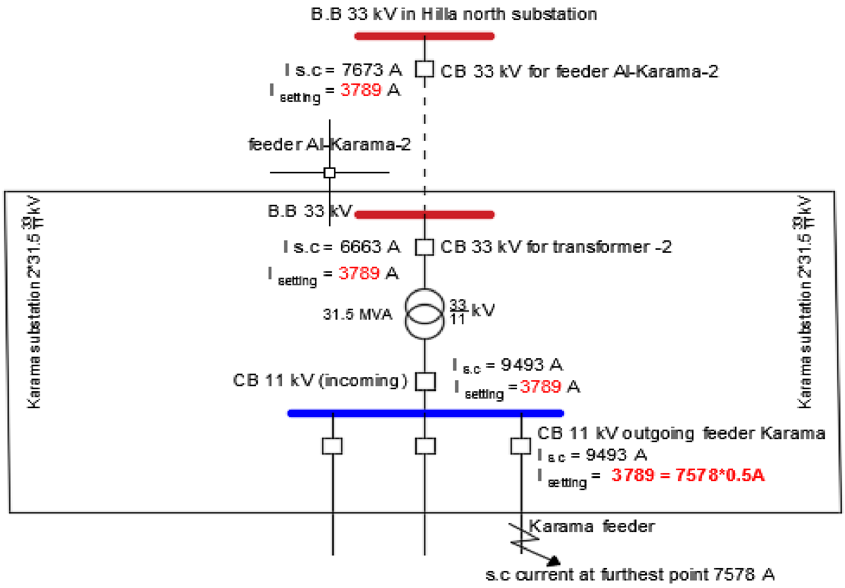
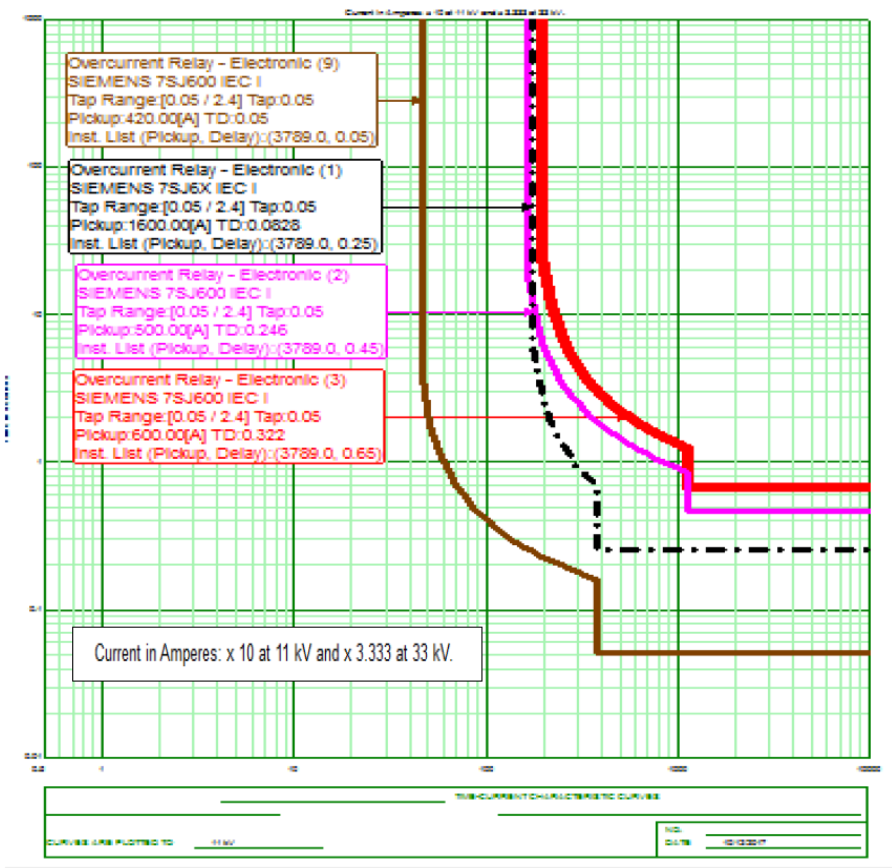


Figure 9: Instantaneous setting of overcurrent relays calculated according to general directorate of energy transmission in middle AL-Furat/MOE.



— Over current relay for CB 33 kV of Hilla north,
— Over current relay for CB 33 kV of transformer-2 Karama substation,
… Over current relay for CB 11 kV of incoming Karama substation,
— Over current relay for CB 11 kV of the outgoing feeders Karama.

Figure 10: TCC curves obtained using CYMDist software according to the instantaneous setting of overcurrent relays for different CBs.

III. Setting earth fault relays with time delay

Earth fault calculations dose not depend on short circuit current for outgoing feeders 11 kV, this is because the vector group for distribution transformer is Dy_{n11}. So that the zero-sequence current in the secondary side of the distribution transformer does not pass to the primary side and so does not pass to the feeder 11kV outgoing from the substation. So that the highest line to ground short circuit current is considered to be 300 A taking into consideration that the earthing resistance is 21.1 Ω connected to the secondary side of the power transformer Dy_{n11}. So, the earth fault setting for all outgoing feeders is the same. The coordination is calculated by referring to section 2, considering that the discrimination time is 0.25 sec. The setting of CB 33 kV in Karama substation and CB 33kV for feeder Al-Karama-2 is equal because the zero-sequence current in the secondary side of the power transformer does not pass to the primary side, as given in Table VII. And the TCC curves as obtained by CYMDist are shown in Figure 11.

$$t = 0.05 \times \frac{0.14}{\left(\frac{300}{30}\right)^{0.02} - 1} = 0.15 \text{ sec}$$

TABLE VII: The setting of earth fault relays with time delay calculated by referring to section 2 for Karama substation.

	CB 33 kV Hilla north - Sub	CB 33 kV Karama -Sub	CB 11 kV Karama-Sub (Incoming)	CB 11 kV Karama-Sub (Outgoing)
CTR	600/5	600/1	300/1	300/1
PSM	0.1	0.15	0.15	0.1
Primary current (A)	60	60	45	30
Operating time +0.25 sec	0.9	0.65	0.4	0.15
TMS (sec)	0.36	0.26	0.11	0.05

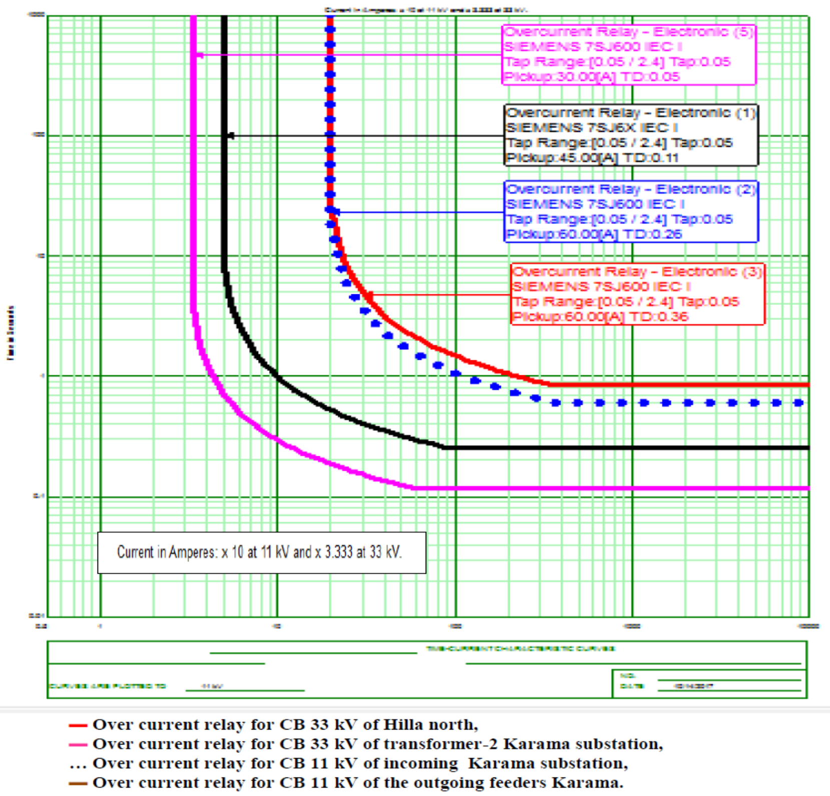


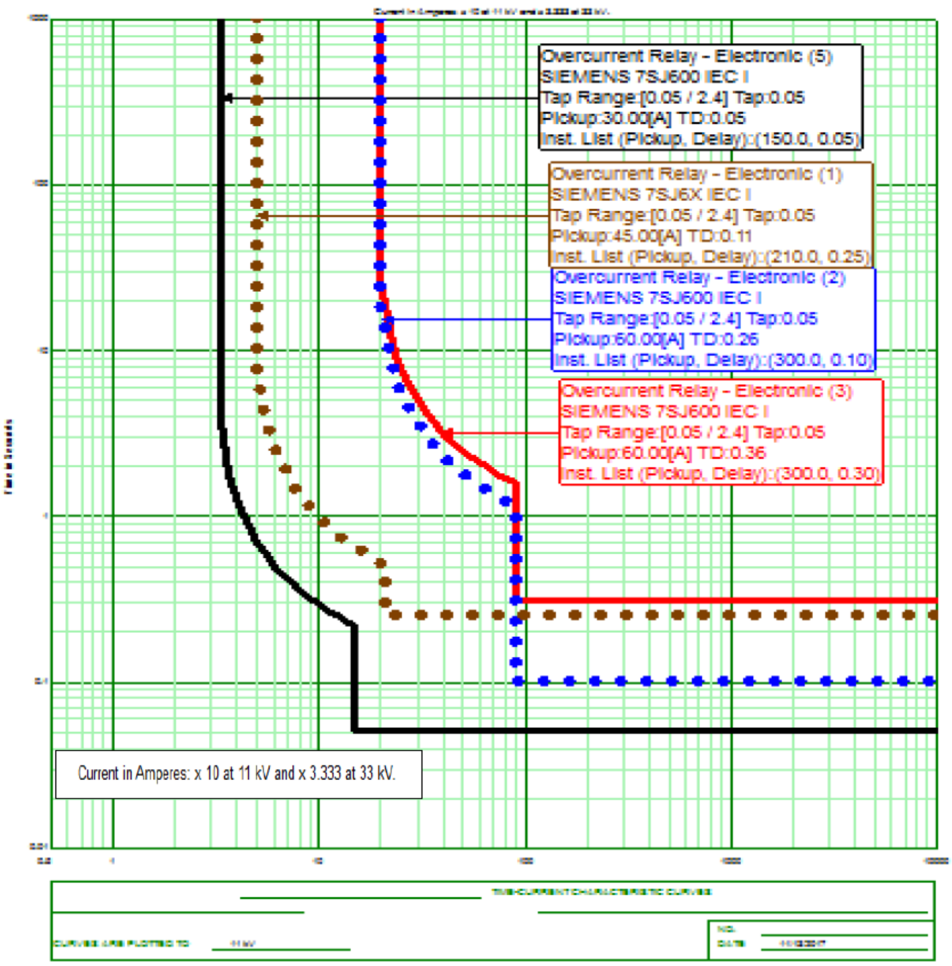
Figure 11: TCC curves obtained using CYMDist software according to the setting of earth fault relays with time delay for different CBs.

IV. Instantaneous setting of earth fault relays

The coordination is calculated by referring to section 2, considering that the margin indefinite time is 0.2 sec. The setting of CB 33 kV in Karama substation and CB 33kV for feeder Al-Karama-2 is equal because the zero-sequence current in the secondary side of the power transformer does not pass to the primary side, as given in Table VIII and the TCC curves as obtained by CYMDist is shown in Figure12.

TABLE VIII: Instantaneous setting of earth fault relays calculated by referring to section 2 for Karama substation.

	CB 33 kV Hilla north - Sub	CB 33 kV Karama -Sub	CB 11 kV Karama-Sub (Incoming)	CB 11 kV Karama-Sub (Outgoing)
CTR	600/5	600/1	300/1	300/1
PSM	2.5	0.5	0.7	0.5
Primary current (A)	300	300	210	150
TMS (sec)	0.36	0.26	0.11	0.05
Definite time (ms)	300	100	250	50



— **Over current relay for CB 33 kV of Hilla north,**
— **Over current relay for CB 33 kV of transformer-2 Karama substation,**
… **Over current relay for CB 11 kV of incoming Karama substation,**
— **Over current relay for CB 11 kV of the outgoing feeders Karama.**

Figure 12: TCC curves obtained using CYMDist software according to the instantaneous setting of earth fault relays for different CBs.

5. Conclusions

The TMS=0.1 sec for the relay of CB 33 kV feeder Al-Karama-2 (as specified by General Directorate of Energy Transmission in Middle Al-Furat/MOE) did not take into consideration that Al-Karama substation has three CBs downstream in series with CB 33 kV of feeder Al-Karama-2. So this TMS =0.1 sec is very low while it should be TMS=0.322 sec according to our calculations, to achieve coordination with Karama substation.

Hukam feeder is overloaded and it is too long beyond design boundaries, where it works with load current almost twice the CT size. While according to the specifications of MOE the current should not exceed 1.2 of the CT size continuously, to avoid CT saturation. It is possible to change the CT size to be 600:1 instead of 300:1 for Hukam feeder as a quick solution, until transfer some of the feeder load, or construct another feeder from another distribution substation.

In the future, it is suggested to avoid large differences in lengths of outgoing feeders, to avoid large differences in short circuit current at the furthest point of each feeder.

In the case of the instantaneous setting of overcurrent relays for unreliable networks, it is preferred to use the one zone method for setting these relays to protect the types of equipment.

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