Palestine Polytechnic University

College of Engineering

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Electrical Power Engineering

Title

Design Distribution Substation

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الإهداء

إلى معلمنا الأول ومعلم الناس الخير.................... نبينا محمد صلى الله عليه وسلم

إلى من زرعوا فينا الطموح والمثابرة و الاجتهاد........................آباؤنا الأفاضل

إلى ينابيع المحبة و العطاء........................أمهاتنا العزيزات

إلى إخوتنا وأخواتنا

إلى معلمينا و معلماتنا

إلى الأصدقاء و الزملاء

إلى من ناضلوا من أجلنا شهدائنا وأسرانا وجرحانا

إلى هذه الأرض التي نحب فلسطين

Abstract

This project aims to design a step down subtransmission substation from 161 kV to 33 kV of 500 MVA capacity. The substation design starts by deciding the substation location. After that power transformers is selected, design a grounding system and protection system.

Before starting the design, a load forecasting must be fulfilled for the substation expected loads to decide the substation capacity. This step must be done to guarantee the substation ability to feed Hebron city with power for the both areas, the areas under the supervision of Hebron Electric and power company (HEPCO) and those under the supervision of southern electric company (SELCO) until the year 2040, based on substation capacity power transformers ratings is considered, grounding system is designed and the required protection devices is selected.

The operation of entering power transformers to the utility is done on stages in order to increase the substation capacity as the load increase. ETAP simulation program was used to determine fault currents and to build the substation grounding grid.

الملخص

يهدف هذا المشروع إلى تصميم محطة نقل كهربائية تعمل على خفض الجهد الكهربائي من 161 كيلو فولت إلى 33 كيلو فولت و بسعة كهربائية تصل إلى 500 ميجا فولت أمبير.ويكون تصميم المحطة من خلال اختيار موقع المحطة بعد ذلك يتم اختيار محولات القدرة ، تصميم نظام التأريض للمحطة و أنظمة الحماية .

قبل البدء بتصميم المحطة الكهربائية , يجب عمل دراسة لتقدير الأحمال التي سوف تغذيها, لضمان قدرة المحطة على تغذية المنطقة الخاضعة لها كل من شركة كهرباء الخليل و شركة كهرباء جنوب الخليل حتى العام 2040م. و من أجل تحديد قدرة المحولات داخل المحطة ,و تصميم نظام التأريض, تصميم قضبان الوصل ,و اختيار أنظمة الحماية المناسبة.

تتم عملية إضافة محولات القدرة تدريجيا وفق خطة تعتمد على النمو في الأحمال مع الوقت. تم استخدام برنامج 'ETAP' من من أجل تحديد تيار دائرة القَصر, و من أجل اعتماد و محاكاة نظام تأريض وفق المعايير العالمية.

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1.1. Overview

In our time the electricity become important as much as food and water, so people can't live without it, however the world now aims to offer the required quantity of power without interruption at the lowest cost.

The process of producing electricity is done in three stages, the first stage is generating the power, then transferring this power through the transmission system and the last stage is power distribution.

The main idea of this project is to make a new design for Tarqumia substation in order to use this substation to feed the smaller substations in Hebron city and in south of Hebron.

1.2. Project Description

Hebron Electric Limited Liability Company was established in 2000 on an area of 91 km2 to serve 340,000 citizens of Hebron and Halhul, with a capital of 25 million Jordanian Dinars and assets of 91 million NIS. The percentage of electricity customers in Hebron and Halhul is 100%, with 50,409 customers until the end of 2017 [1].

In 1997, there was a plan to change some institutions from public to private sector. The plan include transferring the Electricity Department of Hebron Municipality into a Limited Liability Company. Accordingly, the World Bank and the Palestinian Energy Authority have approved on dividing Hebron Governorate into two electricity distribution companies:

- HEPCO (Hebron Electric Power Company) that includes Hebron and Halhul areas.
- SELCO (Southern Electricity Company) that includes Dura and its nearby areas.

There is a difference between HEPCO & SELCO in the power distribution system, HEPCO use a small substations contain power transformers, these substations receive 33 kv feeder from Israeli electric company(IEC) and by using step down transformers it convert the voltage to 11 kV, after that each substation is connected with some distribution transformers of the ratio (11 - 0.4) kV.

In SELCO there is a different situation SELCO doesn't have distribution substations such as HEPCO substations, in SELCO they call it converting substations, they have a main distribution transformers distributed on a seventeen center points, these transformers connected with a main feeder of 33 KV that comes from the IEC & then they step down the voltage to 0.4 kV directly.

1.2. Methodology

1) Obtaining data from HEPCO & SELCO companies about annual loads, existing substations and transformers ratings, protection devices.
2) Using Etap simulation program to draw the network and determine fault currents.

1.3. Objectives

1) Using the international standards to reach a general form for the main steps of designing a subtransmission substation.
2) Design a subtransmission substation in which to be enough to feed the whole Hebron city with power by making a new design for Tarqumia substation with capacity of 500 MVA.

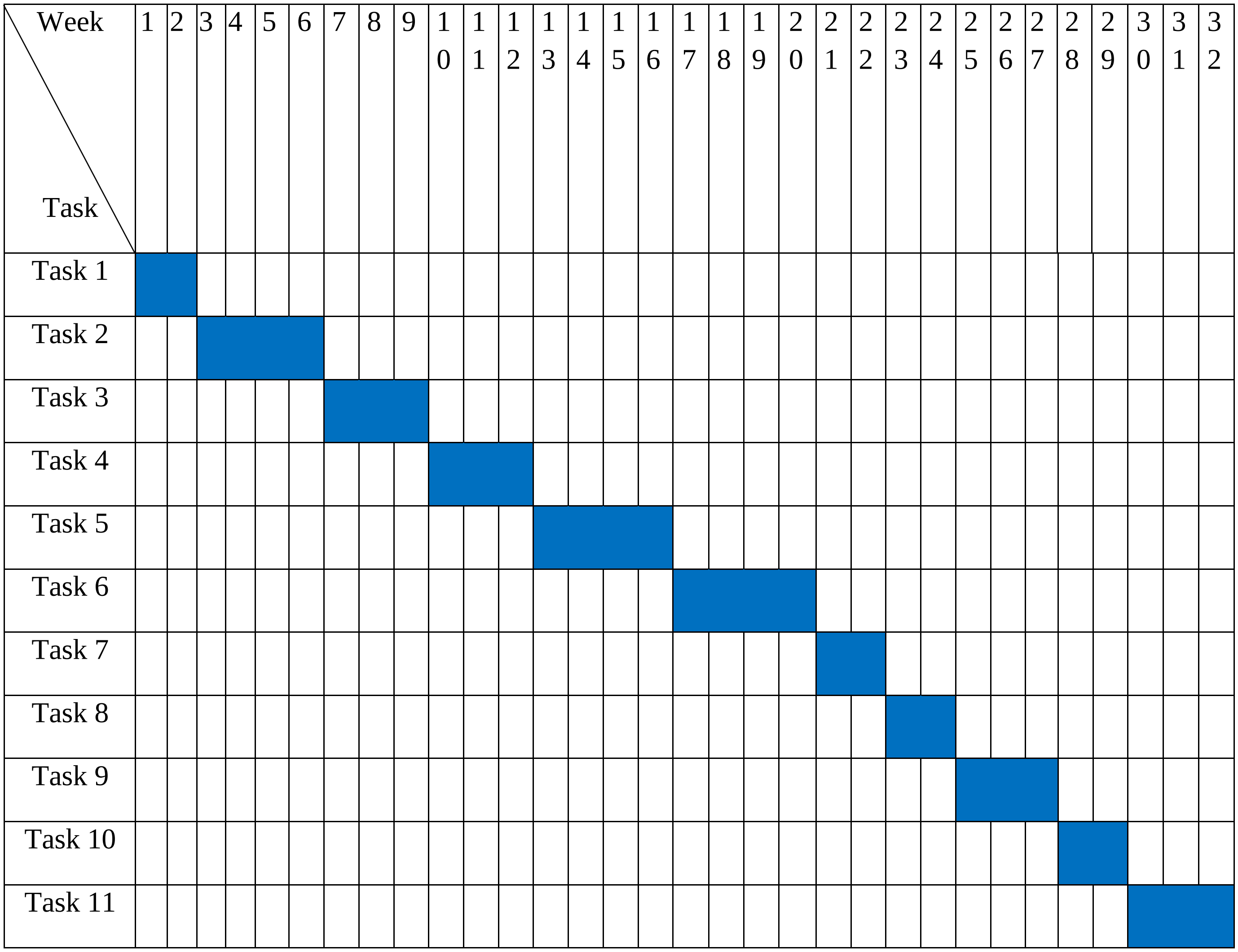
1.4. Background

In this project we consider taking the load forecasting for HEPCO regions from 2018 until 2040 by using regression model depending on six factors, population, load factor, gross domestic product, power system losses, gross domestic product per capita and the cost of kilowatt-hour, these factors affect the load growth according to regression method [2].

1.5. Challenges and Obstacles

1) The difficulties of getting loads data for the last four years especially from SELCO Company.
2) Lack of high power subtransmission substations in the west bank areas.
3) The limitation of operation area of Palestinian power companies which limited into medium voltage.

1.6. Time schedule



Tasks

Task 1: select the project

Task 2: Data collection about the recently loads

Task 3: Study the load forecasting

Task 4: Decide substation capacity

Task 5: Design grounding system

Task 6: Design substation Busbars

Task 7: power transformers selection and installation plan

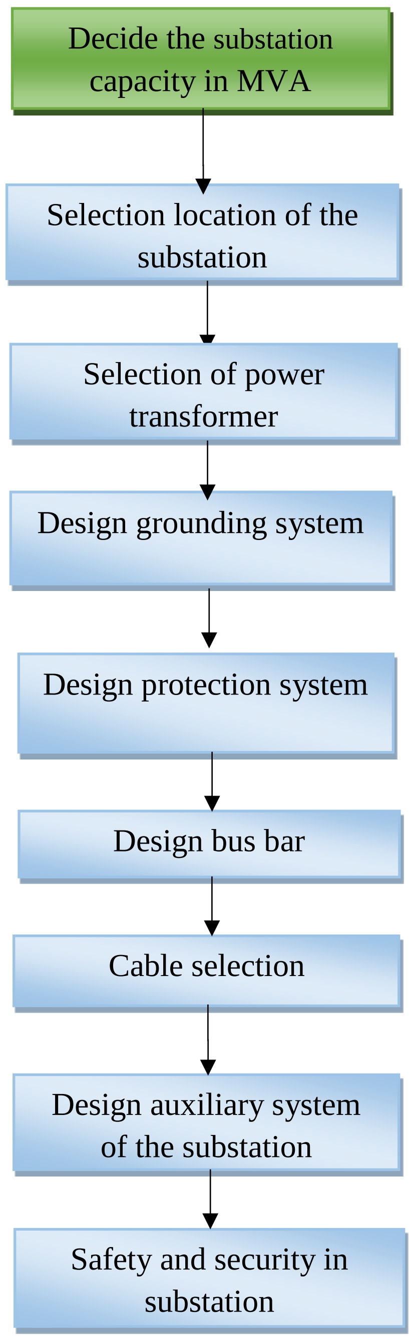
Task 8: substation auxiliary system

Task 9: Design protection system

Task 10: Substation cables selection

Task 11: Safety and security of the substation

1.7. Project flow chart



1.8. Load Analysis

For efficient planning and profit analysis on investment a load forecasting for future loads must be considered, load forecasting is the backbone of any planning process, it has a great impact on future decisions and this reflected as profit or losses to the utility company, it can also be used to determine the period of time that existing power plants can cover before they need to be improved or to decide when to build a new stations, therefore it's very important in the strategic planning process for the future safe of energy to make load forecasting analysis.

So, by using load forecasting for HEPCO and SELCO we can decide the capacity of Tarqumia substation, ratings of power transformers and many other devices. We use long term forecasting model for HEPCO and SELCO loads for about twenty two years.

1.8.1. HEPCO Load Analysis

The electrical network of Hebron city consists of seven main substations that feed the city with power, these substations spread in the city and all of them are fed by the Israeli Electric Company (IEC) through a 33kv feeder connected to the main power control (MPC) that combine all of the seven substations, then the line comes out used to distribute the power to the substations inside Hebron city.

HEPCO substations:

1. **Al-Dahdah Substation.**
2. **Al-Gharbia Substation.**
3. **Al-Fahs Substation.**
4. **Al-Ras Substation.**
5. **Al-Harayek Substation.**
6. **Al-Hussein Substation.**
7. **Umm Al-Daliyeh Substation.**

The following figure shows the spread of stations in Hebron city:

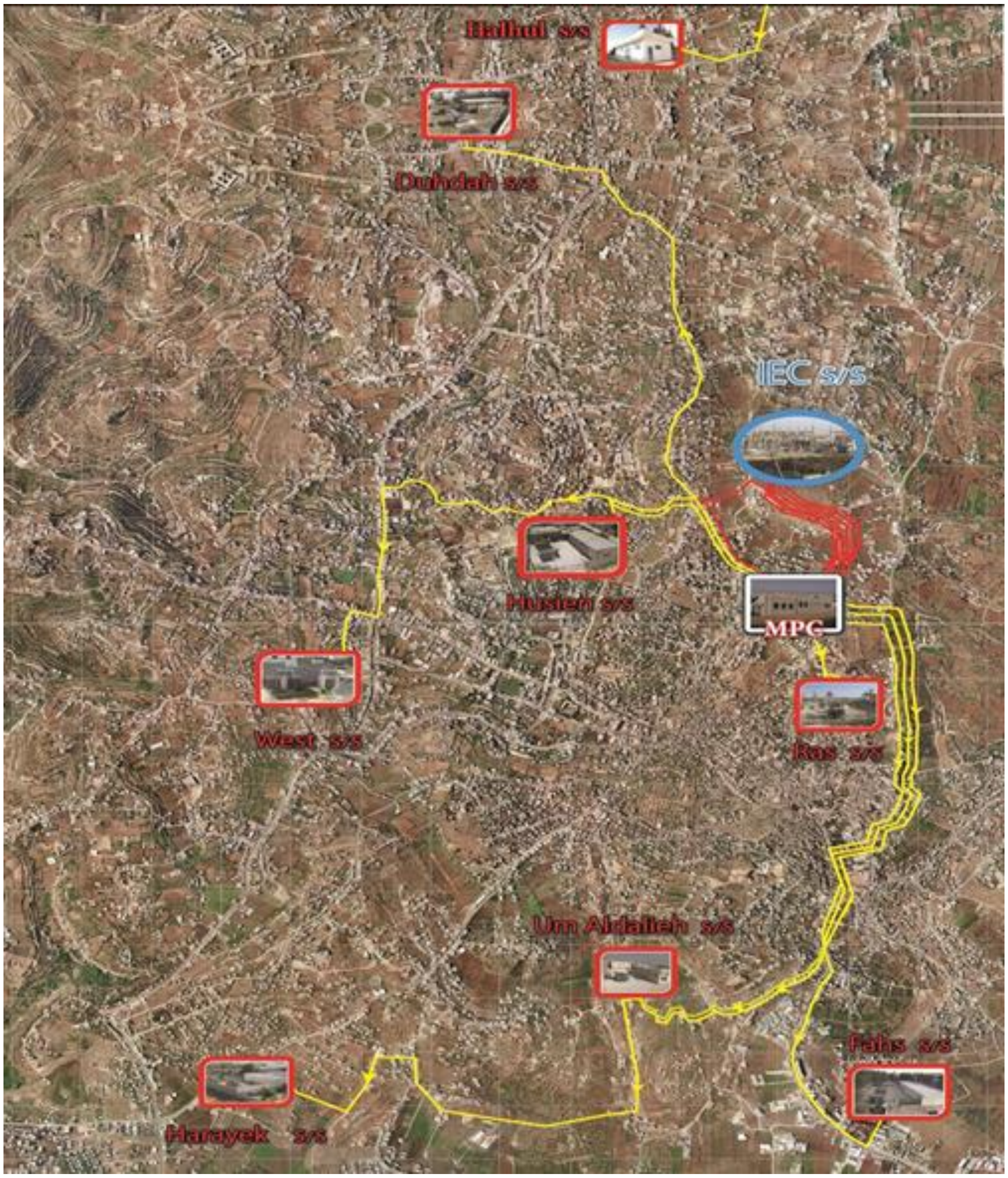


Figure 1.1: spread of HEPCO stations

HEPCO peak load was estimated in a previous study for a long period of time from 2016 to 2035 by using regression forecasting model[3], in table 1.1 if we compare the values of the load estimated by regression method in the years 2016 and 2017 with the real values measured by the SCADA system we will find that its almost the same, so we depend on this study to get the values of the peak load for Hebron city during the required period.

Table 1.1**:** comparison between HEPCO estimated load and measured load in 2016 and 2017

Year	Estimated MW	Measured MW
2016	100.1	99.37
2017	103.87	104.3

However we use the same calculation model of the previous study to calculate the loads for another five years depending on the following equation[3]:

Peak load (PL) = $a_0 + a_1 GDP + a_2\, POP + a_3\, (GDP/CAP) + a_4$ (system losses) $+ a_5$ (LF) $+ a_6$ (cost of KWH)   Equation (1.1)

Table A.1 list the estimated parameters for a detailed peak load demand model [2]. (See appendixA1).

Table A.2 shows the values estimated for the peak load (MW) of HEPCO network for the period from 2018 to 2040. (See appendix A2).

The following figure describes the behavior of HEPCO load growing during the next twenty two years as shown below:

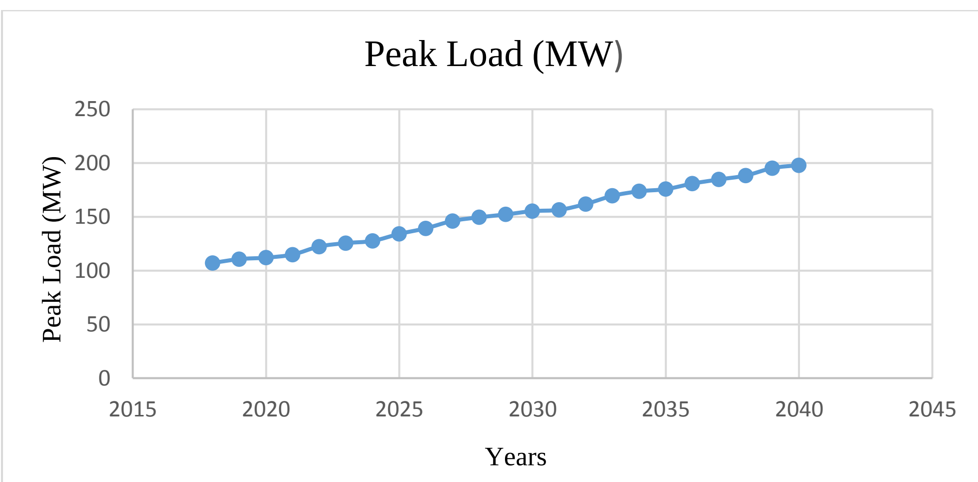


Figure 1.2: behavior of HEPCO Load Growth

1.8.2. SELCO Load Analysis

Accurate forecasts lead to substantial savings in operating and maintenance costs, increased reliability of power supply and delivery system, and correct decisions for future development, but finding an appropriate forecasting model for a specific electricity network is not an easy task especially when the network you want to apply this analysis on it has no recorded readings.

SELCO Company has no SCADA system, so they don't have records for peak loads during the last few years, because of that we forced to depend on the percentage estimated by the company for the load increasing every year.

The percentage of load increasing yearly was estimated to the value of seven percent of the load of the last year [3], so for the seventeen regions under SELCO control the load estimated to the year 2040 by the following relation:

$$PL\ (n+1) = 0.07*PL\ (n) + PL\ (n) \qquad \text{Equation (1.2)}$$

Where:

- PL (n): peak load of the current year.
- PL (n+1): peak load of the next year.
- n: number of year.

Table A.3 shows the peak load of the seventeen regions under SELCO control on 2017 (see appendix A3).

Table A.4 shows the values of the peak load (MVA) estimated by using the relation (2.1) during the period (2017-2040) (see appendix A4).

The following figure describes the behavior of load growing during the period (2017 - 2040):

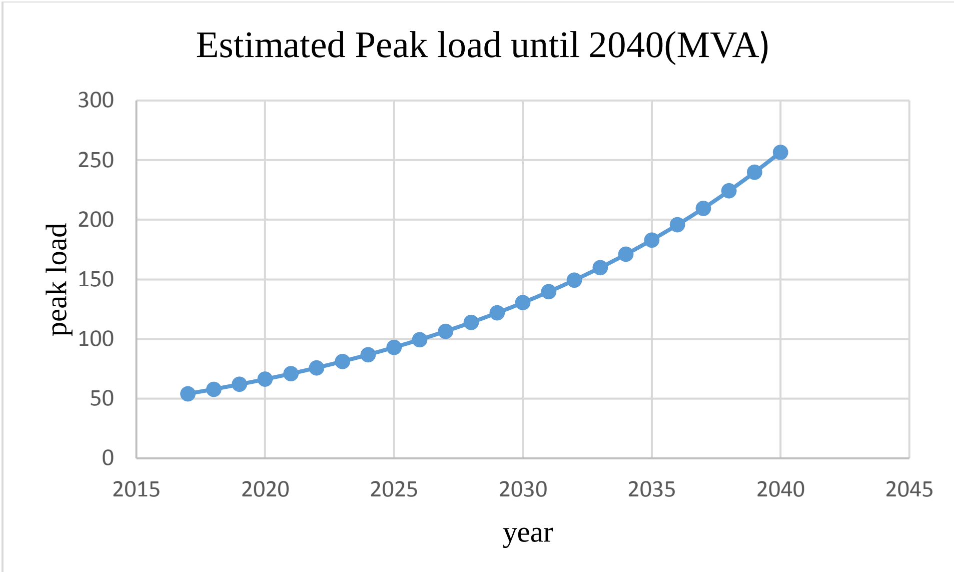


Figure 1.3: Behavior of SELCO Load Growth.

1.8.1 Total Load Estimated For HEPCO & SELCO

As a result of our calculations and load forecasting analysis for HEPCO and SELCO, the total load considered for the substation will be the summation of HEPCO and SELCO peak load (MVA) which estimated on the year 2040.

The following table shows the peak load (MVA) estimated in 2040:

Table 1.2: 2040 HEPCO & SELCO Peak Load (MVA)

Company	2040 Peak load (MVA)
HEPCO	206.3038035
SELCO	256.6522868
Total load	**462.9560903**

HEPCO Existing Substations Analysis

The total capacity of HEPCO substations with their present power transformers is 162 MVA, as shown in the table below [1]:

Table 1.3: HEPCO Substations Capacity

Substation	Number Of Power Transformers	Capacity (MVA)
Al-Dahdah	2*10 MVA	20
Al-Gharbia	2*13 MVA	26
Al-Fahs	2*10 MVA + 1*13 MVA	33
Al-Ras	2*10 MVA	20
Al-Harayek	2*10 MVA	20
Al-Hussein	2*10 MVA	20
Umm Al-Daliyeh	1*10 MVA + 1*13 MVA	23

So, these substations can operate until the year 2030, after that the system must be improved by making a new substations or by improving the existing substations, which can be done by replacing the existing power transformers with a new ones of a bigger capacities.

However HEPCO company knowing that and they start planning to deal with this situation during the next years by building a new substation in Hebron city, so they are in safe side.

1.9. SELCO Existing Transformers Analysis

SELCO company power system consists of 308 distribution power transformers with different capacities distributed on seventeen regions, [3] however the total capacity of these transformers is 115.81 MVA, but a lot of these transformers need to be replaced with a higher transformers capacity, especially in the small areas such as Tuwas, Rabod, Der AL-asal AL-tahta….etc.

CH.2. Power Transformers

2.1 Substation location

2.2 Substation power transformers installation plan

2.3 Back up transformers

2.4 Substation auxiliary system

CH.2. Power Transformers

Power transformers is a one kind of transformers that is used to transfer electrical energy between the generation and distribution primary circuits. In this substation five medium step down power transformers will be installed with total capacity of 500 MVA. These transformers stepping down the voltage that comes from the generating unit with a value of 161 kV to 33 kV.

Power transformers can be classified into three types based on their capacity. Small power transformers, medium power transformers and large power transformers.

1) The range of small power transformers can be from 500-7500kVA.
2) The range of medium power transformers can be from -100MVA.
3) The range of large power transformers can be from 100MVA & beyond.

For Tarqumia substation we select 161/33 KV step down Minera MP Schneider power transformers in order to be installed there as shown in figure 2.1, the substation needs five transformers of 100 MVA capacity, so the total capacity of the substation will reach 500 MVA by the year 2040.

Figure 2.1: **Minera MP Schneider** power transformer

2.1. Substation Location

Selection the location of the substation is very important and must include the following considerations, the current location of Tarqumia substation achieves most of the following considerations.

Considerations of selection the location of the Substation [4]:

1. Locate the substation as much as feasible close to the load center of its service area, so that the addition of load time's distance from the substation is a minimum.
2. Locate the substation such that proper voltage regulation can be obtained without taking extensive measures.
3. Select the substation location such that it provides proper access for incoming sub-transmission lines and outgoing primary feeders.
4. The selected substation location should provide enough space for the future substation expansion.
5. The selected substation location should not be opposed by land use regulations, local ordinances, and neighbors.
6. The selected substation location should help minimize the number of customers affected by any service discontinuity.

Any distribution system is typically started with a distribution substation that is fed by one or more sub-transmission lines [5], in our case the distribution substation is fed directly from a high-voltage transmission line 161 kV. Each distribution substation will serve one or more primary feeders.

2.2. Substation power transformers installation plan

For economic planning for the substation transformers installation, we made a plan to determine the initial capacity of the substation and to determine the exact periods to add a new transformers to the service and increase the substation capacity. It will not be economical to install and use all the five transformers from the beginning of the process, because the load is growing by the time and not constant, so we need to organize the operation of entering the transformers in service on periods depending on the allocation factor.

An “allocation factor” (AF) can be determined based upon the metered load demand KW or kVA and the total connected transformers capacity as shown on equation 2.1.

$$AF = \frac{Metered\ demand}{total\ kVA} \qquad \text{Equation (2.1)}$$

- Metered demand can be either MW or MVA.

- Total MVA: sum of the MVA ratings of all distribution transformers.

- The allocated load per transformer is then determined by equation 2.2:

$$\text{Transformer demand} = AF * \text{MVA transformer} \qquad \text{Equation (2.2)}$$

Table 2.1 shows the total demand in MW per year for Hebron city:

Table 2.1: Hebron city MW demand per year

year	Total Peak Load on the Substation (MW)
2018	162.7590108
2019	170.2036145
2020	175.692929
2021	183.0750145
2022	195.3065681
2023	203.5722892
2024	211.0565785
2025	223.4082798
2026	234.9076116
2027	248.4306838
2028	258.9825318
2029	269.2808021
2030	280.5660737
2031	290.4935113
2032	305.3481639
2033	322.9675407
2034	337.9170867
2035	351.4127076
2036	368.8884464
2037	385.906188
2038	403.5674231
2039	425.6239255
2040	444.4378467

To decide the initial capacity of the substation we made calculations to find the transformers loading percentage by using the allocation factor method at different values of the total MVA of the transformers to check the allocated MW of each transformer and to determine the exact time to add a new transformer to the substation to keep up with the load growing and to offer reliability to the power system.

Table 2.2 shows the allocated load per transformer during the desired period if we start the process with the whole five transformers.

Table 2.2: Allocated load per transformer in case of five transformers

year	Allocation Factor (AF) of 5 transformers	Each of (5*100) MVA Transformer Allocation
2018	0.325518022	32.55180217
2019	0.340407229	34.04072291
2020	0.351385858	35.1385858
2021	0.366150029	36.6150029
2022	0.390613136	39.06131363
2023	0.407144578	40.71445785
2024	0.422113157	42.21131571
2025	0.44681656	44.68165595
2026	0.469815223	46.98152232
2027	0.496861368	49.68613676
2028	0.517965064	51.79650636
2029	0.538561604	53.85616042
2030	0.561132147	56.11321475
2031	0.580987023	58.09870226
2032	0.610696328	61.06963279
2033	0.645935081	64.59350815
2034	0.675834173	67.58341734
2035	0.702825415	70.28254153
2036	0.737776893	73.77768927
2037	0.771812376	77.1812376
2038	0.807134846	80.71348462
2039	0.851247851	85.12478509
2040	0.888875693	88.88756934

According to the allocated values for each transformer as we notice from the table, it’s obvious that if we put all the transformers in service from the beginning they will be loaded at less than of their half rating for the first ten years, so it’s not make sense to start with five transformers, it will be wasting for it if we use all of them. We check another cases to find the best decision.

On the second case we will use four transformers (4*100 MVA) and we check the allocation values. Table 2.3 shows the allocation values for each transformer annually:

Table 2.3: Allocated load per transformer in case of four transformers

year	Allocation Factor (AF) of 4 transformers	Each of (4* 100 MVA) Transformer Allocation
2018	0.406897527	40.68975271
2019	0.425509036	42.55090363
2020	0.439232323	43.92323225
2021	0.457687536	45.76875362
2022	0.48826642	48.82664203
2023	0.508930723	50.89307231
2024	0.527641446	52.76414463
2025	0.558520699	55.85206994
2026	0.587269029	58.7269029
2027	0.62107671	62.10767095
2028	0.647456329	64.74563294
2029	0.673202005	67.32020052
2030	0.701415184	70.14151843
2031	0.726233778	72.62337782
2032	0.76337041	76.33704098
2033	0.807418852	80.74188518
2034	0.844792717	84.47927167
2035	0.878531769	87.85317691
2036	0.922221116	92.22211159
2037	0.96476547	96.476547
2038	1.008918558	100.8918558
2039	1.064059814	106.4059814
2040	1.111094617	111.1094617

This case should not be used from the beginning, because the allocation values of the transformers is less than 50% for the first 5 years and that is not economic for the power system.

On the third case we check if it economic to start the process with 300 MVA capacity (3*100 MVA) or not, table 2.4 shows of the allocation values for each transformer every year:

Table 2.4: Allocated load per transformer in case of three transformers

year	Allocation Factor (AF) of 3 transformers	Each (3* 100 MVA) Transformer Allocation
2018	0.542530036	54.25300362
2019	0.567345382	56.73453818
2020	0.585643097	58.56430967
2021	0.610250048	61.02500483
2022	0.651021894	65.10218938
2023	0.678574297	67.85742974
2024	0.703521928	70.35219284
2025	0.744694266	74.46942659
2026	0.783025372	78.3025372
2027	0.828102279	82.81022794
2028	0.863275106	86.32751059
2029	0.897602674	89.76026736
2030	0.935220246	93.52202458
2031	0.968311704	96.83117043
2032	1.017827213	101.7827213
2033	1.076558469	107.6558469
2034	1.126390289	112.6390289
2035	1.171375692	117.1375692
2036	1.229628155	122.9628155
2037	1.28635396	128.635396
2038	1.345224744	134.5224744
2039	1.418746418	141.8746418
2040	1.481459489	148.1459489

We notice from table (2.4) that the three 100 MVA transformers will be loaded at a small value for a long period of time.

The last case is to start with 200 MVA capacity (2*100MVA), table 2.5 shows the allocation values of each transformer:

Table 2.5: Allocated load per transformer in case of two transformers

year	Allocation Factor (AF) of 2 transformers	Each (2* 100 MVA) Transformer Allocation
2018	0.813795054	81.37950542
2019	0.851018073	85.10180726
2020	0.878464645	87.84646451
2021	0.915375072	91.53750724
2022	0.976532841	97.65328406
2023	1.017861446	101.7861446
2024	1.055282893	105.5282893
2025	1.117041399	111.7041399
2026	1.174538058	117.4538058
2027	1.242153419	124.2153419
2028	1.294912659	129.4912659
2029	1.34640401	134.640401
2030	1.402830369	140.2830369
2031	1.452467556	145.2467556
2032	1.52674082	152.674082
2033	1.614837704	161.4837704
2034	1.689585433	168.9585433
2035	1.757063538	175.7063538
2036	1.844442232	184.4442232
2037	1.92953094	192.953094
2038	2.017837116	201.7837116
2039	2.128119627	212.8119627
2040	2.222189233	222.2189233

This case comes with acceptable values for the allocated load per transformer.

After this analysis for the allocation demand for each transformer at different cases, we made a strategy to determine the initial capacity of the substation and the exact time to add a new transformers to the service.

Therefore it’s obviously clear that the substation must start with a capacity of 200 MVA by using two 100 MVA Minera MP Schneider power transformers. That will be enough for the first four years until the year 2021 and the transformers will be able to handle the load without being overloaded.

After the year 2021 we will install another 100 MVA transformer to the substation capacity to protect the continuity of the substation work and to prevent the installed transformers from being overloaded the thing that could decrease their lives.

The substation will be able work with this capacity until the year 2030, after that another 100 MVA transformer will be entered to the service, at that moment the substation capacity will be 400 MVA.

According to the allocation analysis the transformers will be able to cover the load demand until the year 2036 without being overloaded, after that the last 100 MVA transformer will be installed to keep up with the load growing and keep the substation reliability, and the final substation capacity will be 500 MVA as we planned.

Table 2.6 shows the summary of the transformers installation on the substation during the twenty years' time period:

Table 2.6: transformers installation on the substation during the period (2018-2040)

time period	**number of installed transformers**	**total capacity per time period (MVA)**
2018 - 2021	2*100MVA	200
2022 -2030	3*100 MVA	300
2031 - 2036	4*100 MVA	400
2037 - 2040	5*100 MVA	500

The figure below describes the operation of entering the transformers to the utility by the years:

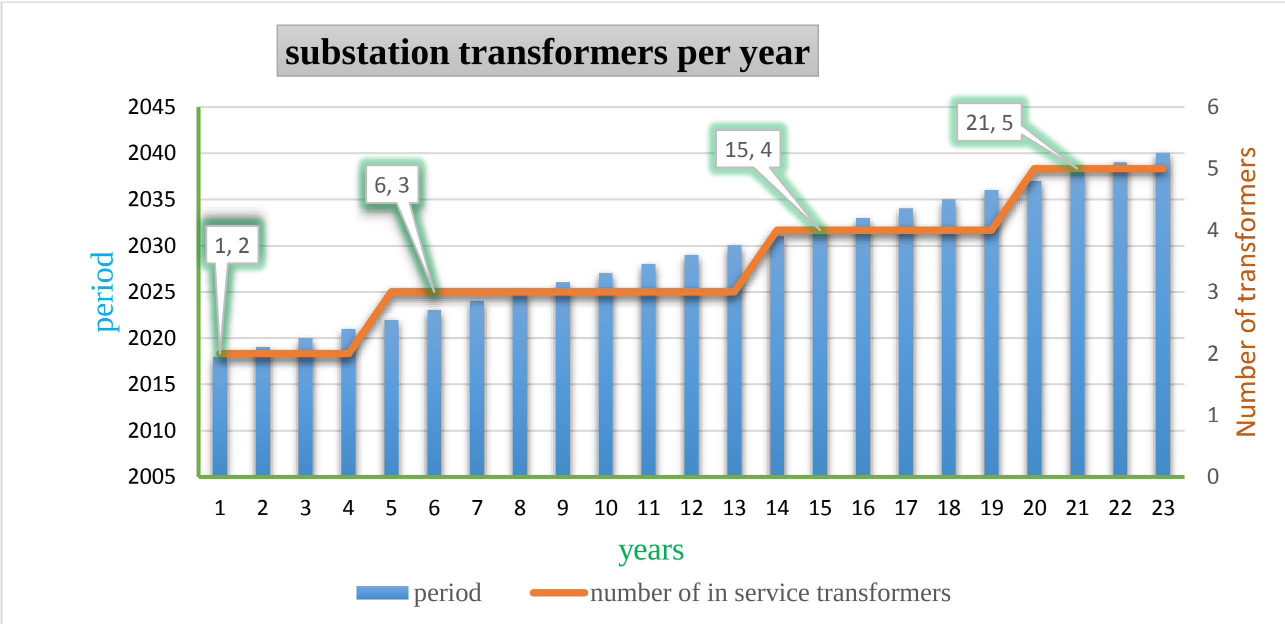


Figure 2.2: Description of entering power transformers to the utility

2.3. Back up transformers

As we know the substation should contain a backup transformer in order to guarantee the continuity of power service in case of transformer failure, figure 2.3 describes the number of the substation backup and service transformers with the substation capacity during the period (2018 – 2040):

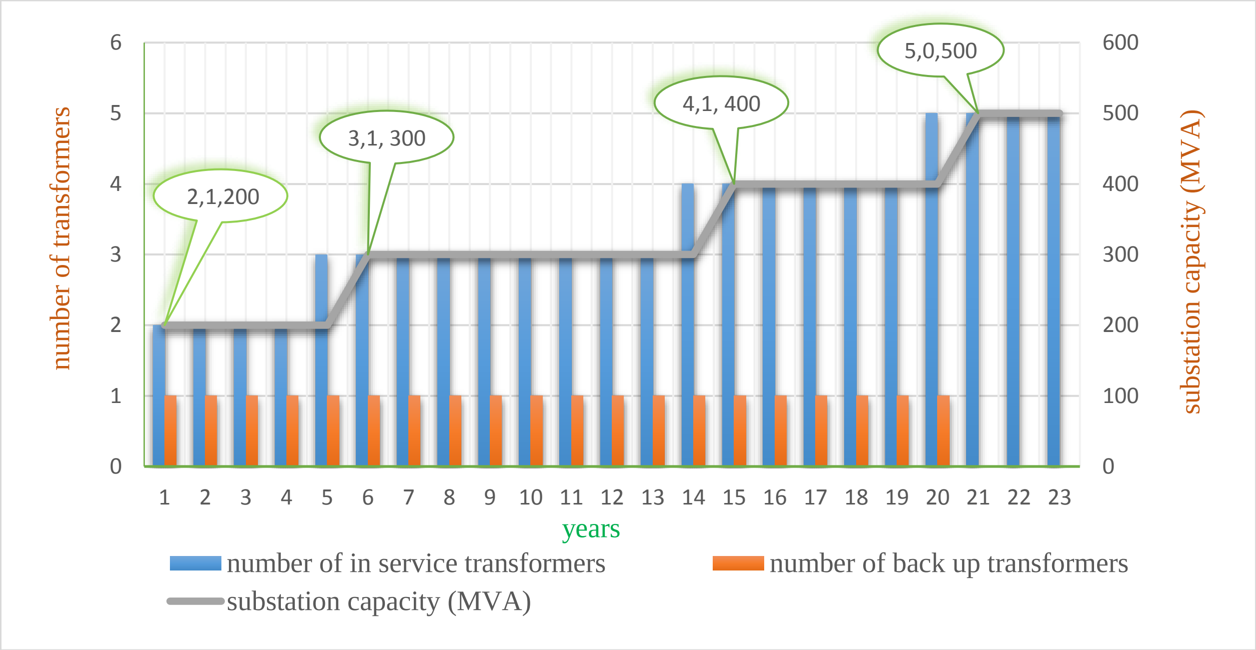


Figure 2.3: substation backup and service transformers with the substation capacity during the period (2018 – 2040)

Table 2.7 shows the description of the substation transformers loading with years:

Table 2.7**:** substation transformers loading under the required period

period	loading per transformer	number of in service transformers	number of back up transformers	substation capacity (MVA)
2018	81.37950542	2	1	200
2019	85.10180726	2	1	200
2020	87.84646451	2	1	200
2021	91.53750724	2	1	200
2022	65.10218938	3	1	300
2023	67.85742974	3	1	300
2024	70.35219284	3	1	300
2025	74.46942659	3	1	300
2026	78.3025372	3	1	300
2027	82.81022794	3	1	300
2028	86.32751059	3	1	300
2029	89.76026736	3	1	300
2030	93.52202458	3	1	300
2031	72.62337782	4	1	400
2032	76.33704098	4	1	400
2033	80.74188518	4	1	400
2034	84.47927167	4	1	400
2035	87.85317691	4	1	400
2036	92.22211159	4	1	400
2037	77.1812376	5	1	500
2038	80.71348462	5	0	500
2039	85.12478509	5	0	500
2040	88.88756934	5	0	500

2.4. Substation auxiliary system

Usually the substation auxiliary system consists of two systems, Ac auxiliary system and DC auxiliary system. AC power is required for substation building small power, lighting, heating and ventilation, some communications equipment, switchgear operating mechanisms, ant condensation heaters and motors. DC power is used to feed essential services such as circuit breaker trip coils and associated relays, supervisory control and data acquisition (SCADA) and communications equipment [6].

2.4.1. Ac auxiliary system

In general, the design criteria of the substation ac auxiliary system is determined by the existing and the future loads inside the substation, these loads are typically measured in kVA. Depending on the substation size, reliability and load requirements the substation should contain multiple sources. One ac source as normal or preferred source and another sources as backup sources.

System stability

System stability considerations are important for the reliability requirements of the substation. If the loss of a substation results in a system disturbance to the electrical grid that could create a blackout condition in the area, the station service system should have an independent power source. The auxiliary power system requirements for redundant supply may also need to include the ability for the station to complete black start operations that’s mean that a local generation source is required to supply the station power system and battery chargers for the protection circuits in the event of a system collapse and subsequent repowering [7].

Substation bus

The substation bus is a good available source for auxiliary station power. When distribution voltage is available then distribution transformers are typically utilized for station service. A station service voltage transformer (SSVT) is used to transform the transmission bus voltage to the ac auxiliary voltage. These transformers are available for voltages from 34.5 kV to 345 kV. Here on this substation we will use a 34.5 kV SSVT, this transformer will be connected to the outgoing 33kV bus on the primary windings and based on the supplied requirements we will decide the secondary voltage value [7].

Depending on understanding the substation load operations and how the loads such as cooling, lightning, etc., are applied, we made an assumption for the substation auxiliary transformer to 900 kVA. We will use a standby generator as a backup auxiliary station power.

2.4.2. Substation DC Auxiliary System

Typically the main purpose of the dc auxiliary system on the substation is to provide a reliable power source for power system protection. DC systems provide power to operate protective relays, monitoring equipment, and control circuits that operate power circuit breakers or other fault-isolating equipment. The dc systems are designed to provide power for these protection systems during outages and when the power systems are intact. The following figure is a simplified dc system block diagram.

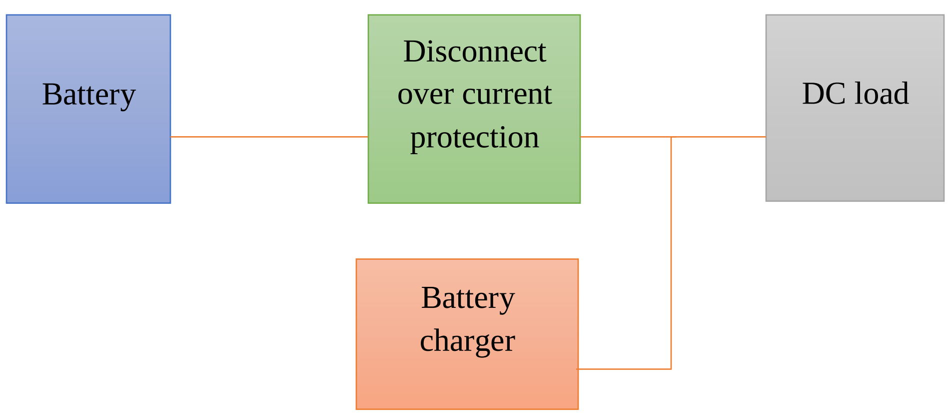


Figure 2.4: The DC system block diagram

Typical equipment served by the dc system

The dc system in a substation serves many critical and non-critical functions and equipment. Some typical equipment served may include:

1. Circuit breakers
2. Circuit switchers
3. Motor operators
4. Protective relay systems
5. SCADA
6. Fire protection/detection
7. Emergency lighting
8. Security systems

As we notice a various types of devices work with a DC voltage, as a result of this many DC to DC converters must be used in order to offer all the ranges of operating DC voltages [7]. Many backup batteries must be installed on the substation in order to provide a backup power source to operate those devices that should not be turned off in case of power outages.

CH.3. Grounding system

3.1 Importance of high-speed fault clearing

3.2 Effect of a thin layer of surface material

3.3 Grid geometry

3.4 Design procedure

CH.3. Grounding system

In principle, a safe grounding design has the following two objectives [8]:

1. To provide means to carry electric currents into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.
2. To reduce the risk of a person in the vicinity of grounded facilities being exposed to the danger of critical electric shock.

3.1. Importance of high-speed fault clearing

High-speed clearing of ground faults can be advantageous for two reasons:

1. The probability of exposure to electric shock can be reduced by fast fault clearing time, in contrast to situations in which fault currents could persist for several minutes or possibly hours.

2. Tests and experience show that the chance of severe injury or death can be reduced if the duration of a current flow through the body is very brief.

An additional incentive to use switching times less than 0.5 s [9], is the results from a previous researches which provides evidence that a human heart becomes increasingly susceptible to ventricular fibrillation when the time of exposure to current is approaching the heartbeat period, but that the danger is smaller if the time of exposure to current is in the region of 0.06 s to 0.3 s.

In reality, high ground gradients from faults are usually infrequent, and shocks from high ground gradients are also infrequent. Further, both events are often of very short duration. Thus, it would not be practical to design against shocks that are merely painful and do not cause serious injury; that is, for currents below the fibrillation threshold.

3.2. Effect of a thin layer of surface material

Based on the assumption of uniform soil resistivity a 0.08 m to 0.15 m (3 in to 6 in) layer of high resistivity material, such as gravel, is often spread on the earth's surface above the ground grid to increase the contact resistance between the soil and the feet of persons in the substation [10].

The relatively shallow depth of the surface material, as compared to the equivalent radius of the foot, precludes the assumption of uniform resistivity in the vertical direction when computing the ground resistance of the feet. However, for a person in the substation area, the surface material can be assumed to be of infinite extent in the lateral direction If the underlying soil has a lower resistivity than the surface material, such as clean large rock with wet resistivity in the thousands of Ω-m, only some grid current will go upward into the thin layer of the surface material, and the surface voltage will be very nearly the same as that without the surface material.

The current through the body will be lowered considerably with the addition of the surface material because of the greater contact resistance between the earth and the feet. However, this resistance may be considerably less than that of a surface layer thick enough to assume uniform resistivity in all directions. The reduction depends on the relative values of the soil and the surface material resistivities, and on the thickness of the surface material.

3.3. Grid geometry

In general, the limitations on the physical parameters of a ground grid are based on economics and the physical limitations of the installation of the grid. The economic limitation is obvious. It is impractical to install a copper plate grounding system. So there is some limitations encountered in the installation of a grid.

For example, the digging of the trenches into which the conductor material is laid limits the conductor spacing to approximately 2 m or more. Typical conductor spacing's range from 3 m to 15 m, while typical grid depths range from 0.5 m to 1.5 m. For the typical conductors ranging from (67 mm2) to (253 mm2), the conductor diameter has negligible effect on the mesh voltage [8].

So, the designer of the grounding system for the substation control and decide all of these parameters to reach the safe case based on the standards.

The area of the grounding system is the single most important geometrical factor in determining the resistance of the grid. The larger the area grounded, the lower the grid resistance and, thus, the lower the GPR.

A practical approach to safe grounding thus concerns and strives for controlling the interaction of two grounding systems, as follows:

1. The intentional ground, consisting of ground electrodes buried at some depth below the earth's surface.
2. The accidental ground, temporarily established by a person exposed to a potential gradient in the vicinity of a grounded facility.

3.4. Design procedure [8]:

1. Step 1: The property map and general location plan of the substation should provide good estimates of the area to be grounded. A soil resistivity testwill determine the soil resistivity profile and the soil model needed (that is, uniform or two-layer model).

2. Step 2: The conductor size is determined by equations. The fault current $3I_0$ should be the maximum expected future fault current that will be conducted by any conductor in the grounding system, and the time, t_c, should reflect the maximum possible clearing time (including backup).

3. Step 3: The tolerable touch and step voltages are determined by equations. The choice of time, *ts*, is based on the judgment of the design engineer.

4. Step 4: The preliminary design should include a conductor loop surrounding the entire grounded area, plus adequate cross-conductors to provide convenient access for equipment grounds, etc.

5. Step 5: Estimates of the preliminary resistance of the grounding system in uniform soil can be determined by the equations. For the final design, more accurate estimates of the resistance may be desired. Computer analysis based on modeling the components of the grounding system in detail can compute the resistance with a high degree of accuracy, assuming the soil model is chosen correctly.

6. Step 6: The current *IG* is determined by the equations. To prevent overdesign of the grounding system, only that portion of the total fault current, 3*I0*, that flows through the grid to remote earth should be used in designing the grid. The current *IG* should, however, reflect the worst fault type and location, the decrement factor, and any future system expansion.

7. Step 7: If the GPR of the preliminary design is below the tolerable touch voltage, no further analysis is necessary. Only additional conductor required to provide access to equipment grounds is necessary.

8. Step 8: The calculation of the mesh and step voltages for the grid as designed can be done by the approximate analysis techniques for uniform soil.

9. Step 9: If the computed mesh voltage is below the tolerable touch voltage, the design may be complete (see Step 10). If the computed mesh voltage is greater than the tolerable touch voltage, the prelimiry design should be revised (see Step 11).

10. Step 10: If both the computed touch and step voltages are below the tolerable voltages, the design needs only the refinements required to provide access to equipment grounds. If not, the preliminary design must be revised (see Step 11).

11. Step 11: If either the step or touch tolerable limits are exceeded, revision of the grid design is required. These revisions may include smaller conductor spacing's, additional ground rods, etc.

12. Step 12: After satisfying the step and touch voltage requirements, additional grid and ground rods may be required. The additional grid conductors may be required if the grid design does not include conductors near equipment to be grounded. Additional ground rods may be required at the base of surge arresters, transformer neutrals, etc. The final design should also be reviewed to eliminate hazards due to transferred potential and hazards associated with special areas of concern.

Grounding grid design for Tarqumia substation

The area of Tarqumia substation is about 8100 square meter, and the following figure shows a geographical description for the substation location:

Figure 3.1: Tarqumia substation geographic location

Step 1.

Field data:

Assume a square 90 m × 90 m grid with ground rods. Consequently, the area occupied by such a grid is A = 8100 m2. An average moisture soil resistivity of 100 Ω-m is assumed, based on soil resistivity measurements after replacing the original soil with a new processed soil. We choose hard-drawn copper to be used as earthing conductor material.

Fault duration (tf) equal current duration (t_c)= 0.5 s

Soil resistivity ρ = 100 Ω-m

Surface layer resistivity (gravel) ρs = 5000 Ω-m

Thickness of gravel surfacing hs = 0.15 m

Depth of grid burial h = 1 m

Conductor spacing's D = 5 m

Duration of shockt_s = 0.5 s

Step 2.

Conductor size:

Ignoring the station resistance, the symmetrical ground fault current as determined by ETAP program is about If = 48 kA on the 33 kV side as shown in figure 3.2. Notice that the 33 kV bus fault current, which has a value of 48 kA should be used to size the grounding conductor. On the other hand the 161 kV bus fault is (If = 20 kA) (see appendix B1).

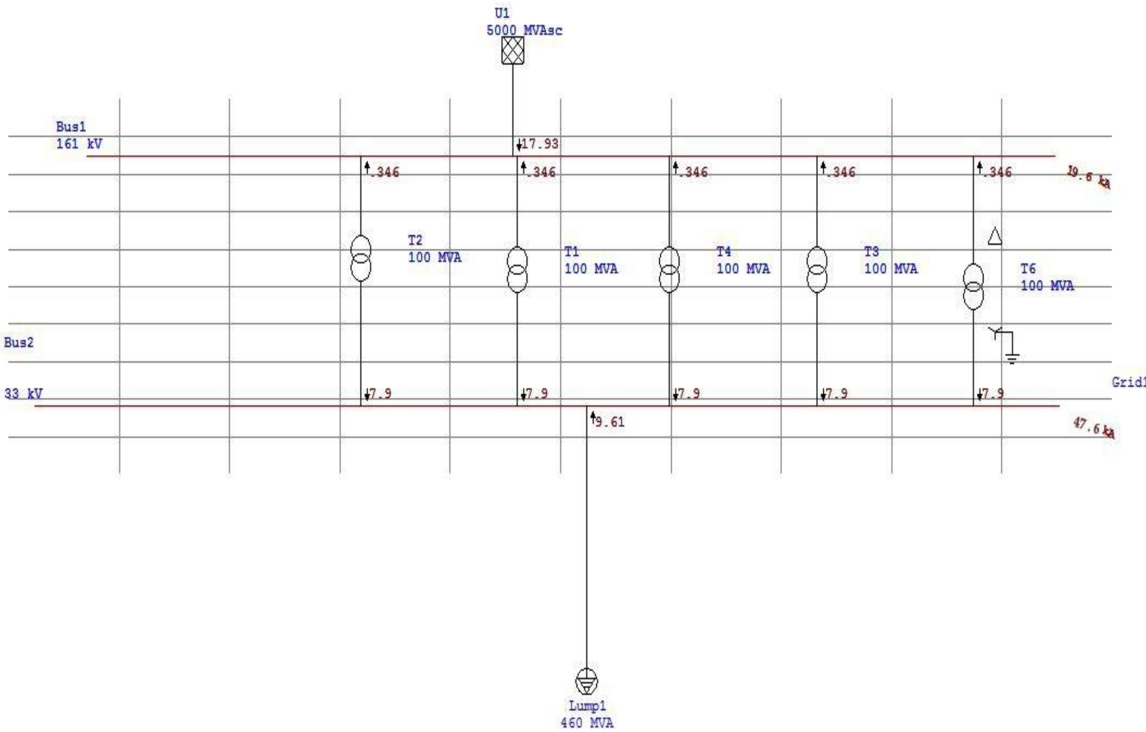


Figure 3.2: fault currents from Etap simulation

For delta grounded-wye transformer connection the equivalent fault impedances of the 161 kV must be transferred to the 33 kV side. It should be noted that, due to the connection of the transformer, only the positive sequence of the 161 kV fault impedance is transferred.

- Conductor area is computed according to the following equation:

$$A_{kcmil} = I * K_f \sqrt{tc} \qquad \text{Equation (3.1)}$$

A_{kcmil}: is the area of conductor in kcmil.
I: is the rms fault current in kA.
tc: is the current duration in second.
K_f : is a constant from IEEE std (80-2013) for the material at various values of Tm (fusing temperature or limited conductor temperature) and using ambient temperature (Ta) of 40 °C.

For hard-drawn copper, the required cross-sectional area in circular mils with K_f = 7.06 is

$$A_{\text{kcmil}} = 48 * 7.06\sqrt{0.5} = 239.624 \text{ kcmil} \qquad \text{Equation (3.2)}$$

Conductor area in mm^2 is computed using the following relation:

$$A_{mm^2} = \frac{A_{\text{kcmil}}}{1.974} = \frac{239.624}{1.974} = 121.39\ mm^2 \text{ (next standard = } 150 mm^2\text{)} \qquad \text{Equation (3.3)}$$

$$A_{mm^2} = \frac{\pi d^2}{4} \longrightarrow d = \sqrt{\frac{4A}{\pi}} \longrightarrow d = 13.82\ mm \text{ (assume 16 } mm\text{)}$$

Step 3.

Touch and step criteria:

For a 0.15 m layer of surface layer material, with a gravel resistivity of 5000 Ω-m, and for an earth with resistivity of 100 Ω-m, assuming that for the particular station the location of grounded facilities within the fenced property is such that the person's weight can be expected to be at least 70 kg.

The factor ***Cs*** for derating the nominal value of surface layer resistivity is dependent on the thickness and resistivity of the surface material and the soil resistivity, and is computed using the following equation:

$$C_s = 1 - \frac{0.09\,(1 - \frac{\rho}{\rho s})}{2hs + 0.09} \qquad \text{Equation (3.3)}$$

Where:

C_s: Derating factor

$$C_s = 1 - \frac{0.09\,(1 - \frac{100}{5000})}{2 * 0.15 + 0.09} = 0.77$$

- **Step and Touch voltages:**

Step voltage:

The difference in surface potential that could be experienced by a person bridging a distance of 1 m with the feet without contacting any grounded object.

Touch voltage:

The potential difference between the ground potential rise (GPR) of a ground grid or system and the surface potential at the point where a person could be standing while at the same time having a hand in contact with a grounded structure.

1. **Step voltage ($E_{step\ 70}$)**

$$E_{step\ 70} = (1000 + 6\ C_s \rho s)\frac{0.157}{\sqrt{t_s}} \qquad \text{Equation (3.4)}$$

$$E_{step\ 70} = (1000 + 6 * 0.77 * 5000)\frac{0.157}{\sqrt{0.5}} = 5350.96 \text{ volt}$$

2. **Touch voltage ($E_{touch\ 70}$)**

$$E_{touch\ 70} = (1000 + 1.5\ C_s \rho s)\frac{0.157}{\sqrt{t_s}} \qquad \text{Equation (3.5)}$$

$$E_{touch\ 70} = (1000 + 1.5 * 0.77 * 5000)\frac{0.157}{\sqrt{0.5}} = 1504.26 \text{ volt.}$$

Step 4.

Initial design:

Assume a preliminary layout of 90 m × 90 m grid with equally spaced conductors, as shown in figure 3.3, with spacing D = 5 m, grid burial depth h = 1 m. The total length of buried conductor, L_T, is 2 × 18 × 90 m = 3240 m. with ground rods of length L= 3 m and diameter of 16 mm to be installed at the grid intersections, so the total number of required rods = 18 * 18 = 324 rod.

Total length of conductors (L_T) = 3240 m

Total length of rods (L_R) = 324 * 3 = 972 m

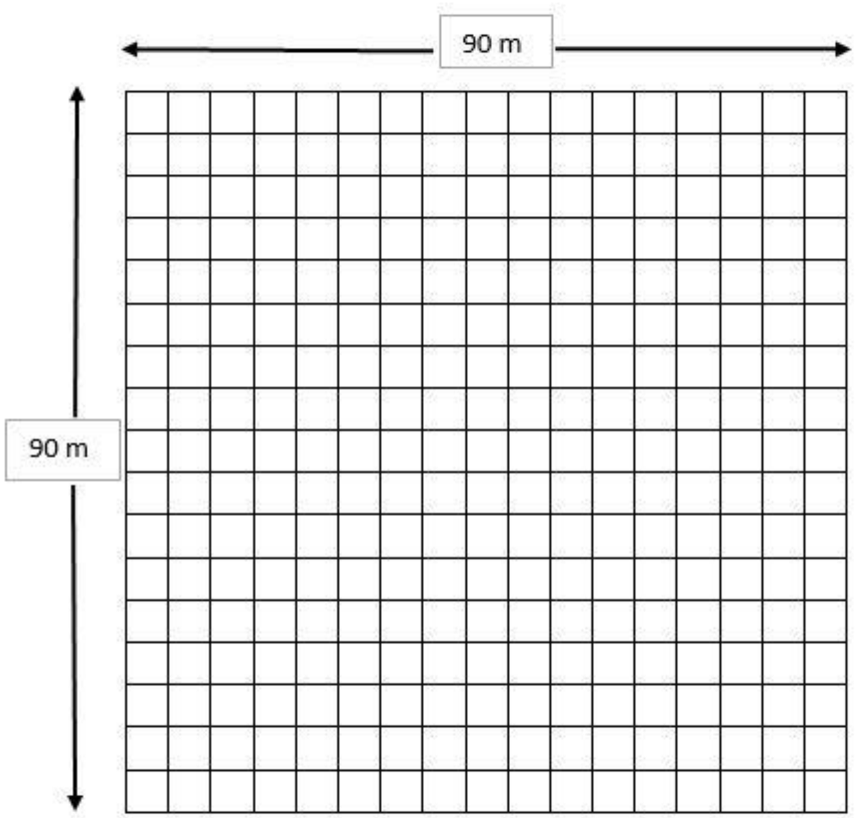


Figure 3.3: grounding grid dimensions

Step 5.

Determination of grid resistance using the below equation:

$$R_g = \rho * [\frac{1}{L_T} + \frac{1}{\sqrt{20*A}} (1+\frac{1}{1+h\sqrt{20/A}})] \qquad \text{Equation (3.6)}$$

$$R_g = 100 * [\frac{1}{3240} + \frac{1}{\sqrt{20*8100}} (1+\frac{1}{1+1\sqrt{20/8100}})] = 0.516\ \Omega$$

Step 6.

Determining maximum grid current *IG:*

Symmetrical grid current:

That portion of the symmetrical ground fault current that flows between the ground grid and surrounding earth. It may be expressed as:

$$I_g = S_f * If \qquad \text{Equation (3.7)}$$

Where:

I_g : Symmetrical grid current

S_f : Fault current division factor

If: fault current

Fault current division factor (S_f):

A factor representing the inverse of a ratio of the symmetrical fault current to that portion of the current that flows between the ground grid and surrounding earth. Here the Current division factor S_f= 0.6.

So,

$$I_g = 0.6 * 20 = 12 \text{ kA}$$

Maximum grid current:

A design value of the maximum grid current, defined as follows:

$$I_G = D_f * I_g \qquad \text{Equation (3.8)}$$

Where:

I_G : Maximum grid current

D_f : Decrement factor

Decrement factor:

An adjustment factor used in conjunction with the symmetrical ground fault current parameter in safety-oriented grounding calculations. It determines the rms equivalent of the asymmetrical current wave for a given fault duration, *tf*, accounting for the effect of initial dc offset and its attenuation during the fault.

The decrement factor (D_f) is obtained based on X/R ratio, and on this project and depending on IEEE std (80-2013) it's found to be D_f = 1.101.

As a result:

$$I_G = 1.101 * 12 = 13.2 \text{ kA} \qquad \text{Equation (3.9)}$$

Step 7.

Ground potential rise (GPR):

The maximum electrical potential that a ground electrode may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage, GPR, is equal to the maximum grid current multiplied by the grid resistance as modeled on the following equation:

$$\text{GPR} = I_G * R_g = 13.2 \text{ KA} * 0.516 = 6.82 \text{ kV} \qquad \text{Equation (3.10)}$$

Here GPR (6820volt) >$E_{touch\ 70}$ (1504.26 volt)

The design procedures aimed at achieving safety from dangerous step and touch voltages within a substation, but it is possible for transferred potentials to exceed the GPR of the substation during fault conditions. Thus, the design procedure described here is based on assuring safety from dangerous step and touch voltages within, and immediately outside, the substation fenced area.

In this case we have to calculate the mesh voltage and depend on it as the basis of the design procedure, because the mesh voltage is usually the worst possible touch voltage inside the substation (excluding transferred potentials).

Step 8.

Mesh voltage (E_{mesh}):

The mesh voltage values are obtained as a product of the geometrical factor, *Km*; a corrective factor, *Ki*, which accounts for some of the error introduced by the assumptions made in deriving *Km*; the soil resistivity, *ρ*; and the average current per unit of effective buried length of the grounding system conductor (I_G/*LM*).

$$\boldsymbol{E_{mesh}} = \frac{\rho * Km * Ki * I_G}{LM} \qquad \text{Equation (3.11)}$$

Km is the mesh factor defined for ***n*** parallel conductors

The geometrical factor *Km* is as follows:

$$Km = \frac{1}{2\pi}\left[\ln\left[\frac{D^2}{16\,h\,d} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right] + \frac{k_{ii}}{k_h}\ln\left[\frac{8}{\pi(2n-1)}\right]\right] \qquad \text{Equation (3.12)}$$

To reflect this effect of current density and to correct some of the deficiencies in the equation for *Km*, [11]the weighting terms, *Kii* and *Kh* should be added in to the equation of *Km.*

For grids with ground rods along the perimeter, or for grids with ground rods in the grid corners, as well as both along the perimeter and throughout the grid area.

$$Kii = 1 \qquad \text{Equation (3.13)}$$

$$Kh = \sqrt{1 + \frac{h}{h_0}} \qquad \text{Equation (3.14)}$$

h_0= 1 m (grid reference depth)

$$Kh = \sqrt{1 + \frac{1}{1}} = 1.4$$

n: number of rods =18

$$Km = \frac{1}{2\pi}\left[\ln\left[\frac{5^2}{16*1*0.16} + \frac{(5+2*1)^2}{8*5*0.16} - \frac{1}{4*0.16}\right] + \frac{1}{4}\ln\left[\frac{8}{\pi(2*18-1)}\right]\right] = 0.14$$

LM is the total length of buried conductors, including cross-connections, and (optionally) the combined length of ground rods in m

$$LM = \text{Lc} + [1.55 + 1.22\ (\frac{Lr}{Lx^2+Ly^2})\ ]L_R \qquad \text{Equation (3.15)}$$

Where:

Lc: is the total length of the conductor in the horizontal grid in m

Lr*:* is the rod length in m

Lx: is the maximum length of the grid in the *x* direction in m

L_y*:* is the maximum length of the grid in the *y* direction in m

Given $Lx = L_y = 90$

$$LM = 3240 + [1.55 + 1.22 (\frac{3}{90^2+90^2})] * 972 = 4746.8196$$

Because of assumptions made in the derivation of *Km*, a corrective factor *Ki* is needed to compensate for the fact that the subject mathematical model of *n* parallel conductors cannot fully account for the effects of a grid geometry; that is, for two sets of parallel conductors that are perpendicular to each other and interconnected at the cross-connection points. For a large number of square and rectangular grids, the mesh voltage was obtained using a computer. From this computer-generated data, a new expression for *Ki* was found to better fit in the mesh voltage equation [12]. This factor is:

$$k_i = 0.644 + 0.148 \text{ n} = 0.644 + 0.148 * 18 = 3.308$$

$$\boldsymbol{E_{mesh}} = \frac{100*64.4*10^3*0.14*3.308}{4746.8196} = 128.78 \text{ volt}$$

As a result : $\boldsymbol{E_{mesh}} < \boldsymbol{E_{touch\,70}}$

The grounding system design is reliable and safe. Figure 3.4 describes the substation grounding grid.

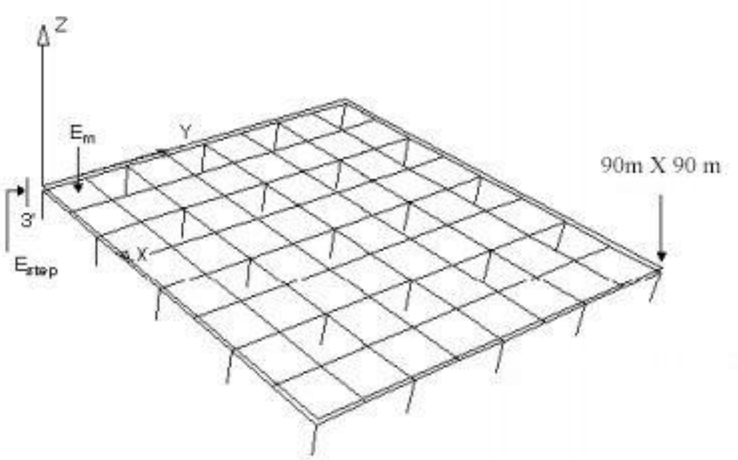


Figure 3.4: substation grounding grid

We build and simulate the grounding grid of Tarqumia substation on etap (see appendix B1)

CH.4. Switchgear and protection

4.1 Introduction

4.2 Function of switchgear

4.3 Switchgear control panel

4.4 Components of Switchgear

4.5 Relay Circuit Diagram

4.6 Instrument transformers

4.7 Reclosers

4.8 Surge Arresters

CH.4. Switchgear and protection

4.1. Introduction

The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear. The term ‘switchgear’ is a generic term that includes a wide range of switching devices like circuit breakers, switches, switch fuse units, off-load isolators, High Rupturing Capacity fuses (HRC fuses), contactors, miniature circuit breakers, etc [13].

It also includes the combination of these switching devices with associated control, measuring, protecting and regulating equipment. The switchgear devices and their assemblies are used in connection with the generation, transmission, distribution, and conversion of electrical energy.

We all are familiar with low voltage switches and re-wirable fuses in our life. Switches are used for opening and closing an electric circuit while fuses are used for over-current and short-circuit protection. In such a way, every electrical device wants a switching and a protecting device.

Various forms of switching and protective devices have been developed. Thus switchgear can be taken as a general term covering a wide range of equipment concerned with the switching, protection, and control of various electrical equipment [13].

4.2. Function of switchgear

A switchgear has to perform the functions of carrying, making and breaking the normal load current like a switch. In addition, it has to perform the function of clearing the fault current for which sensing devices like current transformers, potential transformers and various types of relays, depending on the application, are employed [14]. There also has to be provision for metering, controlling and data, wherein innumerable devices are used for achieving the switchgear function.

4.3. Switchgear control panel:

Some types of equipment are designed to operate under both normal and abnormal conditions. Some equipment is meant for switching and not sensing the fault.

During normal operation, switchgear permits to switch on or off generators, transmission lines, distributors and other electrical equipment. On the other hand, when a failure (e.g. short circuit) occurs on any part of the power system, a heavy current flows through the equipment, threatening damage to the equipment and interruption of service to the customers. However, the switchgear detects the fault and disconnects the unhealthy section from the system .

Similarly, switching and current interrupting devices play a significant role in the modern electrical network, right from generating stations, transmission sub-stations at different voltages, distribution substations, and load centers. The switching device here is called a circuit breaker. The circuit breaker, along with associated devices for protection, metering and control regulation, is called a switchgear.

4.4. Components of Switchgear

Switchgear essentially consists of switching and protecting devices such as switches, fuses, isolators, circuit breakers, protective relays, control panels, lightning arrestors, current transformers, potential transformers, auto re-closures, and various associated equipment [14].

4.4.1. Switches

A switch is a device which is used to open or close an electrical circuit in a convenient way. It can be used under full-load or no-load conditions but it cannot interrupt the fault currents.

4.4.2. Fuses

A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time. It is inserted in series with the circuit to be protected.

When a short circuit or overload occurs, the current through the fuse element increases beyond its rated capacity. This raises the temperature and the fuse element melts (or blows out), disconnecting the circuit protected by it.

4.4.3. Circuit breaker

A circuit breaker is an equipment which can open or close a circuit under all conditions: no load, full load and fault conditions. It is so designed that it can be operated manually (or by remote control) under normal conditions and automatically under fault conditions. For the latter operation, a relay circuit is used with a circuit breaker.
Circuit breakers are classified into different types based on the following criteria.

1. Based on the voltage level

  a. Low voltage circuit breaker
  b. Medium voltage circuit breaker
  c. High voltage circuit breaker

2. Based on where is installed

  a. Outdoor circuit breaker
  b. Indoor circuit breaker

3. Based on the actuating mechanism

  a. Spring Operated Circuit breaker
  b. Pneumatic circuit breaker
  c. Hydraulic circuit breaker

4. Based on the arc interrupting medium

a. Vacuum circuit breaker
b. SF6 circuit breaker
c. Oil circuit breaker
d. Air blast circuit breaker

5. Based on External characteristic design

a. Live tank circuit breaker
b. Dead tank circuit breaker.

For the primary side in our substation the short circuit current from Etap was 20kA, we select outdoor Dead Tank Circuit Breaker 242PMR three pole operation from ABB Company as shown in figure 4.1. The product work with 245kV [15].

Figure 4.1: outdoor Dead Tank Circuit Breaker

For the secondary side in our substation the short circuit current from Etap was 48kA, we select SF6 gas circuit breaker HD4/R36 from ABB Company as shown in figure 4.2. the product scope medium voltage gas circuit breakers with lateral mechanical actuator (spring mechanism) for secondary distribution up to 36 kV, with rated current 4250 A, and 50 kA rated short circuit current capacity . The characteristics of MV breakers are given by international standards such as IEC 62271 [15].

Figure 4.2: SF6 gas circuit breaker HD4/R36

4.4.4. Protective relays

A protective relay is a switchgear device that detects the fault and initiates the operation of the circuit breaker to isolate the defective element from the rest of the system.

They are compact and self-contained devices which can detect abnormal conditions. Protective relays detect the abnormal conditions in the electrical circuits by constantly measuring the electrical quantities which are different under normal and fault conditions. The electrical quantities which may change under fault conditions are voltage, current, frequency, and phase angle. Through the changes in one or more of these quantities, the faults signal their presence, type, and location to the protective relays.

The protective relaying is used to give an alarm or to cause prompt removal of any element of the power system from service when that element behaves abnormally. The abnormal behavior of an element might cause damage or interference within the effective operation of the rest of the system. The protective relaying minimizes the damage to the equipment and interruptions to the service when electrical failure occurs. Along with some other equipment's the relays help to minimize damage and improve the service.

4.5. Relay Circuit Diagram

A typical relay circuit is shown in figure 4.3 below. This diagram shows one phase of a 3-phase system for simplicity.

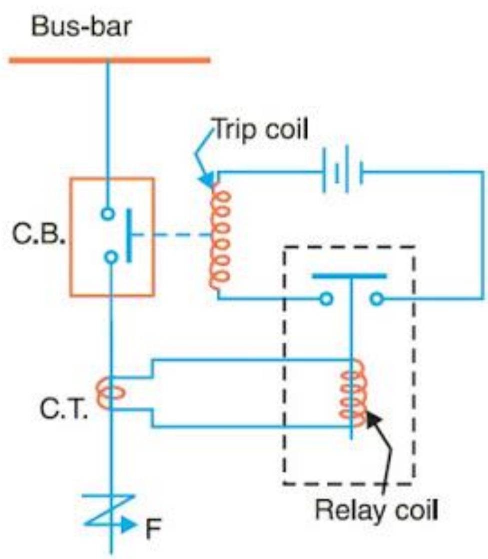


Figure 4.3: Relay Circuit Diagram

The relay circuit connections can be divided into three parts:

- First part is the primary winding of a current transformer (C.T.) which is connected in series with the line to be protected.
- The second part consists of the secondary winding of the current transformer and circuit breaker and the relay operating coil.
- The third part is the tripping circuit which may be either Ac or DC. It consists of a source of supply, the trip coil of the circuit breaker and the relay stationary contacts.
- When a short circuit occurs at point F on the transmission line, the current flowing in the line increases to an enormous value.

- This results in a heavy current flow through the relay coil, causing the relay to operate by closing its contacts.

In turn, closes the trip circuit of the breaker, making the circuit breaker open and isolating the faulty section from the rest of the system.

4.6. Instrument transformers:

In a modern power system, the circuits operate at very high voltages and carry current of thousands of amperes. The measuring instruments and protective devices cannot work satisfactorily if mounted directly on the power lines. This difficulty is overcome by installing instrument transformers on the power lines.

The function of these instrument transformers is to transform voltages or currents in the power lines to values which are convenient for the operation of measuring instruments and relays.

There are two types of instrument transformers:

1. **Current transformers (C.T.)**

A current transformer (CT) basically has a primary coil of one or more turns of heavy cross-sectional area. In some, the bar carrying high current may act as a primary. This is connected in series with the line carrying high current.

Secondary of the current transformer is made up of a large number of turns of fine wire having small cross-sectional area. This is usually rated for 5A. This is connected to the coil of normal range ammeter. Figure 4.4 describes C.T characteristic.

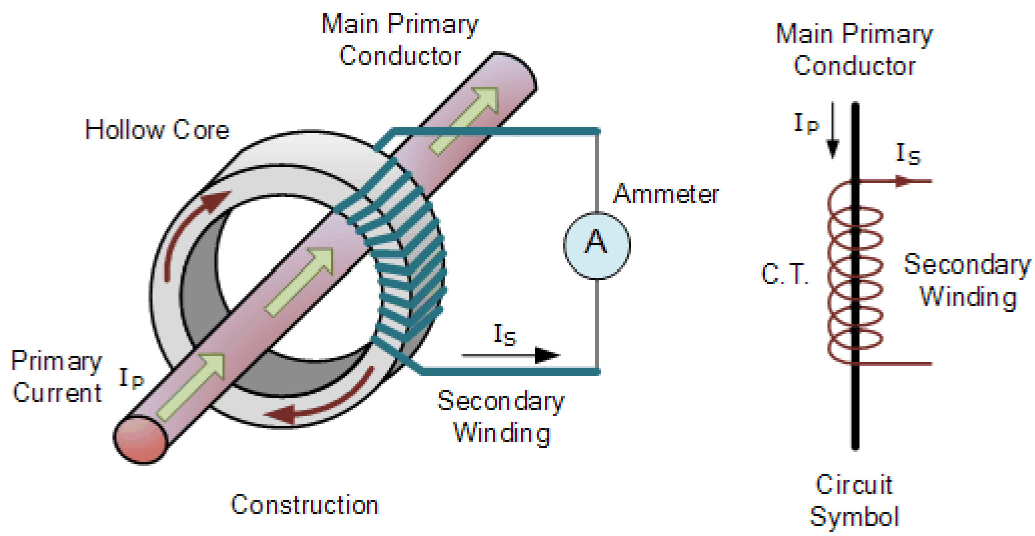


Figure 4.4: C.T. characteristic

2. **Voltage transformers (V.T.)**

It is an instrument transformer in which the secondary voltage is substantially proportional to the primary voltage and differs in phase from it by approximately zero degrees.

4.7. Reclosers

An automatic circuit recloser is a self-controlled protective device used to interrupt and reclose automatically an alternating-current circuit through a predetermined sequence of opening and reclosing followed by resetting, lockout, or hold closed.

Recloser are installed to provide maximum continuity of service to distribution loads, simply and economically, by removing a permanently faulted circuit from the system or by instant clearing and reclosing on a circuit subjected to a temporary fault caused by lightning, trees, wildlife, or similar causes.

Unlike other protection devices, Reclosers are able to distinguish between permanent and temporary faults. They give temporary faults repeated chances to clear or to be cleared by a subordinate protective device. If the fault is not cleared, the recloser recognizes the fault as permanent and operates to lock out.

On our case we need to install a three phase reclosers on the branch distribution feeders of the substation to protect distribution circuits and to switch them.

To select a suitable automatic recloser many parameters such as frequency, continuous current, minimum tripping current, interrupting current, and making current must be considered. After that we select the E-Series ACR with ADVC Controller from Schneider as shown in figure 4.5, to get more information (see appendixC1).

Figure 4.5: E-Series ACR with ADVC Controller

4.7.1. Recloser installation

Recloser installation dimensions must be as described in the figure 4.6 as recommended by the manufacturer. Periodic inspection and maintenance are essential to ensure efficient, trouble-free service of an automatic circuit recloser. Once an automatic circuit recloser is installed, it should be placed on a periodic schedule of test and inspection. Frequency of maintenance should be based on the manufacturer's recommendations, elapsed time in service, and number of operations.

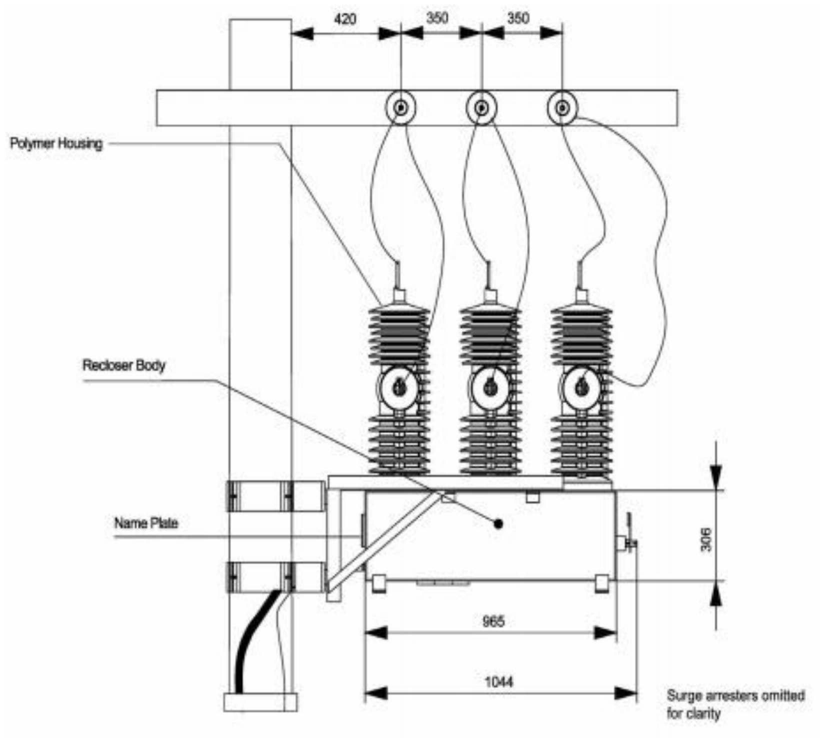


Figure 4.6: Recloser installation dimensions

4.7.2. Recloser control

Reclosers are provided with sequence control devices and operation integrator to change the recloser from instantaneous operations to time-delay operations and to lock out the recloser after a prescribed number of operations. Individual tripping operations of a recloser can be made to follow instantaneous or time-delay, time–current characteristics.

The following figures 4.7 and 4.8 shows the recloser control panel components and its installation:

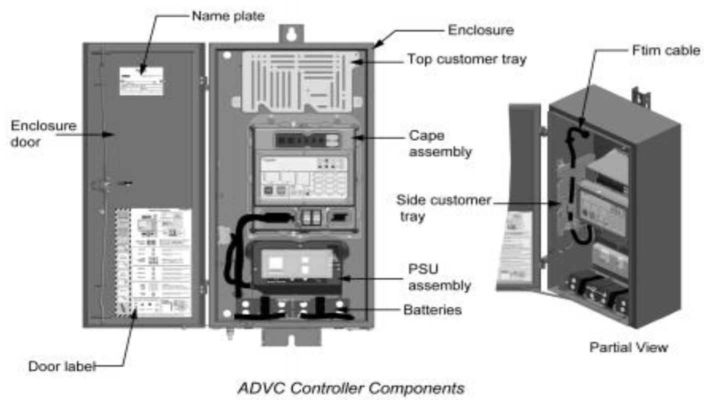


Figure 4.7: recloser control panel components

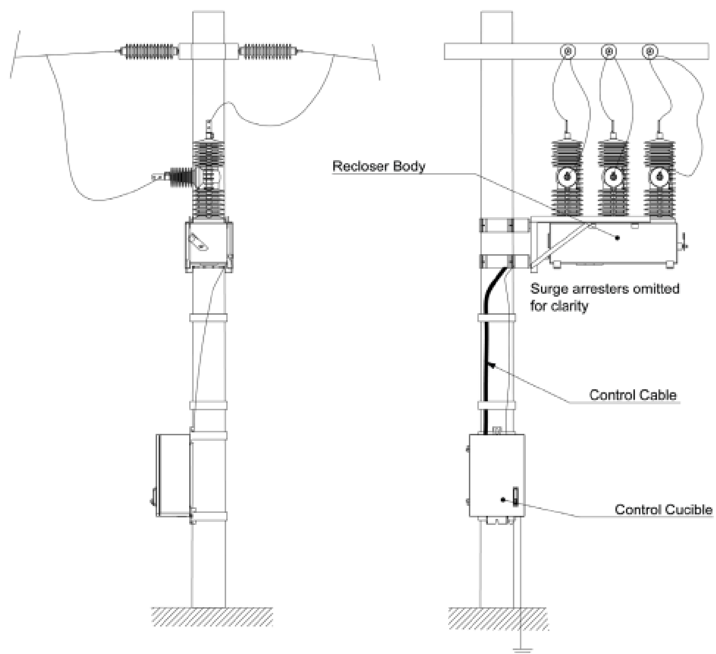


Figure 4.8: recloser and control panel installation

4.8. Surge Arresters

Surge arrester is a very important component for ensuring the safety of the power system, The surge arresters limit harmful overvoltage’s, which are generated in the network by lightning strikes or switching actions thus improving the availability of the power supply. The surge arresters fulfill special high requirements regarding ambient conditions, energy handling capability, protection level and stability in service.

Surge arresters are the basic protective devices against system transient overvoltage’s that may cause flashovers and serious damage to equipment. When a transient overvoltage appears at an arrester location, the arrester conducts internally and discharges the surge energy to ground. Once the overvoltage is reduced sufficiently, the arrester seals off, or stops conducting, the flow of power follow current through itself and the circuit is returned to normal. As voltage-sensitive devices, arresters have to be carefully selected to correlate properly with the system operating voltages [16].

We choose a number of different types of surge arresters from ABB Company to be used depending on the application:

- The most important part of the substation is power transformers, so we choose EXLIM R surge arrester as shown in figure 4.9, this type is efficient for the Protection of switchgear, transformers and other equipment in high voltage systems.

Figure 4.9: EXLIM R surge arrester

Table 4.1 provides the features that should be fulfilled for efficient operation of EXLIM R surge arrester. For EXLIM R surge arrester technical data (see appendix C2).

Table 4.1: EXLIM R surge arrester technical data

max system voltage	**rated voltage**	**creepage distance**		**Dimensions**				**external insulation**	
Us (kV)	Ur (kV)	mm	mass	Amax	B	C	1.2/50 µs dry	50 Hz wet (60s)	250/2500 µs wet
kVrms	kVrms		kg	Mm	mm	mm	kVpeak	kVrms	kVpeak
170	132-168	5302	120	1969	600	300	788	442	640

Figure 4.10 related to the upper parameters Amax, B and C that perform the surge arrester dimensions.

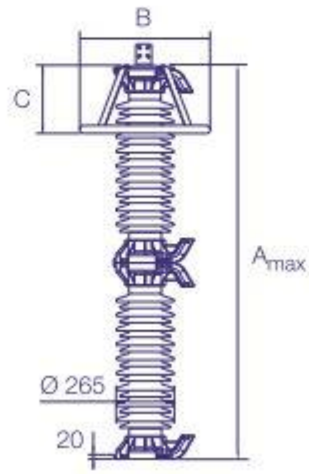


Figure 4.10: surge arrester dimensions

DMX-N Gapless Metal Oxide Surge Arresters for the low voltage side of the transformers. This type of surge arrester has been verified to meet or exceed all heavy duty distribution class requirements of ANSI C62.11 (IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits) as a normal duty distribution class arrester. Figure 4.11 describes the DMX-N surge arrester that is designed to meet the performance data described in table C.3 (see appendix C3).

Figure 4.11: DMX-N Gapless Metal Oxide surge arrester

- For the switchgears we choose MWK surge arresters as shown in figure 4.12 (see appendix C4)

Figure 4.12: MWK surge arrester

- For capacitor banks we choose POLIM-D surge arresters as shown in figure 4.13 (see appendix C4)

Figure 4.13: POLIM-D surge arrester

- For power electronic components we choose POLIM-C**...N** surge arresters as shown in figure 4.14 (see appendix C5)

Figure 4.14: POLIM-C...N surge arrester

4.8.1. Location

In general, surge arresters should be located at or near the main transformers on both the high- and low-voltage sides. It may be desirable to also locate arresters at the line entrances or, in some cases, on a bus that may be connected to several lines. They should be located to give maximum possible protection to all major substation equipment [16]. In many cases, the arresters protecting the main transformer may be mounted directly on the transformer.

Lightning strokes can produce surges with steep wave fronts, voltage gradients, reflections, or oscillations and high rates of rise of current, which can result in large differences in the line-to-ground voltage between even closely spaced points. It is extremely important to locate the arresters as close as practical to the apparatus requiring protection.

The arrester lead length should be kept as short as practical. If possible, the arrester should be connected directly to the jumper connecting the equipment to the system. Following is a general guide for determining maximum separation distances between arrester lead tap and transformer, considering the effect of arrester lead length.

4.8.2. Arrester Separation Distance and Lead Length

Impressed Voltage: The voltage impressed on the substation transformer after arrester operation may be much higher than the arrester discharge voltage if either arrester separation distance (S) or lead length (L) is excessive. Consequently, these factors have to always be considered in applying arresters [16].

Separation Distance: Arrester separation distance (S) is defined as the distance from the line arrester lead junction to the transformer bushing. Voltage reflections result when the discharge voltage traveling as a wave arrives at the transformer. If the arrester is very close to the transformer, these reflections are cancelled almost instantaneously by opposite polarity reflections from the arrester. As the separation distance increases, the cancellation becomes less and less effective, and the voltage at the transformer may increase to almost twice the arrester discharge voltage [16].

Lead Length: Arrester lead length (L) is defined as the total length of the conductor from the junction of the surge arrester lead with the line or transformer circuit to physical ground, but not including the length of the arrester itself. When the arrester discharges, surge current flows to ground over the lead length. The resulting voltage drop, L di/dt, is proportional to the lead length and adds to the arrester discharge voltage [16].

CH.5. Bus-bar Design

5.1 Introduction

5.2 Substation Busbar Design

5.3 Calculation of Tarqumia substation 161 kV bus

5.4 Calculation of Tarqumia substation 33 kV Bus-bar

5.5 Substation Disconnectors (Isolators)

5.6 Substation secondary side Disconnectors

CH.5. Bus-bar Design

5.1. Introduction

In electric power distribution substation, a busbar is a conductive material which is factory assembled to distribute electric power from a supply point to numerous output circuits. A busbar is designed sufficiently rigid to efficiently support its own weight, and to hold numerous forces such as mechanical vibration and also the electro mechanical forces provided during short circuit.

Busbars come in a multiple shapes and sizes such as solid bars, flat strips, or rods and are commonly composed of copper and aluminum as shown in figure 5.1. Their cross-sectional size and material composition determine the amount of current that can be safely carried by the busbar. Every shape has his benefits and own properties that make it special from others. Some shapes used in high voltage and other used in low voltages.

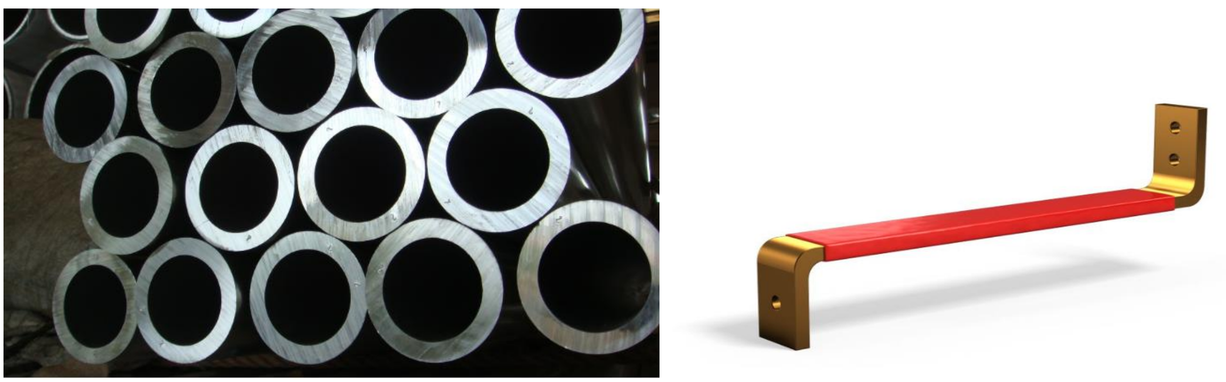


Figure 5.1: Busbar shapes

However, it’s so important to consider the expected total force applied to the busbar for busbar sizing, this force may include the weather such as the effect of ice and wind on the busbar beam, and the short circuit current force which can happen in the worst case and shouldn’t be ignored. The length of busbar included a multiple spans and a span is the length of a busbar supported by fixed or slip fit bus support as will be shown during the design calculations.

5.2. Substation Busbar Design

To design a bus for a substation many factors should be considered such as [17]:

1. Bus Location in the Substation and Its Proximity to Other Equipment.

2. Future Substation Expansion.

3. Conductor Selection.

4. Short-Circuit Conditions.

5. Wind and Ice Load.

6. Insulator Strength.

7. Conductor Sag.

8. Aeolian Vibration.

9. Conductor expansion.

10. Location of Conductor Couplers.

5.3. Calculation of Tarqumia substation 161 kV bus

As design for a rigid bus calculation shall consider the following [18]:

1. **Material and Size Selection:** Select the material and size of the bus conductors needed to maintain the required rated current.

Taking the maximum estimated load at 2040, HEPCO shall has 204.303 MVA, and SELCO shall has 256.652 MVA. So Tarqumia substation load equal to 462.955 MVA to calculated the rated current we use the following equation:

$$I_{rated} = \frac{total\ power\ (MVA)}{\sqrt{3}\times Nominal\ voltage(KV)} \qquad \text{Equation (5.1)}$$

So,

$$I_{rated} = \frac{462.955\ MVA}{\sqrt{3} \times 161\ kV}$$

$$I_{rated} = 1660.17\ A$$

For our case we select the conductor 6063-T6 aluminium alloy due to his conductivity approximately 23 percent higher and a minimum yield strength approximately 29 percent lower than the 6061-T6 alloy. Consequently, the 6063-T6 alloy can carry higher currents. From IEEE standard schedule 40 pipe (see appendix D6).

Select 2.5 inch (6.35 cm) bus size depending on the rated current next standard 1663 A. as shown in figure 5.2 having an outside diameter equal to 2.875 inch (7.303 cm) and a wall thickness of 0.203 in (0.516cm).

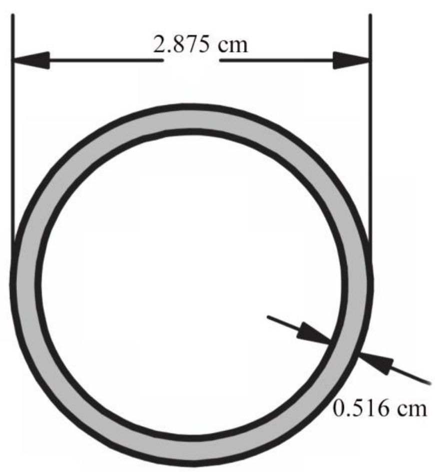


Figure 5.2: high voltage side busbar dimensions

2. **Spacing:** determine the bus conductor centreline-to-centreline (see appendixD1). Selecting 2.74 depending on 161 kV and 750 BIL.

3. **Short circuit:** Calculating the maximum short circuit force the bus can has by the following equation [18]:

Where:

$$\mathrm{F_{sc}} = 13.9 \times 10^{-5} \times \mathrm{K_{sc}} \times \frac{\mathrm{i}^2}{\mathrm{D}} \qquad \text{Equation (5.2)}$$

$\mathrm{F_{sc}}$: Maximum short-circuit force on center conductor for a three-phase flat bus configuration of round or square tubular conductors with the conductors equally spaced, in newtons per meter .

$\mathrm{K_{sc}}$: Short-circuit force reduction factor (0.5 to 1.0; 0.67 recommended).

i = rms value of three-phase symmetrical short-circuit current, in amperes.

D = Centreline-to-centreline spacing of bus conductors in centimetres.

By equation (5.2)

$$F_{sc} = 13.9 \times 10^{-5} \times 0.67 \times \frac{(20 \times 10^3)^2}{274}$$

$$F_{sc} = 136 \; N/m$$

4. **Loading:** Determine the total bus conductor loading, table 5.1 lists the values for wind and ice loading for the various loading districts defined in the National Electrical Safety Code.

Table 5.1**:** NESC Conductor Wind and Ice loads [19]

Load	Heavy	Medium	Light
Radial thickness of ice in millimetres	12.5	6.5	0
Horizontal wind pressure in pascals	190	190	430

The ice loading can be determined using the following Equation:

$$w_I = 0.704[(d_1)^2 + (d_2)^2] \quad \text{Equation (5.3)}$$

Where:

W_I = Ice loading, in Newton's per meter.

d_1 = Outside diameter of conductor with ice, in centimeters.

d_2 = Outside diameter of conductor without ice, in centimetres **(see appendix D2)**.

The wind loading can be determined using the following Equation:

$$F_w = 0.01 \times C_D \times P_W \times d_1 \quad \text{Equation (5.4)}$$

Where:

F_W = Wind loading, in newtons per meter

C_D = Drag coefficient, see figure 5.3 [17]

The drag coefficient can be determine by the following table depending on the shape of the bus:

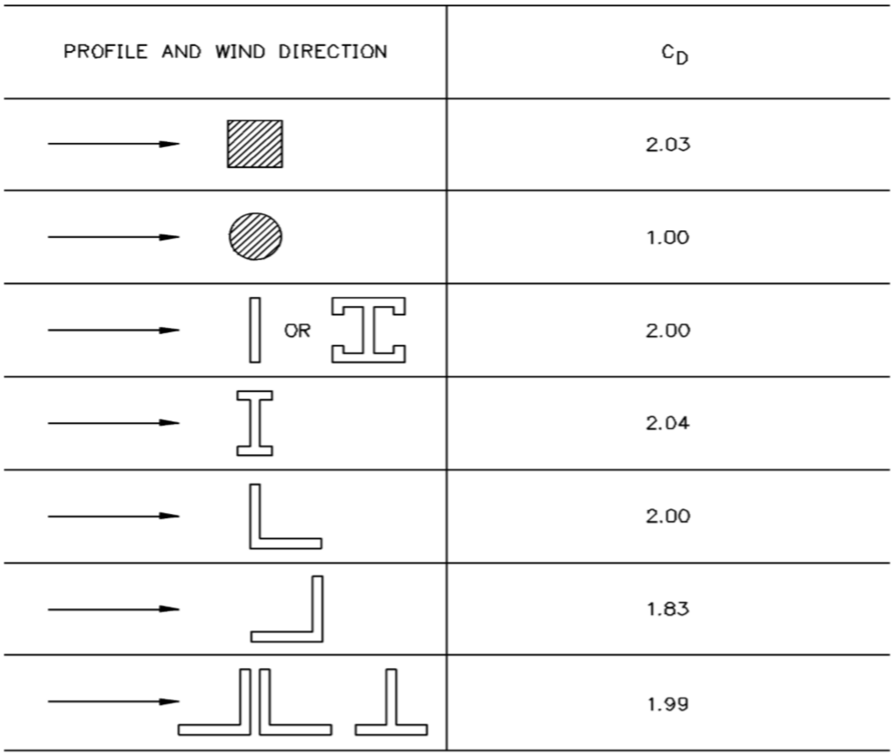


Figure 5.3: Drag coefficient for Structural Shapes

P_W = Wind pressure, in Pascal from table 5.1.

d_1 = Outside diameter of conductor with ice, in centimetres.

The total bus conductor loading can be determined using the following equation:

$$F_T = \sqrt{(F_{sc} + F_W)^2 + (W_C + W_i)^2} \qquad \text{Equation (5.5)}$$

Where:

F_T = Total bus conductor loading, in newton’s per meter.

F_{sc} = Maximum short-circuit force, in newton’s per meter.

F_w = Wind loading, in newton’s per meter.

W_C = Conductor weight, in newton’s per meter.

W_I= Ice loading, in newton's per meter (pounds per foot).

Selecting the worst weather case can occurs from table 5.1 at Radial thickness of ice of 12.5 mm and Horizontal wind pressure 190 Pascal.

Applying equation (5.3) to find Ice loading. Considering, The Outside diameter of conductor without ice (see appendix D1), $d_2 = 7.303\ cm$. The Outside diameter of conductor with ice:$d_1 = (2 \times 1.25\ cm) + \ d_2$ = 9.803 cm, then:

$$w_I = 0.704[(9.803)^2 + (7.303)^2]$$

$$w_I = 30.106\ N/m$$

Applying equation (5.4) for Wind loading as we choose the cylinder shape $C_D = 1$, see figure 5.3.

$$F_w = 0.01\ \times 1\ \times 190\ \times 9.803$$

$$F_w = 18.625\ N/m$$

Calculating the total force by equation 5.5, consider the weight of the conductor $W_c = 29.245\ N/m$ (see appendix D2)

$$F_T = \sqrt{(136 + 18.625)^2 + (29.245 + 30.106)^2}$$

$$F_T = 165.6\ N/m$$

5. **Span or Support Spacing:** Maximum bus support spacing can be determined using the following equation:

$$\mathrm{L_M} = \mathrm{K_{SM}}\sqrt{\frac{\mathrm{F_B S}}{\mathrm{F_T}}} \qquad \text{Equation (5.6)}$$

Where:

L_M= Maximum bus support spacing, in meters.

K_{SM}= Multiplying factor (see appendix D4).

F_B= Maximum desirable fiber stress of conductor, in kilopascals.

For 6063-T6 aluminium alloy

$$F_B = 1.38 \times 10^5 \text{ KPa}$$

Find the supporting space by equation (5.6):

$$L_M = 0.096 \sqrt{\frac{1.38 \times 10^5 \times 17.436}{165.6}}$$

Maximum bus support spacing is $L_M = 11.57\ meter$. Therefore to be in safe side we shall select a value less than 11.57.Assuming a span length of L= 5 meter.

6. **Deflection:** Calculate the maximum vertical conductor deflection using the following equation:

$$y = K_{DM} \frac{(W_C + W_I)L^4}{EI} \qquad \text{Equation (5.7)}$$

Where:

y = Maximum vertical conductor deflection, in centimetres.

K_{DM} = Multiplying factor (see appendix D4).

W_C = Conductor weight, in Newton's per meter (see appendix D2).

W_I = Ice loading, in newtons per meter.

L = Bus support spacing, in meters.

E = Modulus of elasticity, in kilopascals.

I = Moment of inertia, in$centimeters^4$.

The modulus of elasticity for 6063-T6 AL = 6.9 x 10^7 KPa. The Moment of inertia for 6063-T6 AL = 63.683 cm^4(see appendix D2)

By equation (5.7)

$$y = 6.9 \times 10^4 \frac{(29.245 + 30.106) \times (5)^4}{6.9 \times 10^7 \times 63.683} = 0.582\ cm$$

So, the maximum vertical conductor deflection is $y = 0.582\ cm$, but the maximum allowable deflection is 1/200 of the span length therefore:

$$y_{max} = \frac{5 \times 100}{200}$$

$$y_{max} = 2.5\ cm$$

As allowable deflection is larger than maximum vertical conductor deflection our assumption 5 meter is well.

7. **Cantilever Strength:** Determine the minimum required support insulator cantilever strength using the following equation:

$$\mathrm{W_S} = 2.5 \times (\mathrm{F_{SC}} + \mathrm{F_W})\mathrm{L_S} \qquad \text{Equation (5.8)}$$

Where:

W_S: Minimum insulator cantilever strength, in Newton's (see appendix D3).

F_{SC} : Maximum short-circuit force, in newtons per meter.

F_W : Wind loading, in newtons per meter.

L_S : span length, in meters.

Determine the technical reference number for insulators depending on Cantilever Strength (see appendix D1). Determine the minimum required support insulator cantilever strength by equation (5.8):

$$w_s = 2.5 \times (136 + 18.625) * 5$$

$$w_s = 1932.81\ N$$

At BIL equal to 750 kV Selecting insulators of tech. ref 291 cantilever strength equal to 5338 N.

8. **Thermal Expansion:** Provide for thermal expansion of conductors. The amount of conductor thermal expansion can be calculated using the following equation:

$$\Delta L = \alpha L \Delta T \qquad \text{Equation (5.9)}$$

Where:

ΔL = Conductor expansion, in centimetres (final length minus initial length)

α = Coefficient of linear thermal expansion: For aluminium, α = 2.3 x 10-5 per degree Celsius.

L = Initial conductor length, in centimetre's (at initial temperature).

ΔT = Temperature variation, in degrees Celsius (Fahrenheit) (final temperature minus initial temperature) (the highest temperature is 42 c° and the lower is 5 c°(see appendix D5).

So, by substitution in equation 5.9:

$$\Delta L = 2.3 \times 10^{-5} \times 25 \times 100 \times (42 - 5)$$

$$\Delta L = 2.127\ cm$$

9. **Couplers:** Locate conductor couplers. The couplers used on rigid buses should be as long as possible to provide maximum joint rigidity and strength. Clamp-type bolted couplers should have the quantity and size of clamping bolts listed in NEMA Std. CC1 as shown in table 5.2.

To prevent conductor damage from bending caused by its own weight and external loads, carefully position couplers. Welding and bolting can cause appreciable loss of conductor strength in the immediate coupler locations. Consequently, position couplers where the least amount of bending will occur.

Table 5.2**:** Ideal Locations for Couplers in Continuous Uniformly Loaded Rigid Conductors

Quantity of Conductor Spans	Ideal Coupler Locations Measured to the Right from the Left-most Support
1	*
2	0.750L, 1.250L
3	0.800L, 1.276L, 1.724L, 2.200L
4	0.786L, 1.266L, 1.806L, 2.194L 2.734L, 3.214L
5	0.789L, 1.268L, 1.783L, 2.196L, 2.804L, 3.217L, 3.732L, 4.211L
6	0.788L, 1.268L, 1.790L, 2.196L, 2.785L, 3.215L, 3.804L, 4.210L, 4.732L, 5.212L

5 conductor spans has been mentioned in table 5.3:

Table 5.3: high voltage suggested coupler positions and spacing

Number of suggested coupler positions	Required coupler spacing (meter)
1	3.945
2	6.34
3	8.915
4	10.98
5	14.02
6	16.08
7	18.66
8	21.05

By our Busbar length which is 25 meter we divided the Busbar to 5 spans each span equal to 5 meter we select the following suggested coupler positions [2, 4, 6, 8] as shown in figure 5.4.

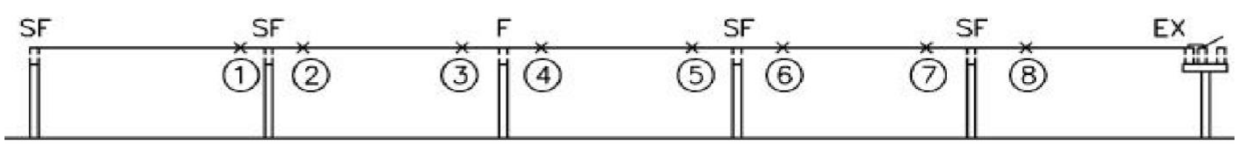


Figure 5.4: suggested coupler positions and spacing

Legend:

SF: Slip-fit bus support

F: fixed bus support

EX: Expansion terminal

10. **Aeolian Conductor Vibration:** In short spans (less than 6 meters) the vibrations are usually of small enough magnitude to be neglected.

5.4. Calculation of Tarqumia substation 33 kV Bus-bar

1. **Material and Size Selection**

$$I_{rated} = \frac{total\ power\ (MVA)}{\sqrt{3}\times Nominal\ voltage(KV)} \quad \text{Equation (5.11)}$$

So,

$$I_{rated} = \frac{462.955\ MVA}{\sqrt{3}\times 33\ KV}$$

$$I_{rated} = 8099.63\ A$$

The power cable design is considered as double circuit system, so the current in each line will be:

$$I = \frac{8099.63}{2} = 4049.76A \quad \text{Equation (5.12)}$$

Selecting the conductor 6063-T6 aluminium alloy from IEEE standard schedule 40 pipe. Select 6 in (15.24cm) bus size depending on the rated current next standard 4064 A. having an outside diameter equal to 6.625 in (16.8275 cm) and a wall thickness of 0.280 in (0.711 cm) as shown in figure 5.5**.** (See appendix D6).

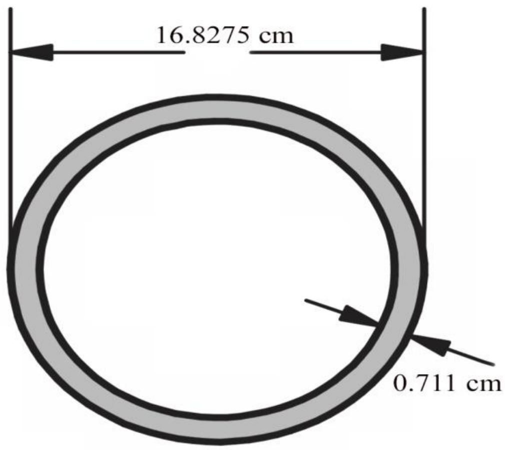


Figure 5.5: 33 kV busbar dimensions

2. **Spacing:** Selecting 0.914 depending on 33 kV and 200 BIL.

3. **Short circuit calculation:** Calculating the maximum short circuit force the bus can has by **equation (5.2)**

$$F_{sc} = 13.9 \times 10^{-5} \times 0.67 \times \frac{(48 \times 10^3)^2}{91.4}$$

$$F_{sc} = 2348\ N/m$$

4. **Loading:** Determine the total bus conductor loading. Considering, the Outside diameter of conductor without ice (see appendix D2), $d_2 = 16.83cm$`. The Outside diameter of conductor with ice: $d_1 = (2 \times 1.25\ cm) + d_2$ = 19.33 cm. Applying equation (5.3) to find ice loading:

$$w_I = 0.704[(19.33)^2 + (16.83)^2]$$

$$w_I = 462.45\ N/m$$

As we choose the cylinder shape. $C_D = 1$, see figure 5.3. By equation (5.4) the wind loading is calculated:

$$F_w = 0.01 \times 1 \times 190 \times 19.33$$

$$F_w = 36.73\ N/m$$

Consider the weight of the conductor $W_c = 95.790\ N/m$(see appendix D2). And then calculating the total force by the equation (5.5):

$$F_T = \sqrt{(2348 + 36.73)^2 + (95.790 + 462.45)^2}$$

$$F_T = 2449.2\ N/m$$

5. **Span or Support Spacing:** finding the supporting space by equation (5.5):

As we choose two spans $K_{DM} = 0.090$ (see appendix D4), by equation (5.6)

$$L_M = 0.090\sqrt{\frac{1.38 \times 10^5 \times 139.257}{2449.2}} = 8.97$$

Maximum bus support spacing is $L_M = 8.97\ meter$. Therefore to be in safe side we shall select a value less than 8.97 meter. Assuming a span length of L= 1.43 meter so it can fit with an appropriate cantilever strength.

6. **Deflection:** Calculate the maximum vertical conductor deflection by equation (5.7). The modulus of elasticity for 6063-T6 AL = 6.9 x 10^7 KPa. Moment of inertia for 6063-T6 AL = 1171.691 cm^4(see appendix D2).

$$y = 6.9 \times 10^4 \frac{(95.790\ + 462.45) \times (1.43)^4}{6.9 \times 10^7 \times\ \ 1171.691} = 0.00199\ cm$$

The maximum vertical conductor deflection is $y = 0.00199\ cm$. But the maximum allowable deflection is 1/200 of the span length, so:

$$y_{max} = \frac{1.43\ \times 100}{200}$$

$$y_{max} = 0.715\ cm$$

As allowable deflection is larger than Maximum vertical conductor deflection our assumption 1.43 meter is well.

7. **Cantilever Strength:** Determine the minimum required support insulator cantilever strength by equation (5.8):

$$w_s = 2.5\ \times (2348 + 36.73\ ) * 1.43$$

$$w_s = 8525.41\ N$$

At BIL equal to 200 kVSelecting insulators of tech. ref 210 cantilever strength equal to 8896 N (see appendix D3).

8. **Thermal Expansion:** Provide for thermal expansion of conductorsby equation (5.9)

$$\Delta L = 2.3 \times 10^{-5} \times 2.86 \times 100 \times 50$$

$$\Delta L = 0.33\ cm$$

9. **Couplers:** We have 5 conductor spans as shown in table 5.4:

Table 5.4: medium voltage suggested coupler positions and spacing

Number of suggested coupler positions	Required coupler spacing (meter)
1	1.072
2	1.787

10. **Aeolian Conductor Vibration:** In short spans (less than 6 meters) the vibrations are usually of small enough magnitude to be neglected.

5.5. Substation Disconnectors (Isolators)

Disconnector is an equipment used in the transmission and grid substations for the purpose of disconnecting the power source either for maintenance purpose or for bus transfer. This will be installed in incoming and outgoing sides of the substation according to the requirement. This will be operated in conjunction with the Circuit breaker for any switching on / off and maintenance purpose.

5.5.1. Mode of operation

The disconnector and earthing switch are operated via independent operating mechanisms. The operating energy from the operating mechanism of the disconnector is transmitted via operating rod to the rotary pedestal. The three phases of the disconnector are connected by gang operating linkages for three phase operation. During opening and closing operation, the current path, mounted on rotary insulator rotate through an angle of approximately 76° [15].

These disconnectors can be supplied manually or by motor operated mechanism as required. Operating mechanisms contain auxiliary switches for control and signaling as well as provisions for electrical interlocks.

5.5.2. Substation primary side disconnectors

In order to provide a good reliability and efficient disconnecting, we choose the horizontal double break disconnector type eDB170 for the primary side of Tarqumia substation. The eDB170 Disconnectors are designed as per IEC 62271-102 and IEC 62271-1 standards [15].

1. The eDB Disconnectors have the following features
2. Suitable for a wide range of environmental conditions
3. Easy and quick erection
4. Dead centre interlocking for reliability under extreme conditions
5. Superior design of mechanical interlock
6. Strong rotary pedestals
7. Ice breaking capacity

The following figure describes the eDB disconnector:

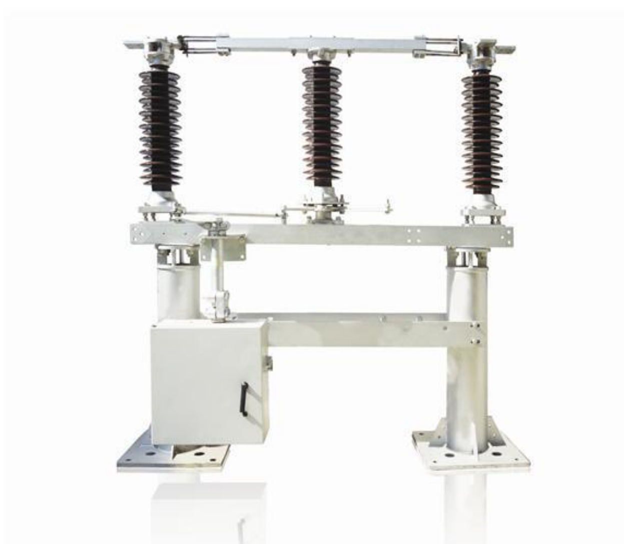


Figure 5.6**:** horizontal double break disconnector type eDB170

For eDB170 disconnector technical data see (appendix D7)

5.5.3. Installation and dimensions

The disconnectors are delivered in following assemblies - lower part with rotary pedestals and operating rod, current path, support insulators and operating mechanism. As all mechanical adjustments are carried out in the factory, only mounting of the assemblies, installation of the coupling rods between the poles, connection of the high-tension leads and the electrical connection leading to the operating mechanisms is required at the site [15].

Table 5.5 describes the required dimension of the disconnector for reliable installation and efficient operation for the following figure 5.7:

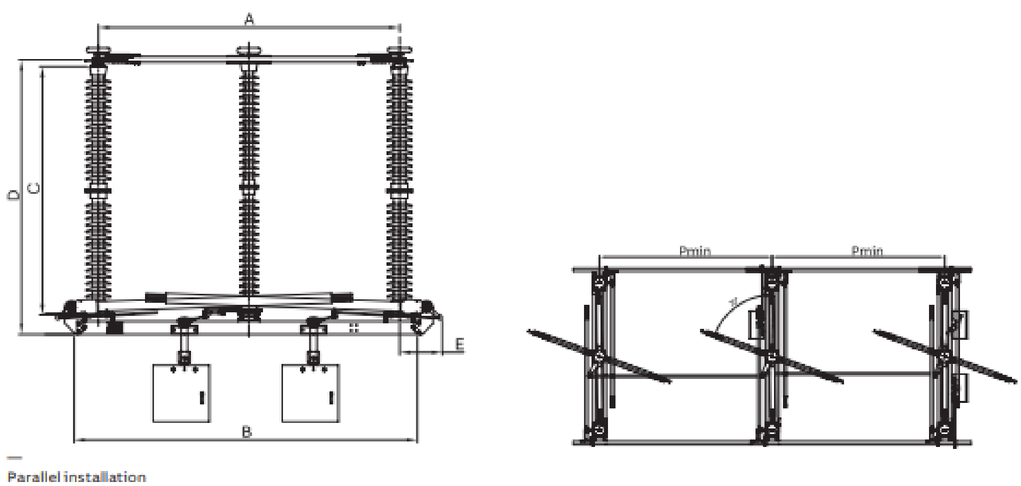


Figure 5.7: horizontal double break disconnector type eDB170 installation dimensions**.**

Table 5.5: horizontal double break disconnector type eDB170 dimensions

Dimensions	**eDB170 inch/(mm)**
Support insulator distance (A)	2200/(866)
Base frame length (B)	2600/(1024
Insulator height (C)	1700/(669)
Disconnector height (D)	1930/(760
Earth switch attachment length (E)	400/(157)
Minimum distance between poles (p) **1. Parallel arrangement**	3520/(1386)
2. Series arrangement	4920/(1937)

5.6 Substation secondary side Disconnectors

For the substation secondary side we choose eDB36 disconnector with the appropriate dimensions as showed follows [15].

For eDB36 disconnector technical data see (appendix D8)

Figure 5.8 shows the main dimensions of the disconnector with the required dimensions values in table 5.6:

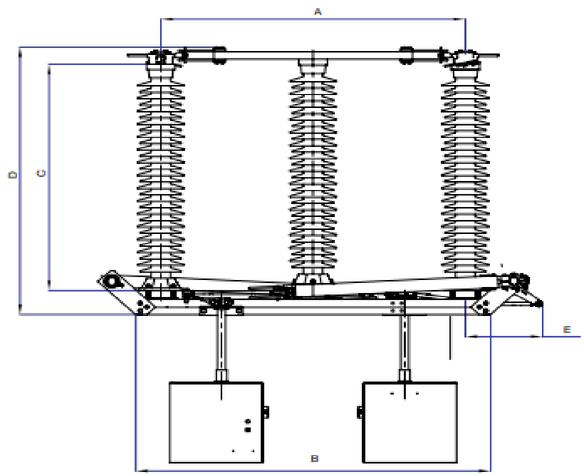


Figure 5.8: eDB36 dimensions

Table 5.6: the required dimensions values for eDB36 disconnector in mm

Dimensions	eDB36 (mm)
Support insulator distance (A)	1000
Base frame length (B)	1280
Insulator height (C)	508
Disconnector height (D)	738
Earth switch attachment length (E)	450

CH.6. Substation Cables

6.1 Introduction

6.2 Power Cable Selection conditions

6.3 Choice of voltage

6.4 Determination of the cross sectional area

6.5 Current carrying capacities

6.6 Buried cables

6.7 Cables laid in air

6.8 Inductance

6.9 Capacitance

6.10 Substation Cables Selection

6.11 Control Cables

CH.6. Substation Cables

6.1. Introduction

Electrical power can be transmitted and distributed either by overhead system or byunderground cables. The ground cables have several advantages such as ruggedconstruction, greater service reliability, increased safety, lesser chances of faults, low maintenance cost, better appearance and lesser interference from external disturbance like storms, lightening ice, trees, etc.,. As compared to overhead system.

However their major drawback is that they have greater installation cost end insulation problems at high voltages compared with the equivalent overhead systems. Hence, cables are mainly employed where it is impracticable to use overhead lines. Earlier day's underground cables were mainly uses in thickly populated areas and thatto these are limited for low and medium voltages only, but now a days due to requirement even extra high voltages for longer distances. The possibility of supply interruption due to lightning in cables is lesser but if a fault occurs due to any reason it is not easily located. Or long distance power transmission, cables can't be used to their large charging currents.

In this part we describe the cables which considered to be used at Tarqumia substation. These cables divided into two types:

1- Power cables.

2- Control cables.

6.2. Power Cable Selection conditions

Select any cable to observe the following [20]**:**

1 - International or Special Standard. (Alternatively, the precise usage of the cable).

2 - Rated voltage.

3 - Copper or Aluminum conductors.

4 - Size of each conductor.

5 - Insulation material: XLPE or others.

6 - Number and identification of conductors.

7- Other requirements.

6.3. Choice of voltage

The rated voltage is specified as Vo / V; where: Vo is the rated voltage between conductor and screen or outer metallic protection. V the rated voltage between any two conductors.

In three phase systems Vo is V / 3 The voltage of the cable must be chosen according to the maximum voltage Um in normal working conditions, which must not exceed the rated voltage by more than 20%.

6.4. Determination of the cross sectional area

The determination of the cross sectional area depends on the:

- Current carrying capacities in continuous loading,
- Permissible short-circuit current,
- Conditions of installation (temperature, spacing,...).

6.5. Current carrying capacities

The heat produced by the cable under the set conditions must be able to dissipate to the ambient environment at any point of the cable installation; therefore the loading of the cable must be limited accordingly. The current carrying capacities shown in the electrical characteristics tables are calculated according to the internationally adopted method of the IEC publication 60287 for a maximum core temperature of 90˚C, at the following installation conditions.

6.6. Buried cables

The stated values are for cables or ducts placed in the ground at a depth of 800 mm of average thermal resistivity of 100˚C.cm/w and spaced so that the temperature rise in each duct has no effect on the other ducts (space being greater than 1 meter), for a soil temperature of 20˚C [21].

Where the thermal resistivity is different (not 100˚ C cm/w) the current rating should be multiplied by the correction factors shown in table 6.1.

Table 6.1: Correction factor for different soil thermal resistivity

Nature of the soil	Soil thermal resistivity ˚C.cm/w	Correction factor
Very wet soil	**40**	**1.25**
	50	**1.21**
	70	**1.13**
Normal soil	**85**	**1.05**
	100	**1.00**
Dry soil	**120**	**0.94**
	150	**0.86**
Very dry soil	**200**	**0.76**
	250	**0.70**
	300	**0.65**

Where the temperature of the soil is different (not 20˚C) the current rating should be multiplied by the following correction factors shown in table 6.2.

Table 6.2: Correction factor for different soil temperature

Soil Temperature (˚C)	Carrying core Temperature (˚C)								
	65	70	75	80	85	90	95	100	105
0	1.20	1.18	1.17	1.15	1.14	1.13	1.13	1.12	1.11
5	1.15	1.14	1.13	1.12	1.11	1.10	1.10	1.09	1.08
10	1.11	1.10	1.09	1.08	1.07	1.07	1.06	1.06	1.06
15	1.05	1.05	1.04	1.04	1.04	1.04	1.03	1.03	1.03
20	1	1	1	1	1	1	1	1	1
25	0.94	0.95	0.95	0.96	0.96	0.96	0.97	0.97	0.97
30	0.88	0.89	0.90	0.91	0.92	0.93	0.93	0.94	0.94
35	0.82	0.84	0.85	0.87	0.88	0.89	0.89	0.90	0.91
40	0.75	0.77	0.80	0.82	0.83	0.85	0.86	0.87	0.87
45	0.67	0.71	0.74	0.76	0.78	0.80	0.82	0.83	0.84
50	0.58	0.63	0.67	0.71	0.73	0.76	0.77	0.79	0.80

When several cables or ducts are laid underground with less than one meter spacing the current rating values should be multiplied by the following correction factors shown in table 6.3.

Table 6.3: Correction factor of proximity effect for underground cables

Single or multi core cables					
Number of circuits	**Touching cables**	**One diameter spaced cables a = D**	**a = 0.25m**	**a = 0.5m**	**a = 1.0m**
2	0.76	0.79	0.84	0.88	0.92
3	0.64	0.67	0.74	0.79	0.85
4	0.57	0.61	0.69	0.75	0.82
5	0.52	0.56	0.65	0.71	0.80
6	0.49	0.53	0.60	0.69	0.78

Where:

D = overall outer sheath diameter.

a = Space between cables.

6.7. Cables laid in air:

The stated values are for cables or ducts laid "in air" with an ambient temperature of 30˚C and out of direct sunlight, spaced so that the temperature rise of individual cables has no influence on others. The spacing between adjacent cables is at least twice the cable or duct diameter [21].

When the ambient temperature is different (not 30˚C) the current rating values should be multiplied by the following correction factors at Table 6.4:

Table 6.4**:** Correction factor for different air temperature

Ambient Temperature (˚C)	**Carrying Core Temperature (˚C)**						
	65	70	75	80	85	90	95
0	1.36	1.32	1.29	1.26	1.24	1.22	1.21
5	1.31	1.27	1.25	1.22	1.21	1.19	1.18
10	1.25	1.22	1.2	1.18	1.17	1.15	1.14
15	1.2	1.17	1.15	1.14	1.13	1.12	1.11
20	1.13	1.12	1.11	1.1	1.09	1.08	1.07
25	1.07	1.06	1.05	1.05	1.04	1.04	1.04
30	1	1	1	1	1	1	1
35	0.93	0.94	0.94	95	0.95	0.96	0.96
40	0.85	0.87	0.88	0.89	0.9	0.91	0.92
45	0.76	0.79	0.82	0.84	0.85	0.87	0.88
50	0.65	0.71	0.75	0.77	0.8	0.82	0.83
55	0.53	0.61	0.67	0.71	0.74	0.76	0.78
60	0.38	0.5	0.58	0.63	0.67	0.71	0.73
65		0.35	0.47	0.55	0.6	0.65	0.68
70			0.33	0.45	0.52	0.58	0.62
75				0.32	0.43	0.5	0.55
80					0.3	0.41	0.48
85						0.29	0.39
90							0.28

When several cables or ducts are grouped, the current ratings values should be corrected as mentioned Table 6.5 & Table 6.6:

Table 6.5: Single Corecables

Method of laying	Number of ducts Number of layers	1	2	3	
Touching	1	0.97	0.89	0.87	3 cables in horizontal layer
	2	0.94	0.85	0.81	
	3	0.93	0.84	0.79	
One diameter spaced cables a = D	1	1.0	0.98	0.96	3 cables in triangular formation
	2	0.97	0.93	0.89	
	3	0.96	0.92	0.86	

Table 6.6: Multicore cables

Method of laying	Number of ducts Number of layers	1	2	3	4	6
Touching	1	1.0	0.88	0.82	0.78	0.76
	2	1.0	0.87	0.80	0.76	0.73
	3	1.0	0.86	0.79	0.75	0.71
One diameter spaced cables a = D	1	1.0	1.0	0.98	0.95	0.91
	2	1.0	0.98	0.86	0.92	0.87
	3	1.0	0.98	0.95	0.91	0.85

Note: the space H between layers must not be less than 30cm

6.8. Inductance:

The Inductance L depends on the geometrical characteristics of the cable as well as the disposition of conductors [21]**.**

For unarmored cables: $L = 0.05 + 0.46\log\frac{D_m}{r}$ (mH/km) Equation (6.1)

Where: r = Conductor Radius

D = Distance between Conductors

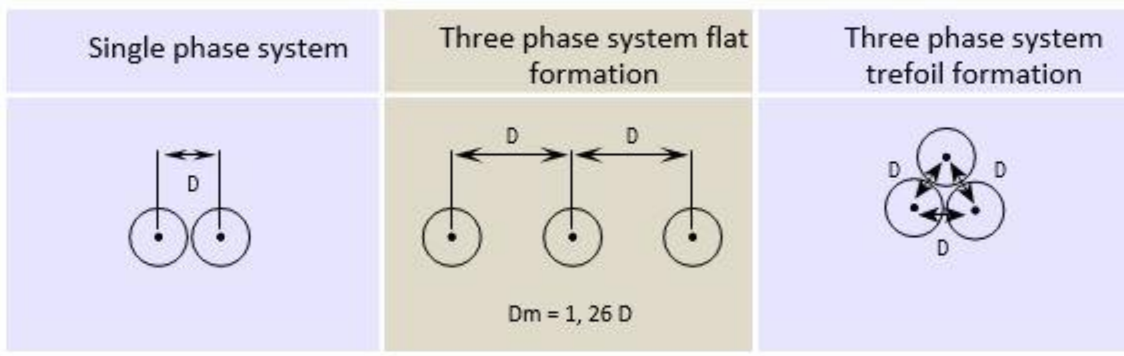


Figure 6.1: Distance between Conductors

For armoured Cables increase the inductance of about 10%

6.9. Capacitance:

The capacitance is formulated as following:

$$C = \frac{2.3}{18 \ln\frac{D}{d}}$$ Equation (6.2)

d = Diameter of conductor (including the eventual semi-conductive layer)

D = Diameter of insulated Conductor

Conductors short - circuit current:

Table 6.7: Current density at different temperature

Temperature of conductor before overload T (˚C)	Current density (A/ mm2) conduct or metal over load time in secs									
	Copper					Aluminium				
	0.1	0.5	1	2	5	0.1	0.5	1	2	**5**
20	556	249	179	124	78	366	164	116	82	51
30	537	241	170	120	76	354	195	112	79	50
70	464	207	147	103	65	325	145	103	92	46
90	439	196	139	98	62	287	128	91	64	40

For an overload duration (t) different than those figured in the above table, the correspondent current density is given by the following formula [21]:

$$\text{Current density for a duration (t)} = \frac{\text{Current density for 1 sec}}{\sqrt{t}} \qquad \text{Equation (6.3)}$$

6.10. Substation Cables Selection:

6.10.1. At 161 kV side:

On this side, two size of the same type will be selected for the cable. The first cable will be the main cable which will provide the substation at power, the second cable will provide each transformer of the five transformers on the power.

The first cables: this cables comes from Israeli Electric Company (IEC) and feed the substation with power, the power of this cables is 500MVA.

These cables will be transported through huge towers show Figure 6.2:

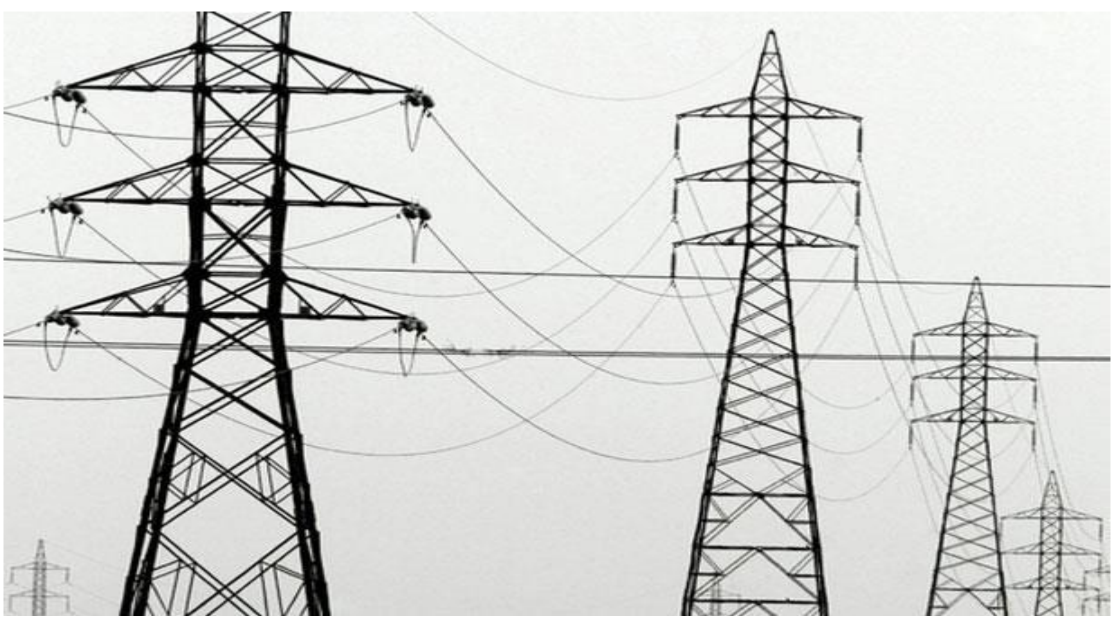


Figure 6.2: Transmission line

The rated current that will pass in this cables is:

$$I = \frac{S*PF}{\sqrt{3}*V_S} = \frac{500MVA*1}{\sqrt{3}*161kv} = 1.793\ kA \qquad \text{Equation (6.4)}$$

Where:

I: rated current.

P: substation power.

Vs: primary voltage.

PF: power Factor.

Note: this current for each phase.

We used BS EN 50182 standard to choose these cables. For this standard at 161 kV was selected Aluminum Conductor Steel Reinforced (ACSR) cables show Figure 6.3.

Figure 6.3: Aluminum Conductor Steel Reinforced (ACSR)

And the data sheet for Aluminum Conductor Steel Reinforced (ACSR) cables According to BS EN 50182 [22]. (See appendix E1)

But haven't bears 1.7932 KA at this standard. We need more than one cable, selected cable bears 616 A (see appendix E1). Three cables each cable bears 616 A. So three cables bears 1.848 KA Wrapped around each other.

From Appendix E2 the name product code of this cable is LION and the data sheet of LION from Aluminum Conductor Steel Reinforced (ACSR). (See appendix E2).

For general in this design (3 cable for each phase) in the air the minimum horizontal distance between cables is 1.5 meter and the minimum vertical distance is 4 meter (see appendix E3) [22], so selected :

Horizontal: 2.5 m

Vertical: 4

From the data sheet (see appendix E2), the size of cable is 225mm^2, so the size of each phase is 675 mm^2 , and the overload time is 0.5 sec . So the current density is 128 A/mm^2.

The maximum temperature of core is 90 C° , and the air temperature of Tarqumia is 30 C° from Palestine Weather [23]. So the correction factors equal one that mean: the same current capacity from the Table 6.4.

The second cables: this cable Connect between the main bus and transformers, and the power for each transformer is 100 MVA so,

The rated current equal:

$$I = \frac{S * PF}{\sqrt{3} * V_s} = \frac{100MVA * 1}{\sqrt{3} * 161kv} = 358.6A$$

Used the same standard (BS EN 50182), and the same cable type Aluminum Conductor Steel Reinforced (ACSR).

So the name product of this cable is COYOTE, current capacity of this cable is 414A single core foe each phase.

These cables are hung on special stands show Figure 6.4. For this design (one cable for each phase) we selected 1.5 meter between phases Knowing the minimum distance is 0.75 [20]. Show (see appendix E3).

The maximum temperature and air temperature at the same first cables, so the current capacity at the same (414A).

At 161 kV there is no insulator.

Figure 6.4: Special stands for cable installation

6.10.2. At 33 kV side:

All cables are selected at the same, And All cables are buried underground. These cables connect between the secondary of each transformer and distribution buss in substation. These cables are isolated.

We used IEC 60502-2 standard and the type of cables is Copper Conductor XLPE Insulated. For the data sheet of this cable (see appendix E4).

The rated current at secondary for each transformer equal:

$$I = \frac{S*PF}{\sqrt{3}*V_S} = \frac{100MVA*1}{\sqrt{3}*33kv} = 1.75kA$$ For each phase

We selected two cables from CX5-T101-X70 product code for each phase, the current capacity for this cable is 912 A (see appendix E4), so the current capacity for two cables is 1824 A (for each phase).

Depth of the burial of these cables equal 0.5 meter and the de-rating factor equal one (see appendix E5). The type of soil is normal and the Soil thermal resistivity equal 100˚C.cm/w so the Correction factor equal one that's mean: the same current capacity. And the distant between each phase equal one meter.

From the data sheet (see appendix E4), the size of cable is 800mm^2, so the size of each phase is 1600 mm^2 , and the overload time is 0.5 sec . So the current density is 129 A/mm^2 . At 90C° from the Table (6.7).

6.11. Control Cables:

The power used for control cables was estimated to be 10 KVA, according to IEC 60502-1 (low voltage) [20]. Selected Copper Conductors PVC Insulated.

The data sheet of these cable at (see appendix E6)

The rated voltage is 0.4 kV and energy is 10 KVA so the rated current equal

$$I = \frac{S * PF}{\sqrt{3} * V_s} = \frac{10KVA * 1}{\sqrt{3} * 0.4kv} = 43.3A$$

We select CP1-T101-U08 product code, from data sheet size of conductor is 4mm^2.

CH.7. Safety and security of the substation

7.1 Fences and walls

7.2 Entrance-equipment locks

7.3 Lighting

7.4 Electric and magnetic fields

7.5 Additional security measures

7.6 Substation Fire Protection

CH.7.Safety and security of the substation

Access to electric supply substations by unauthorized personnel could make a problem. These intrusions may cause losses, damage or misoperation of equipment and facilities and may create potential safety and environmental liabilities. So here we presents a various methods and technics to mitigate or to prevent unauthorized persons from entering the substation.

7.1. Fences and walls

According to the National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-1997), the substation requires fences and walls to be employed in order to keep unauthorized persons away from the substation.

Two types of fences can be used [24]:

a) Chain linked fences

This type of fence is the least vulnerable to graffiti and is generally the lowest-cost option. Chain-link fences can be galvanized or painted in dark colors to minimize their visibility, or they can be obtained with vinyl cladding. They can also be installed with wooden slats or colored plastic strips woven into the fence fabric, the following figure describes the chain linked fence:

Figure 7.1: chain linked fences

b) Wood fences

Wood fences should be constructed using naturally rot-resistant or pressure-treated wood, in natural color or stained for durability and appearance. A wood fence can be visually overpowering in some settings. Wood fences should be applied with caution because wood is more susceptible to deterioration than masonry or metal, the following figure describes the wooden fence:

Figure 7.2: wooden fences

c) Walls

It's usually used in Palestine. Although metal panel and concrete block masonry walls cost considerably more than chain-link and wood fences, they deserve consideration where natural or landscaped screening does not provide a sufficient aesthetic treatment, the following figure describes the substation walls:

Figure 7.3: substation walls

Each of these options is available in a range of types, shapes, and colors, and can be used in combination for an attractive architectural appearance. Brick and precast concrete can also be used in solid walls, but these materials can be far more expensive. These materials should be considered where necessary for architectural compatibility with neighboring facilities. Walls can be subject to graffiti, and this should be part of the consideration of their use [24].

7.2. Entrance-equipment locks

All entrances to substations should be locked. All equipment's located outdoors and within the substation fence should have a provision for locking cabinets and operating handles where unauthorized access could cause a problem. Padlocks should be of a type that can utilize a nonreproducible key. Similar locking devices should be used on gates and doors to any buildings within the substation fence [25].

7.3. Lighting

The entire interior of the substation may be provided with dusk-to-dawn lighting to provide a minimum light level of 21.52 Lux (2 foot-candles). Placement of lighting posts should be such as not to assist an intruder who may climb the posts to enter the substation. All wiring to the lighting posts should be in conduit or concealed to minimize tampering by an intruder. In addition, areas outside the substation, but within the facility property, should also be considered for lighting to deter loitering near the substation [25].

7.4. Electric and magnetic fields

Electric substations produce electric and magnetic fields. These power frequency electric and magnetic fields are a natural consequence of electrical circuits and are found around appliances and machines in the home and workplace [24].

In a substation, the strongest fields around the perimeter fence come from the feeders entering and leaving the substation. The strength of fields from equipment inside the fence decreases rapidly with distance, reaching very low levels at relatively short distances beyond substation fences.

Electric and magnetic field sources in a substation

Typical sources of electric and magnetic fields in substations include the following:

1. Transmission and distribution lines entering and exiting the substation
2. Bus work
3. Transformers
4. Air core reactors
5. Switchgear and cabling
6. Circuit breakers
7. Ground grid
8. Capacitors

9. Battery chargers
10. Computers

Many methods can be used to reduce the effect of electric and magnetic fields. The designer of an electric substation can typically reduce the effect of electric and magnetic fields on workplace by follows [24]:

1. Increase the height of the buses. If the height of buses doubles, the level of electric field directly underneath the bus decreases by more than 50%.
2. Decrease the phase spacing and bus diameter. Theoretically, a decrease of 50% of either phase spacing or bus diameter could cause a reduction in the electric field level by approximately 10%.
3. Optimize substation layout. The presence of nearby buses, either grounded or at lower voltages, acts as a shield and reduces the electric field in the immediate area.
4. Use natural shielding. Trees, and other vegetation along the property line may reduce the electric field level there.

7.5. Additional security measures

The following additional security measures should be considered [25]:

1. Structures and poles should be kept a sufficient distance from the fence perimeter to minimize the potential use of the structure itself to scale the fence.
2. All sewer and storm drains that are located inside the substation perimeter, with access from the outside, should be spiked or fitted with vertical grillwork to prevent entry.
3. Manhole covers or openings should be located on the inside of the substation perimeter fence.
4. Driveway barriers (gates, guardrails, ditches, etc.) at the property line for long driveways can help limit vehicular access to the substation property.
5. Signs should be installed on the perimeter fence to warn the public that:
    a. Alarm systems are providing security for the substation.
    b. Entry is not permitted.

c. There is a danger of shock inside.

7.6. Substation Fire Protection

Substation fire protection conditions are very necessary for substation safety. Proper electrical clearances are necessary for the design, construction, and operation of electric supply substations.

Minimum External Clearances between Transformer Live Parts of Different Phases

For high voltage terminals of the transformer at 161 kV nominal voltage, the minimum clearance between top shed of insulator of bushings of different phases is 1321 mm [26].

The minimum phase to phase and phase to earth clearance and terminal spacing's for transformers shall comply with **IEC 60076-3** except that the minimum phase to phase and phase to earth clearance and spacing's for 33 kV shall be 500 mm respectively. Spacing's shall include an additional allowance of 150 mm for the space taken up by the terminal connection.

Table 7.1 describes the minimum external clearances between transformer live parts of different phases

Table 7.1: Separation between large transformers

nominal terminal voltage	minimum clearance mm (inch)
161 kv	1321 (53)
33 kv	500 (20)

Large oil-filled transformers should be separated by at least 30 ft (9.1 m) of clear space and/or a minimum 1 h fire rated barrier.

Separation of large transformers from buildings

According to IEEE Guide for Substation Fire Protection, the typical oil quantities on three phase power transformers for typical MVA rating described in table 7.2:

Table 7.2: typical oil quantities on three phase power transformers for typical MVA

Gallons of oil	Typical MVA ratings
12 000 and above	100 MVA and above
10 000–11 999	50–99 MVA
8000–9999	30–49 MVA
2000–7999	5–29 MVA
1999 and below	5 MVA

Transformers containing 2000 gal (7571 L) or more of insulating oil should be at least 20 ft (6.1 m) from any building. If these large oil-filled transformers are located between 20 and 50 ft (6.1–15.2 m) of a building, the exposed walls of the building should constitute, or be protected by, at least a 2 h fire-rated barrier. The barrier should extend in the vertical and horizontal directions such that any point of the transformer is a minimum of 50 ft (15.2 m) from any point on the wall not protected by the barrier. Should it be necessary to encroach on the above minimums, the installation of a transformer fire protection system should be considered.

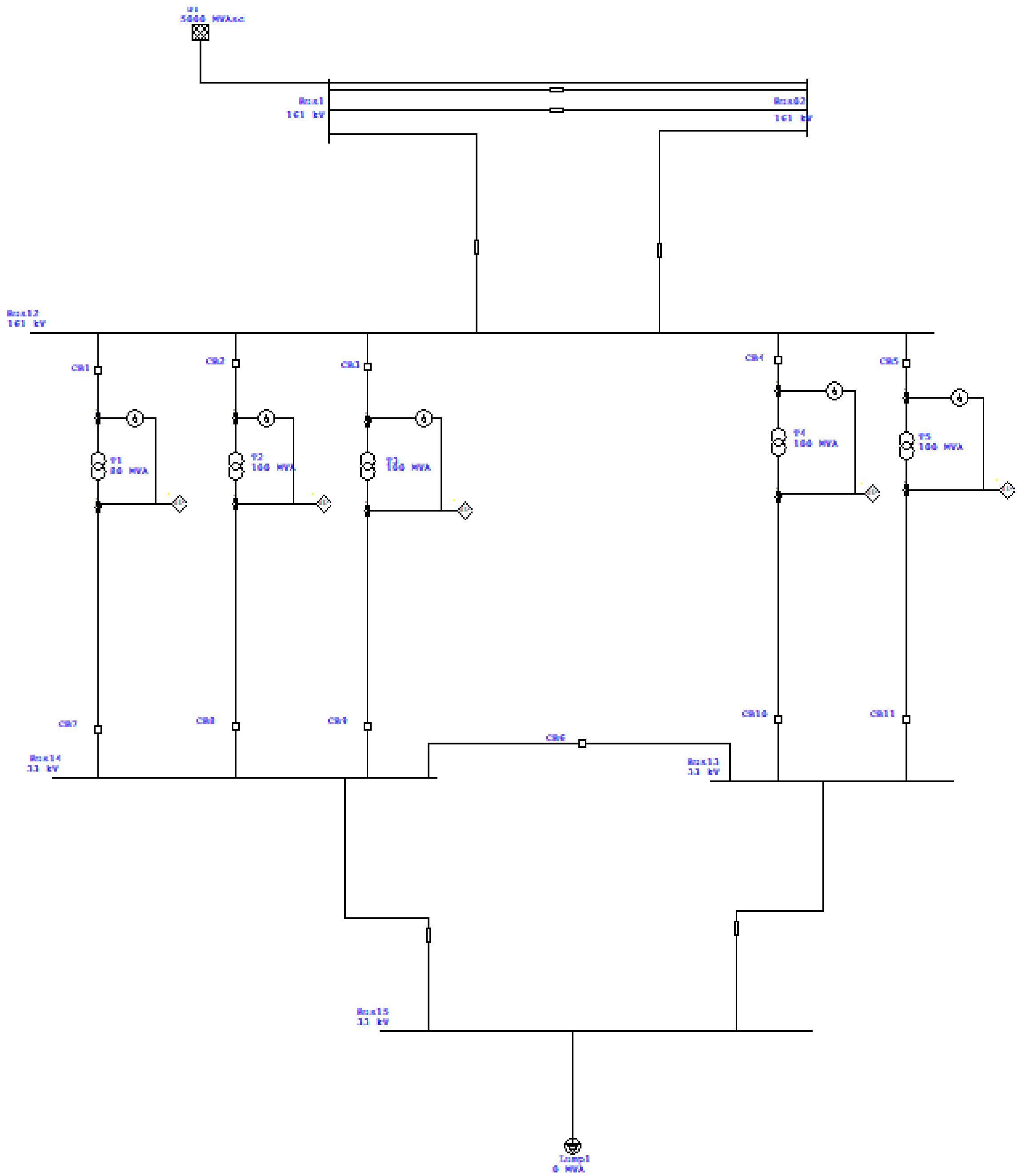
Conclusion:

- The substation design must be done after studying the load growth of the area to be worked on to ensure that the substation can feed this area for the required period of time.
- The designer of the substation buses must consider the physical forces in the design because it has an effect on the bus beam, so it should be designed to deal with many physical factors in addition of short circuit current.
- The substation grounding grid must be designed carefully to ensure the safety for substation equipment's especially power transformers beside the other protection devices.
- The substation must contain a backup source such as DC batteries to provide a reliable power source for power system protection in case of power interruption.

Recommendations

- The substation capacity should be improved by the time as the load growing.
- Safety and security inside and outside the substation should be considered to keep unauthorized persons away from the substation.
- Separation between control building and power transformers and between power transformers themselves must be considered based on the instructions motioned in IEEE guide for fire protection.

Substation Single Line Diagram



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Appendix A1

Table A.1: load forecasting coefficients

a0	303.3
a1	0.2086
a2	-0.001091
a3	-0.009341
a4	-0.004291
a5	-0.8837
a6	10.98

Appendix A2

Table A.2: Forecasting Data for Hebron City

Year	Peak Load (MW)	GDP (M$)	POP	GDP/CAP	System Losses(KW)	Load Factor (%)	Cost Of Energy (ILS/KWH)
2018	107.1464028	1156.32	264460	4656.16	9969.71	78.09	0.587
2019	110.698124	1232.23	271672.6	4934.88	10251.63	78.77	0.587
2020	112.0220541	1308.14	278885.2	5213.6	10533.55	82.03	0.59175
2021	114.9471783	1384.05	286097.8	5492.32	10815.47	84.61	0.6876
2022	122.4097835	1459.96	293310.4	5771.04	11097.39	81.39	0.7299
2023	125.5727296	1535.87	300523	6049.76	11379.31	82.5	0.7291
2024	127.5970498	1611.78	307735.6	6328.48	11661.23	83.61	0.6246
2025	134.106584	1687.69	314948.2	6607.2	11943.15	81.22	0.6469
2026	139.3547971	1763.6	322160.8	6885.92	12225.07	80.02	0.6501
2027	146.1891723	1839.51	329373.4	7164.64	12506.99	77.04	0.6545
2028	149.5841144	1915.42	336586	7443.36	12788.91	78.09	0.67
2029	152.2244956	1991.33	343798.6	7722.08	13070.83	78.77	0.587
2030	155.3158257	2067.24	351011.2	8000.8	13352.75	80.03	0.59175
2031	156.4757459	2143.15	358223.8	8279.52	13634.67	84.61	0.6878
2032	161.9491551	2219.06	365436.4	8558.24	13916.59	83.39	0.7099
2033	169.5306012	2294.97	372649	8836.96	14198.51	79.5	0.7091
2034	173.7395614	2370.88	379861.6	9115.68	14480.43	78.61	0.6426
2035	175.7427556	2446.79	387074.2	9394.4	14762.35	81.22	0.6569
2036	180.9215977	2522.7	394286.8	9673.12	15044.27	79.85	0.6401
2037	184.7816599	2598.61	401499.4	9951.84	15326.19	80.36	0.6545
2038	188.3641781	2674.52	408712	10230.56	15608.11	81.03	0.6565
2039	195.3564532	2750.43	415924.6	10509.28	15890.03	78.09	0.6785
2040	198.0516514	2826.34	423137.2	10788	16171.95	79.2	0.6351

GDP: gross domestic product.

POP: population.

GDP/CAP**:** gross domestic product per capita.

Appendix A3

Table A.3: 2017 SELCO peak load

Region Name	2017 Peak Load (MVA)
Tuwas	0.08
Seka and Almajd	1
Der AlasalAlfoqa	0.6
Der AlasalAltehta	0.25
Bet AlroushAltehta	0.25
Bet AlroushAlfoqa	0.5
Bet Mersem	1
Dora	13
Der Razeh	0.25
Abda	3
Karma	0.3
Rabod	0.25
Abu Alerqan	0.16
Abu Alasga	0.3
Dahriya	8.5
Alramadeen	2.7
Yatta	22
Total load on 2017	54.14

Appendix A4

Table A.4 SELCO Peak Load Until 2040

year	Estimated Peak load until 2040(MVA)
2017	54.14
2018	57.9298
2019	61.984886
2020	66.32382802
2021	70.96649598
2022	75.9341507
2023	81.24954125
2024	86.93700914
2025	93.02259978
2026	99.53418176
2027	106.5015745
2028	113.9566847
2029	121.9336526
2030	130.4690083
2031	139.6018389
2032	149.3739676
2033	159.8301453
2034	171.0182555
2035	182.9895334
2036	195.7988007
2037	209.5047168
2038	224.170047
2039	239.8619503
2040	256.6522868

Appendix B1

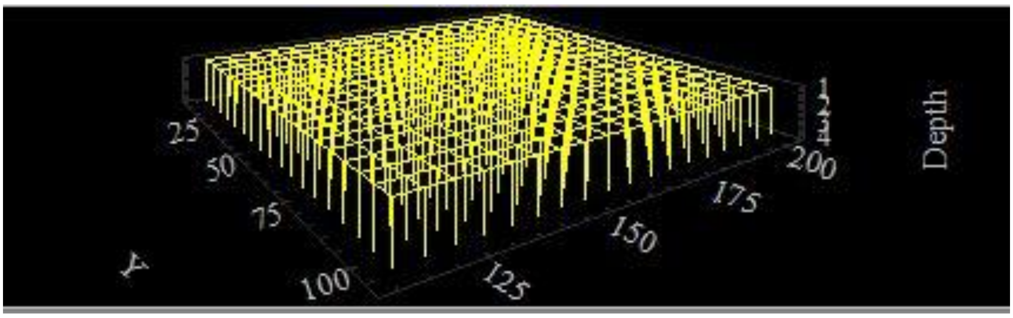

Figure B.1: Etap simulation for substation grounding grid

Appendix C1

Main

Range of product	E series
Product or component type	Recloser

Complementary

Rated voltage	38 kV 27 kV 15 kV
[In] rated current	630...800 A
[Icm] rated short-circuit making capacity	12.5 kA RMS voltage 32.5 kA peak 16 kA RMS voltage 41.6 kA peak
Operating time	0.1 s closing 0.05 s opening
Mechanical durability	10000 cycles full load 10000 cycles
[Icw] rated short-time withstand current	16 kA 12 kA
Breaking capacity	12.5 kA 16 kA
Charging current	25 A cable charging 5 A line charging 40 A cable charging
[Uimp] rated impulse withstand voltage	150 kV phase to earth 150 kV across interrupter 170 kV across interrupter 170 kV phase to earth
Rated short-duration power frequency withstand voltage	60...70 kV phase to earth 60...70 kV across interrupter

Environment

Ambient air temperature for operation	-40...50 °C
Environmental characteristic	Solar radiation 1.1 kW/m²
Relative humidity	0...100 %

Figure C.1: E series recloser technical data

Appendix C2

Zinc Oxide Surge Arrester EXLIM R

Brief performance data

Arrester classification as per IEC 60099-4 Ed 3.0	Station; SL
Arrester classification as per IEEE Std C62.11-2012	Station
System voltages (U_s)	52 - 170 kV
Rated voltages (U_r)	42 - 168 kV
Nominal discharge current (IEC)	10 kA_{peak}
Lightning impulse classifying current (ANSI/IEEE)	10 kA_{peak}
Charge, energy and current withstand:	
Repetitive charge transfer rating, Q_{rs} (IEC)	1.2 C
Thermal energy rating, W_{th} (IEC)	5 kJ/kV (U_r)
Single impulse energy capability (2 ms to 4 ms impulse)	2.5 kJ/kV (U_r)
Discharge current withstand strength:	
High current 4/10 μs	100 kA_{peak}
Low current 2000 μs, (based on Q_{rs})	600 A_{peak}
Energy class as per IEEE standard (switching surge energy rating)	-
Single-impulse withstand rating as per IEEE standard	1.2 C
Repetitive charge transfer test value - sample tests on all manufactured block batches	1.5 C
Short-circuit/Pressure relief capability	50 $kA_{rms(sym)}$
Mechanical strength:	
Specified long-term load (SLL)	3000 Nm
Specified short-term load (SSL)	7500 Nm
Service conditions:	
Ambient temperature	-50 °C to +45 °C
Design altitude	max. 1000 m
Frequency	15 - 62 Hz
Line discharge class (as per IEC60099-4, Ed. 2.2)	Class 2

Figure C.2: Zinc oxide surge arrester technical data

Appendix C3

Table C.3: **DMX-N Gapless Metal Oxide** Surge Arresters technical data

Maximum system voltages (Vm)	2.52 - 36.2 kVrms
Duty cycle rated voltages (Vr)	3 - 45 kVrms
Classifying current (IEEE)	5 kApeak
Discharge current withstand strength:	
High current 4 / 10 µs	65 kApeak
Low current 2000 µs	150 Apeak
Energy capability:	3.3 kJ/kV of MCOV
Short-circuit / pressure relief capability	16 kArms sym
Service conditions:	
Ambient temperature	-50 °C to + 45 °C
Design altitude	6000 ft / 1830 m
Frequency	15 - 62 Hz
Type tested to the following standards: IEEE standard C62.11a	

Appendix C4

Type	POLIM-D	POLIM-D..PI-2 / PI-3	POLIM-K	MWD	MWK
Technical data					
System voltage U_s	≤ 52 kV	≤ 52 kV	≤ 52 kV	≤ 52 kV	≤ 52 kV
Continuous operating voltage U_c	≤ 44 kV	≤ 42 kV	≤ 44 kV	≤ 44 kV	≤ 44 kV
Nominal discharge current I_n	10 kA	10 kA	10 kA	10 kA	10 kA
High current impulse	100 kA	65 kA	100 kA	100 kA	100 kA
IEC line discharge class	1	1	2	2	2
Application	Indoor and outdoor	Indoor and outdoor	Indoor and outdoor	Indoor	Indoor and outdoor
Applications					
Recommended for the overvoltage protection of:					
Transformers	●	●	●	●	●
Overhead lines	●		●		●
Cables			●	●	●
Rotating machines				●	●
Capacitors, capacitor banks	●		●	●	●
Cable sheath protection of HV-cables				●	●
Switchgear and switching cubicles				●	●
Metal-encapsulated switchgear		●			
Inductances, reactors, PLC line traps	●				
Transformers of arc furnace					
Further medium voltage apparatuses	●		●	●	●
Component of secondary equipment					
Power electronics					

Figure C.4: surge arresters technical data and applications

Appendix C5

Type	POLIM-C..N	POLIM-C..LB	POLIM-I..N	POLIM-S..N	POLIM-R..N	POLIM-H..N
						
Technical data						
System voltage U_s	≤ 7.5 kV	≤ 5 kV	≤ 72 kV	≤ 72 kV	≤ 1 kV	≤ 72 kV
Continuous operating voltage U_c	≤ 7.5 kV	≤ 4.8 kV	≤ 56 kV	≤ 56 kV	≤ 1 kV	≤ 58 kV
Nominal discharge current I_n	10 kA	10 kA	10 kA	10 kA	20 kA	20 kA
High current impulse	100 kA	100 kA	100 kA	100 kA	100 kA	100 kA
IEC line discharge class	2	2	2	3	4	4
Application	Indoor and outdoor	Indoor	Indoor and outdoor	Indoor and outdoor	Indoor and outdoor	Indoor and outdoor
Applications						
Recommended for the overvoltage protection of:						
Transformers	●		●	●		●
Overhead lines			●	●		●
Cables			●	●		●
Rotating machines	●		●	●		●
Capacitors, capacitor banks			●	●		●
Cable sheath protection of HV-cables	●	●				●
Switchgear and switching cubicles						
Metal-encapsulated switchgear						
Inductances, reactors, PLC line traps		●				
Transformers of arc furnace				●		●
Further medium voltage apparatuses	●	●	●	●		●
Components of secondary equipment	●				●	
Power electronics	●				●	

Figure C.5: surge arresters technical data and applications

Appendix D1

Table D.1: spacing between conductors

Nominal Phase-to-Phase Voltage kV	Maximum Phase-to-Phase Voltage kV	BIL kV	Minimum Metal - to-Metal for Rigid Conductors meters (inches)	Centerline-to-Centerline Phase Spacing for Rigid Buses meters (inches)	Minimum to Grounded Parts for Rigid Conductors meters (inches)	Minimum Between Bare Overhead Conductors and Ground for Personal Safety meters (feet) (3)	Minimum Between Bare Overhead Conductors and Roadways Inside Substation Enclosure meters (feet) (4)
7.5	8.3	95	0.178 (7)	0.457 (18)	0.152 (6)	2.44 (8)	6.10 (20)
14.4	15.5	110	0.305 (12)	0.610 (24)	0.178 (7)	2.74 (9)	6.40 (21)
23	25.8	150	0.381 (15)	0.762 (30)	0.254 (10)	3.05 (10)	6.71 (22)
34.5	38	200	0.457 (18)	0.914 (36)	0.330 (13)	3.05 (10)	6.71 (22)
46	48.3	250	0.533 (21)	1.22 (48)	0.432 (17)	3.05 (10)	6.71 (22)
69	72.5	350	0.787 (31)	1.52 (60)	0.635 (25)	3.35 (11)	7.01 (23)
115	121	550	1.35 (53)	2.13 (84)	1.07 (42)	3.66 (12)	7.62 (25)
138	145	650	1.60 (63)	2.44 (96)	1.27 (50)	3.96 (13)	7.62 (25)
161	169	750	1.83 (72)	2.74 (108)	1.47 (58)	4.27 (14)	7.92 (26)
230	242	900	2.26 (89)	3.35 (132)	1.80 (71)	4.57 (15)	8.23 (27)
230	242	1050	2.67 (105)	3.96 (156)	2.11 (83)	4.88 (16)	8.53 (28)
345	362	1050	2.67 (105)	3.96 (156)	2.13 (84)*	4.88 (16)	8.53 (28)
345	362	1300	3.02 (119)	4.43 (174)	2.64 (104)*	5.49 (18)	9.14 (30)

Appendix D2

Table D.2: outside diameter of conductor

NOMINAL PIPE SIZE		DIAMETER				WALL THICKNESS		AREA		WT/FT	WT/M	MOMENT OF INERTIA		SECTION MODULUS		RADIUS OF GYRATION	
		IN.		CM													
IN.	CM	OUTSIDE	INSIDE	OUTSIDE	INSIDE	IN.	CM	$IN.^2$	CM^2	LB	N/M	$IN.^4$	CM^4	$IN.^3$	CM^3	IN.	CM
½	1.27	0.840	0.622	2.134	1.580	0.109	0.277	0.250	1.615	0.294	4.290	0.017	0.712	0.041	0.667	0.261	0.664
¾	1.91	1.050	0.824	2.667	2.093	0.113	0.287	0.333	2.146	0.391	5.706	0.037	1.540	0.071	1.155	0.334	0.848
1	2.54	1.315	1.049	3.340	2.664	0.133	0.338	0.494	3.186	0.581	8.479	0.087	3.634	0.133	2.176	0.421	1.068
1 ¼	3.18	1.660	1.380	4.216	3.505	1.140	2.896	0.669	4.313	0.786	11.470	0.195	8.104	0.235	3.844	0.540	1.371
1 ½	3.81	1.900	1.610	4.826	4.089	1.145	2.908	0.800	5.158	0.940	13.718	0.310	12.899	0.326	5.345	0.623	1.581
2	5.08	2.375	2.067	6.033	5.250	0.154	0.391	1.075	6.932	1.264	18.446	0.666	27.709	0.561	9.187	0.787	1.999
2 ½	6.35	2.875	2.469	7.303	6.271	0.203	0.516	1.704	10.994	2.004	29.245	1.530	63.683	1.064	17.436	0.947	2.406
3	7.62	3.500	3.068	8.890	7.793	0.216	0.549	2.229	14.377	2.621	38.249	3.017	125.577	1.724	28.251	1.164	2.957
3 ½	8.89	4.000	3.548	10.160	9.012	0.226	0.574	2.680	17.287	3.151	45.983	4.788	199.292	2.394	39.231	1.337	3.396
4	10.16	4.500	4.026	11.430	10.226	0.237	0.602	3.174	20.477	3.733	54.476	7.232	301.019	3.214	52.668	1.510	3.835
5	12.70	5.563	5.047	14.130	12.819	0.258	0.655	4.300	27.741	5.057	73.798	15.160	631.007	5.451	89.326	1.878	4.770
6	15.24	6.625	6.065	16.828	15.405	0.280	0.711	5.581	36.009	6.564	95.790	28.150	1171.691	8.498	139.257	2.245	5.702

Appendix D3

Table D.3: insulator cantilever strength

BIL (IMPULSE WITHSTAND)	TECHNICAL REFERENCE	UPRIGHT CANTILEVER STRENGTH		UNDERHUNG CANTILEVER STRENGTH		BOLT CIRCLE TOP		BOLT CIRCLE BOTTOM		HEIGHT		LEAKAGE DISTANCE	
kV	NUMBER	POUNDS	(NEWTONS)	POUNDS	(NEWTONS)	IN.	(CM)	IN.	(CM)	IN.	(CM)	IN.	(CM)
95	202	2000	(8896)	2000	(8896)	3	(7.62)	3	(7.62)	7.5	(19.1)	10.5	(26.7)
95	202	4000	(17792)	4000	(17792)	5	(12.7)	5	(12.7)	7.5	(19.1)	10.5	(26.7)
110	205	2000	(8896)	2000	(8896)	3	(7.62)	3	(7.62)	10	(25.4)	15.5	(39.4)
110	225	4000	(17792)	4000	(17792)	5	(12.7)	5	(12.7)	12	(30.5)	15.5	(39.4)
150	208	2000	(8896)	2000	(8896)	3	(7.62)	3	(7.62)	14	(35.6)	24	(61.0)
150	227	4000	(17792)	4000	(17792)	5	(12.7)	5	(12.7)	15	(38.1)	24	(61.0)
200	210	2000	(8896)	2000	(8896)	3	(7.62)	3	(7.62)	18	(45.7)	37	(94)
200	231	4000	(17792)	4000	(17792)	5	(12.7)	5	(12.7)	20	(50.8)	37	(94)
250	214	2000	(8896)	2000	(8896)	3	(7.62)	3	(7.62)	22	(55.9)	43	(109)
250	267	4000	(17792)	4000	(17792)	5	(12.7)	5	(12.7)	24	(61.0)	43	(109)
350	216	1500	(6672)	1500	(6672)	3	(7.62)	3	(7.62)	30	(76.2)	72	(183)
350	278	3000	(13344)	3000	(13344)	5	(12.7)	5	(12.7)	30	(76.2)	72	(183)
550	286	1700	(7562)	1700	(7562)	5	(12.7)	5	(12.7)	45	(114)	99	(251)
550	287	2600	(11564)	2600	(11564)	5	(12.7)	5	(12.7)	45	(114)	99	(251)
650	288	1400	(6227)	1400	(6227)	5	(12.7)	5	(12.7)	54	(137)	116	(295)
650	289	2200	(9786)	2200	(9786)	5	(12.7)	5	(12.7)	54	(137)	116	(295)
750	291	1200	(5338)	1200	(5338)	5	(12.7)	5	(12.7)	62	(157)	132	(335)
750	295	1850	(8229)	1850	(8229)	5	(12.7)	5	(12.7)	62	(157)	132	(335)
900	304	950	(4226)	950	(4226)	5	(12.7)	5	(12.7)	80	(203)	165	(419)
900	308	1450	(6450)	1450	(6450)	5	(12.7)	5	(12.7)	80	(203)	165	(419)
1050	312	800	(3558)	800	(3558)	5	(12.7)	5	(12.7)	92	(234)	198	(503)
1050	316	1250	(5560)	1250	(5560)	5	(12.7)	5	(12.7)	92	(234)	198	(503)
1050	362	2300	(10230)	2300	(10230)	7	(17.8)	7	(17.8)	92	(234)	198	(503)
1300	324	1000	(4448)	1000	(4448)	5	(12.7)	5	(12.7)	106	(269)	231	(587)
1300	367	1450	(6450)	1450	(6450)	5	(12.7)	7	(17.8)	106	(269)	231	(587)
1300	368	2000	(8896)	2000	(8896)	7	(17.8)	7	(17.8)	106	(269)	231	(587)
1300	369	2050	(9118)	2050	(9118)	5	(12.7)	7	(17.8)	106	(269)	231	(587)

Appendix D4

Table D.4: multiplying factors

(K_{SM}, K_{SE}, K_{DM}, K_{DE})

Bus System	K_{SM}	(K_{SE})	K_{DM}	(K_{DE})
Conductor fixed both ends (single span)	0.110	(1.0)	2.6×10^4	(4.50)
Conductor fixed one end, simply supported other end (single span)	0.090	(0.82)	5.4×10^4	(9.34)
Conductor simply supported (single span)	0.090	(0.82)	1.3×10^5	(22.5)
Conductor simply supported (two equal spans)*	0.090	(0.82)	5.4×10^4	(9.34)
Conductor simply supported (three or more equal spans)*	0.096	(0.88)	6.9×10^4	(11.9)

Appendix D5

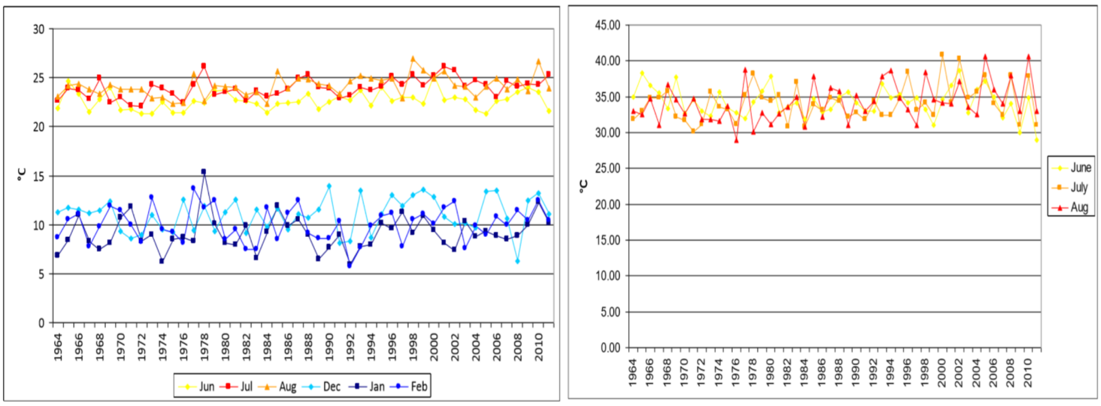

Figure D.5: temperature variation for Hebron

Appendix D6

Table D.6: busbar dimensions

Nominal Size in	A Outside Diameter of Tube in	B Wall Thickness in	Area sq in	Weight lbs/ft	Inductive reactance 1 ft spacing 60 Hz microhm/ ft	6063-T6 DC Resistance at 20ºC microhms/ ft	60 Hz Rac/RDC at 70ºC	AC Resistance at 70ºC 60 Hz microhms/ft	Current Ratings Amp at 60 Hz (1) (2) (3) (4) Outdoor
Schedule 40 Pipe									
1	1.315	0.133	0.494	0.581	68.24	31.120	1.00039	36.580	681
1 1/4	1.660	0.140	0.669	0.786	62.68	22.990	1.00050	27.030	859
1 1/2	1.900	0.145	0.800	0.940	59.45	19.220	1.00064	22.600	984
2	2.375	0.154	1.075	1.264	54.15	14.300	1.00082	16.820	1234
2 1/2	2.875	0.203	1.704	2.004	49.85	9.019	1.00220	10.620	1663
3	3.500	0.216	2.228	2.621	45.19	6.897	1.00300	8.126	2040
3 1/2	4.000	0.226	2.680	3.151	42.05	5.736	1.00380	6.761	2347
4	4.500	0.237	3.174	3.733	39.28	4.842	1.00470	5.712	2664
4 1/2	5.001	0.247	3.688	4.337	36.81	4.167	1.00570	4.920	2984
5	5.563	0.258	4.300	5.057	34.31	3.574	1.00680	4.224	3348
6	6.625	0.280	5.581	6.564	30.23	2.754	1.00950	3.263	4064

Appendix D7

Table D.7: eDB170 disconnector technical data

Type designation	eDB170
Voltage (kV)	170
Rated voltage (*Ur*) (kV)	170
Rated frequency (*fr*) (Hz)	50
Rated normal current (*Ir*) (A)	1600 , 2500
To earth and between poles (kV)	325
Across the isolating distance (kV)	375

Appendix D8

Table D.8: eDB36 disconnector technical data

Type designation	eDB36
Voltage (kV)	36
Rated voltage (*Ur*) (kV)	36
Rated frequency (*fr*) (Hz)	50
To earth and between poles (kV)	70
Across the isolating distance (kV)	80

Appendix E1

Product Code	Cross Sectional Area		Number and Nominal Diameter of Wires		Max. DC. resistance at 20˚C	Rated strength	Approx. overall diameter	Approx. Weight	Current carrying capacity
	Aluminum	Steel	Aluminum	Steel					
	mm²		No x Ø (mm)		fi/Km	KN	mm	Kg/Km	Amp
MOLE	10.6	1.77	6 x 1.50	1 x 1.50	2.7027	4.14	4.50	42.8	79
GOPHER	26.2	4.37	6 x 2.36	1 x 2.36	1.0919	9.58	7.08	106.0	140
FOX	36.7	6.11	6 x 2.79	1 x 2.79	0.7812	13.21	8.37	148.1	173
RABBIT	52.9	8.81	6 x 3.35	1 x 3.35	0.5419	18.42	10.1	213.5	219
SKUNK	63.2	36.9	12 x 2.59	7 x 2.59	0.4568	52.79	13.0	463.0	255
HORSE	73.4	42.8	12 x 2.79	7 x 2.79	0.3936	61.26	14.0	537.3	280
OTTER	83.9	14.0	6 x 4.22	1 x 4.22	0.3415	28.81	12.7	338.8	293
HARE	105.0	17.5	6 x 4.72	1 x 4.72	0.2730	36.04	14.2	423.8	338
COYOTE	131.7	20.1	26 x 2.54	7 x 1.91	0.2192	45.86	15.9	520.7	417
TIGER	131.2	30.6	30 x 2.36	7 x 2.36	0.2202	57.87	16.5	602.2	421
DINGO	158.7	8.81	18 x 3.35	1 x 3.35	0.1814	35.87	16.8	505.2	465
CARACAL	184.2	10.2	18 x 3.61	1 x 3.61	0.1562	40.74	18.1	586.7	512
JAGUAR	210.6	11.7	18 x 3.86	1 x 3.86	0.1366	46.57	19.3	670.8	550
BEAR	264.4	61.7	30 x 3.35	7 x 3.35	0.1093	111.50	23.5	1213.4	658
SHEEP	375.1	87.5	30 x 3.99	7 x 3.99	0.0771	156.30	27.9	1721.3	822
BISON	381.7	49.5	54 x 3.00	7 x 3.00	0.0758	121.30	27.0	1442.5	806
ZEBRA	428.9	55.6	54 x 3.18	7 x 3.18	0.0674	131.92	28.6	1620.8	868
CAMEL	476.0	61.7	54 x 3.35	7 x 3.35	0.0608	146.40	30.2	1798.8	928
MOOSE	528.5	68.5	54 x 3.53	7 x 3.53	0.0547	159.92	31.8	1997.3	992

Appendix E2

Table E.2: data sheet of ACSR cables

code name	**Nominal aluminium area**	**Equivalent copper area**	Stranding and wire diameter		Overall diameter	Total area			Weights			**Calculated breaking load**	Maximum dc resistance at 20 oC
			Steel	Aluminum		Steel	Aluminum	Total	steel	Aluminium	Total		
	mm2	mm2	Mm	mm	mm	mm2	mm2	mm2	kg/km	kg/km	kg/km	kN	Ω /km
TIGER	125	80.7	30/2.36	7/2.36	16.52	131.2	30.62	161.8	362	240	602	58	0.2202
WOLF	150	96.8	30/2.59	7/2.59	18.13	158.1	36.88	194.9	437	289	726	69.2	0.1828
DINGO	150	97.9	18/3.35	1/3.35	16.75	158.7	8.81	167.5	437	69	506	35.7	0.1815
LYNX	175	113	30/2.79	7/2.79	19.53	183.4	42.79	226.2	507	335	842	79.8	0.1576
CARACAL	175	113.7	18/3.61	1/3.61	18.05	184.2	10.24	194.5	507	81	587	41.1	0.1563
PANTHER	200	129	30/3.00	7/3.00	21	212.1	49.48	261.6	586	388	974	92.3	0.1363
LION	225	145	30/3.18	7/3.18	22.26	238.3	55.6	293.9	659	436	1095	100.5	0.1212
BEAR	250	161	30/3.35	7/3.35	23.45	264.4	61.7	326.1	730	483	1213	111.2	0.1093
GOAT	300	194	30/3.71	7/3.71	25.97	324.3	75.67	400	896	593	1489	135.8	0.0891
SHEEP	350	226	30/3.99	7/3.99	27.93	375.1	87.53	462.6	1034	684	1718	156.3	0.077
ANTELOPE	350	226	54/2.97	7/2.97	26.73	374.1	48.49	422.6	1032	379	1411	118.5	0.0773

Appendix E3

Table E.3: data sheet of XLPE cables

Product Code	Nominal Cross sectional area	Max. Conductor Resistance		Capacitance	Inductance		Current Rating				Approx. Overall Diameter	Approx. Weight
		DC at 20 °C	AC at 90 °C				Ground		Duct	Laid in free air (Shaded)		
	mm²	fi/Km	fi/Km	µf/km	mh/km		A		A	A	mm	Kg/Km
CX5-T101-X14	50	0.387	0.4937	0.1412	0.4910	0.5372	237	236	202	248	250	36.2	1750
CX5-T101-X15	70	0.268	0.3420	0.1596	0.4596	0.5058	289	287	247	306	308	38.1	2040
CX5-T101-X16	95	0.193	0.2465	0.1711	0.4433	0.4895	343	340	294	369	369	39.3	2335
CX5-T101-X17	120	0.153	0.1957	0.1844	0.4270	0.4732	388	384	334	422	421	40.7	2625
CX5-T101-X18	150	0.124	0.1589	0.1976	0.4193	0.4656	431	423	373	477	470	43.5	3120
CX5-T101-X19	185	0.0991	0.1274	0.2135	0.4025	0.4488	483	469	420	541	528	45.4	3575
CX5-T101-X20	240	0.0754	0.0975	0.2358	0.3854	0.4316	553	528	483	630	608	48	4255
CX5-T101-X30	300	0.0601	0.0784	0.2599	0.3706	0.4168	616	580	542	715	679	50.8	4955
CX5-T101-X40	400	0.047	0.0623	0.2839	0.3575	0.4037	687	636	608	811	758	53.6	5900
CX5-T101-X50	500	0.0366	0.0498	0.3151	0.3432	0.3894	764	692	680	921	844	57.2	7170
CX5-T101-X60	630	0.0283	0.0402	0.3467	0.3320	0.3782	839	744	753	1033	931	61.1	8675
CX5-T101-X70	800	0.0221	0.0333	0.3864	0.3197	0.3660	912	792	825	1147	1013	65.8	10725
AX5-T101-X14	50	0.641	0.8219	0.1412	0.4910	0.5372	184	184	157	192	195	36.2	1465
AX5-T101-X15	70	0.443	0.5682	0.1567	0.4640	0.5102	225	224	192	238	242	37.8	1615
AX5-T101-X16	95	0.32	0.4105	0.1711	0.4433	0.4895	268	267	230	288	290	39.3	1760
AX5-T101-X17	120	0.253	0.3247	0.1844	0.4270	0.4732	304	302	262	330	332	40.7	1895
AX5-T101-X18	150	0.206	0.2646	0.1976	0.4193	0.4656	339	336	294	374	374	43.5	2225
AX5-T101-X19	185	0.164	0.2109	0.2135	0.4025	0.4488	382	378	332	427	424	45.4	2445
AX5-T101-X20	240	0.125	0.1611	0.2349	0.3861	0.4323	441	432	385	500	492	47.9	2765
AX5-T101-X30	300	0.1	0.1293	0.2571	0.3717	0.4180	494	479	434	570	555	50.5	3100
AX5-T101-X40	400	0.0778	0.1012	0.2820	0.3568	0.4030	558	534	494	656	631	53.4	3525
AX5-T101-X50	500	0.0605	0.0796	0.3142	0.3443	0.3905	630	593	562	755	716	57.3	4080
AX5-T101-X60	630	0.0469	0.0628	0.3462	0.3326	0.3788	705	651	633	861	805	61.2	4755
AX5-T101-X70	800	0.0367	0.0506	0.3900	0.3186	0.3649	783	708	709	979	898	66.2	5630

Appendix E4

Table E.4: underground cables depth laying

Depth of laying m	Direct buried			Duct		
	Single core		Three cores	Single core		Three cores
	<= 185	> 185		<= 185	> 185	
0.5	1	1	1	1	1	1
0.8	0.96	0.94	0.96	0.96	0.95	0.97
1.25	0.92	0.9	0.92	0.92	0.9	0.94
1.75	0.9	0.86	0.9	0.9	0.88	0.92
2.5	0.88	0.83	0.88	0.88	0.85	0.9
3	0.87	0.81	0.87	0.87	0.84	0.89

Appendix E5

Table E.5: data sheet of multicore cable

Product Code	Nominal Cross sectional area	Maximum Conductor Resistance		Current Rating						Approx. Overall Diameter	Approx. Weight
		DC at 20 °C	AC at 70 °C	Laid in ground			Laid in free air (Shaded)				
				Flat	Trefoil	Duct	Flat Seperated	Flat Touched	Trefoil Touched		
	mm^2	fi/Km	fi/Km	A	A	A	A	A	A	mm	Kg/Km
CP1-T101-U08	4	4.61	5.51	53	53	38	50	37	35	7.1	87
CP1-T101-U10	10	1.83	2.17	88	89	62	89	9	62	8.3	154
CP1-T101-U12	25	0.727	0.8701	143	144	101	143	112	109	10.6	320
CP1-T101-U14	50	0.387	0.4635	203	205	148	214	170	165	13.4	545
CP1-T101-U16	95	0.193	0.232	296	301	224	332	267	259	17.1	1020
CP1-T101-U18	150	0.124	0.1501	378	383	292	442	357	347	20.5	1550
CP1-T101-U20	240	0.0754	0.0931	494	501	393	608	496	481	25.8	2500
CP1-T101-U40	400	0.047	0.0608	629	639	516	819	669	648	32	3975
CP1-T101-U60	630	0.0283	0.041	792	807	672	1113	893	864	39.7	6385
CP1-T101-U80	1000	0.0176	0.0308	956	975	845	1478	1154	1116	51.7	10345

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