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Department of Power and Control

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the Requirements for the Degree of

MASTER

In **Power Engineering**

Option: **Power Engineering**

Title:

Dimensioning And Design Of a MV Distribution Power System For The New City of Bejaia "Oued Ghir"

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Abstract

The distribution power system is the closest network to the customers and it is the basic subsystem of the power system. Generation and transmission subsystems are designed to fit the dimension of the distribution system. Therefore, the distribution network should be designed economically to satisfy the needs of the customers by ensuring the quality and continuity of supply (reliability). To achieve this goal, a good long-term planning should be carried out during the design.

In this project, the data of the new city of Bejaia "Ighzer Ouzarif" which is under realization have been used to dimension and design an optimal distribution power system for it. The design has been performed by following the method of design and by using some international standards, approximations and optimization algorithms to minimize the cost of the project.

After finishing the design, the system has been evaluated by performing load flow analysis and short circuit analysis under the most unfavorable cases. Then, it is simulated using the software ETAP for designing and testing power systems.

The obtained results show that the designed system is operating safely under the worst cases. This means that the objective of the project is achieved.

Keywords – MV, distribution power system, optimization, cost, quality, short circuit, load flow, reliability.

Dedication

I have a great pleasure to dedicate this modest work to my beloved **Mother** and my **family members** whose affection, love, encouragement and prays of day and night make me able to get such success and honor.

Along with all my **friends**, **teachers** from primary school to my last year of university.

And to all with whom I spent wonderful moments.

Ilyes LOUAHEM M'SABAH

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Med Lamdjed CHIBA

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List of abbreviations

CB : Circuit Breaker

D.transformer: Distribution transformer

DT: Distribution transformer

D.substation: Distribution substation

F: Failure

FC: Fault Current

HV: High Voltage

kVA: kilo Volt Ampere

kDA: kilo Dinar Algerian

LV: Low Voltage

MV: Medium Voltage

MST: Minimum Spanning Tree

MVA: Mega Volt Ampere

P.school: Primary school

SW: Switch

General introduction

Distribution power system planning and design is one of the important aspects for obtaining an economical operation of power systems. To minimize the cost of the distribution system and satisfy the needs of customers in the new city of Bejaia "Ighzer Ouzarif", a proper planning and design is going to be applied through this project.

In this particular project, the primary distribution system is 30 kV level underground system. It is buried one meter deep to protect it from the different hazards and to keep the landscape proper. The secondary distribution is 380-220 V.

The planning and design should be performed according to the specifications of the national company of electricity and gas “Sonelgaz” which imposes some conditions like the type of materials, the ratings of the distribution transformers and so on. Therefore, the designer must find solutions that satisfy the requirements of the client and respect the international standards of design. For this, the report has been divided as follow:

Chapter one: describes briefly the Algerian power system.

Chapter two: deals with the method of designing distribution power systems.

Chapter three: the method of design has been applied for Ighzer Ouzarif city.

Chapter four: simulation of the designed 30 kV distribution system.

1 An overview of the Algerian power system

Algeria is the largest country in Africa and the Arab world with an area of 2,381,741 m^2. It is very rich with natural resources (oil, gas and solar radiation) and it is ranked with the largest energy producing countries in the world. This potential energy is used in producing electricity and distributing it to the customers through the power system.

1.1 Power generation

Algeria became a major in power generation with an installed capacity that reached 19,471 MW in 2017 [12]. This capacity is distributed on the different types of power plants (gaz turbine, diesel, hydrolic, PV...), which most of them are conventional (based on conventional energy like gas, steam and diesel) as shown in fig.1.1 [8]

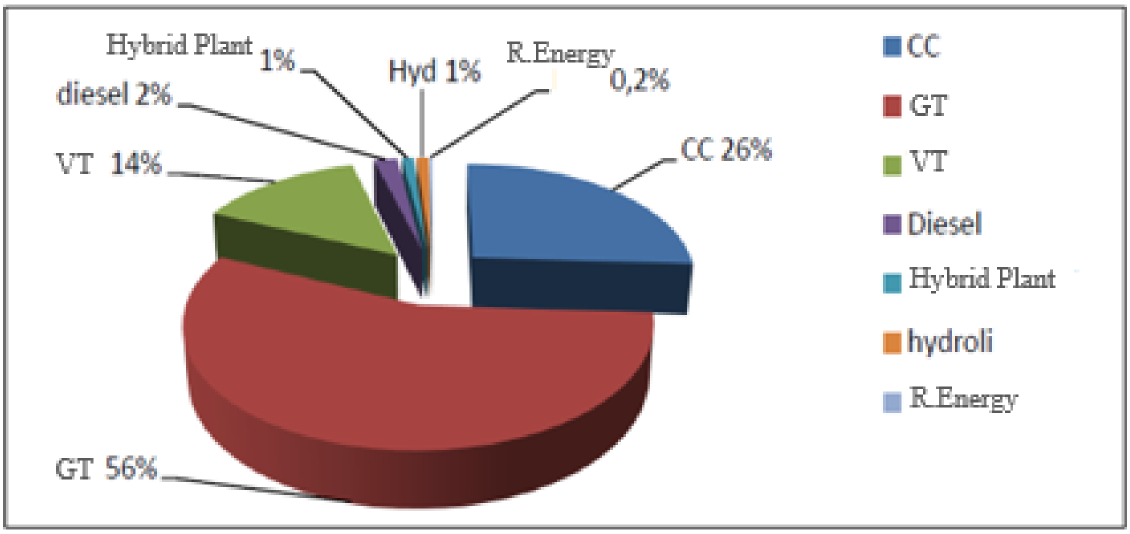


Figure 1.1: Types of installed power plants

1.2 Transmission

Once the power is generated, a step-up transformer is used to set up the output voltage of the generator to a high level (220kV, 400 kV) in order to reduce the losses, then it is transmitted to the customers at different levels (400kV, 220kV, 60kV) through the transmission system which includes transmission lines and high voltage (HV) substations.
In 2017, the transport network reached a length of 29,379 km and by 2027 it is expected to reach 32,890 km [12]

1.2.1 Substation

A substation is a part of the power system. It is mostly used to transform voltages from high levels to low levels and controls the exchange of energy. The main equipments of a substation are:
Lightening Arrestor: it protects the substation equipment from transient high voltage and limits the flow of current by diverting the current of the surges to the earth.
Bus-bars: conductors where all the power is concentrated from the incoming feeders and distributed to the outgoing feeders.
Isolators: type of switches used to isolate the circuit under no-load conditions.
Circuit Breakers: type of electrical switches which must operate as a perfect conductor in the normal cases and as a perfect isolator in the abnormal cases (faults).
Instrument transformers: current transformers (CTs) and potential transformers (PTs) are used for measurement, control and protection purposes by reducing currents to 1A/5A and voltages to 110V.
Power transformer: used to step down the voltage for further transport and distribution (220kV,110kV,60kV,30kV,10kV)
Relays: sense the faults and send trip signals to the circuit breakers to open.
Insulators: used to support and separate electrical conductors without allowing current through themselves.

Capacitor banks: draw leading current which increases the power factor (compensators) of the network and the power transfer capability of the system.
Wave Trapper: it is placed on incoming lines for trapping the high-frequency waves coming from the remote substation which disturb the waves of voltage and current. Wave trapper trips the high-frequency wave and diverts them to the telecommunication panel.
Batteries: DC voltage is needed in substations as well as power stations to insure the continuity of operation of control systems, protective systems and emergency lightening circuits.
The figure below shows the elements of the 400kV/220kV substation (El Kseur) [4]

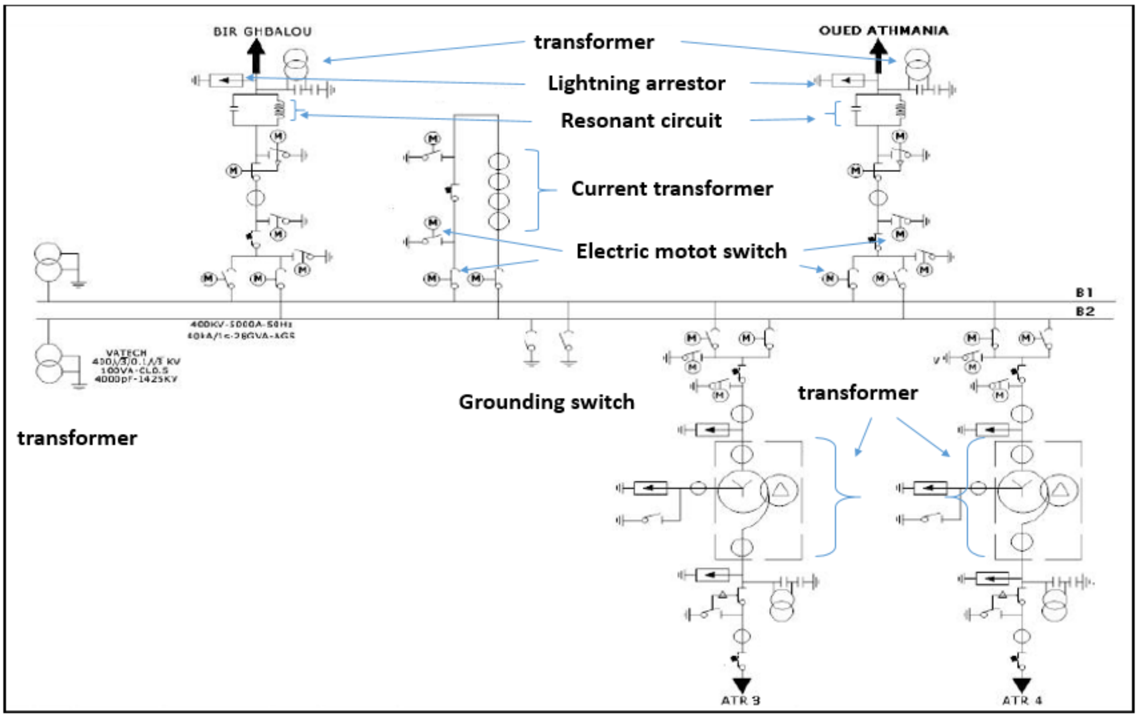


Figure 1.2: Scheme of a 400kV-220kV substation (El Kseur)

1.3 Distribution

The distribution system is the final stage in the delivery of electric power. It carries electricity from the transmission system to individual consumers.

1.3.1 Distribution substations

They connect between the transmission system and the distribution transformers to step down the high voltage to medium voltage (MV) (30kV, 10kV).

1.3.2 Primary feeders

Primary distribution lines carry the medium voltage coming from the distribution substations to the distribution transformers (10/0.4kV or 30/0.4 kV) which are located near the customer's premises to step down the medium voltage to utilization voltage 400V/220V. Large customers like industries are directly fed from the primary feeders.

1.4 National company of electricity and gaz: Sonelgaz

Sonelgaz is the state-owned company which has been created in 1969 to replace the public establishment of Electricity and Gas of Algeria (EGA) [1].
At the beginning, the company was given the monopoly over the distribution and selling of natural gas within the country as well as the production, distribution, importation, and exportation of electricity until the year of 2002 where the law N° 02-01 has been established to open the sector for private companies in order to create the competition.
Today Sonelgaz is organized into 16 industrial groups engaged in core businesses, production, transport and distribution of electricity, transport and distribution of gas through pipelines, works and peripherals. These groups are:
SPE: Société de Production de l'Electricité.
SKTM: Sharikat Kahraba wa Takat Moutadjadida.
CEEG: Société de l'Engineering de l'Electricité et du Gaz.
GRTE: Gestion du Réseau de Transport de l'Electricité.

GRTG: Gestion du Réseau de Transport de Gaz.

OS: Opérateur Système électrique.

SDC: Société de Distribution de l'électricité et du gaz du Centre.

SDA: Société de Distribution de l'électricité d'Ager.

SDE: Société de Distribution de l'électricité de l'Est.

SDO: Société de Distribution de l'électricité du l'Ouest.

Kahrif: for rural electrification.

Kahrakib: in charge of infrastructure and electrical installation.

Etterkib: electrical installation.

Inerga: civil engineering.

Kanaghaz: realization of gas network.

AMC: fabrication of energy and control meters.

In this project we aim to design an optimal distribution system for the new city of Bejaia 'Ighzer Ouzarif' with a high quality of supply and a minimum cost. The next chapter will go through the different steps of designing this system.

2 Method of design

The design of distribution power systems is subjected to some rules and standards. However, it is not an exact science. The designer can do some estimations and approximations based on his/her own experience about the environment and customer's behaviour.

This chapter will describe step by step the method applied in order to design the MV distribution system of the new city Ighzer Ouzarif.

2.1 Load demand

The demand of an electrical system generally refers to the amount of energy that must be provided to ensure feeding the system properly. To achieve that, the demand is calculated using the following steps:

First, the maximum rated power of each load of the system is determined from its nameplate. Then, this value is multiplied by the corresponding utilization factor U_K to find the real consumed power-most of the loads don't run at full load-. After that, for each group of loads connected in the same circuit, a coincidence (simultaneity) factor K_S is used due to the fact that not all the loads are running at the same time. The values of the simultaneity factors for residential use are defined in the international standards IEC 60364 [15] as shown in the table below.

Table 2.1: Coincidence factors of residential loads

Use	Coincidence factor
Lighting	1
Electric heating	1
Room air conditioning	1
Water heater	1
Power socket (N being the number of power sockets supplied by the same circuit)	0.1 + 0.9/N
Cooking appliances	0.7

For a building with a specified number of apartments, the values of the coincidence factors according to the standards NF C 14-100 [5] are shown in table 2.2

Table 2.2: Coincidence factors for residential buildings

Number of apartments	Coincidence factor
2 to 4	1
5 to 9	0.78
10 to 14	0.63
15 to 19	0.53
20 to 24	0.49
25 to 29	0.46
30 to 34	0.44
35 to 39	0.42
40 to 49	0.41
50 and above	0.40

Note:

The determination of coincidence factors is the responsibility of the designer since it requires a detailed knowledge of the installation and the conditions in which the individual circuits are being exploited. For this reason, it is not possible to give precise values for general application. Thus, the following formula can be used

$$Ks = \frac{\sum_{i=1}^{n} Fi}{\sum_{i=1}^{n} Gi} \tag{2.1}$$

Where

Fi: coincident maximum demand of circuit i

Gi: maximum demand of circuit i

2.2 Distribution transformers sizing and optimization

After the estimation of the power needed for each group of loads, the next step is to find the optimal number of distribution transformers (MV/LV) to power these loads.

The ratings of the available distribution transformers are indicated in table 2.3 [5]

Table 2.3: Rated power and voltage for MV/LV distribution transformers

Pole transformer (kVA)	25-50-100-160
Transformer in cabinet (kVA)	160-250-400-630-1000
Primary voltage (kV)	10-30
Secondary voltage (V)	230-400

To find the optimal number of distribution transformers with the minimum cost, a mathematical model should be constructed by defining the objective function to be minimized and the set of constrains (equalities and/or inequalities)

2.2.1 Construction of the model

The objective of this project is to satisfy the consumers needs with the minimum cost. This objective can be expressed mathematically as follow:

1- The summation of the installed power (transformers) is greater than or equal to the loads demand, this can be written as:

$$\sum_{i=1}^{n} Ni.Ti >= L \tag{2.2}$$

where

Ni: the number of transformer i

Ti: the rated power of transformer i

L: the loads demand

n: number of transformer types

2- The maximum number of each transformer can be obtained when it is assumed that only transformer i is going to be used

$$Ni <= \frac{L}{Ti} \tag{2.3}$$

3- The cost of these transformers should be minimum

$$\sum_{i=1}^{n} Ci.Ni = Min \tag{2.4}$$

where Ci is the cost of the transformer i. So the final model is written as follow:

$$\begin{cases} Min(F) = \sum_{i=1}^{n} Ci.Ni \\ \quad subject\ to \\ \sum_{i=1}^{n} Ni.Ti >= L \\ \quad Ni <= \frac{L}{Ti} \qquad i = 1, 2, , n \end{cases} \tag{2.5}$$

This model is linear and can be solved using one of the mixed-integer linear programming approaches.

2.3 Transformers placement and network connection

The quality and cost of distribution systems are related to the location of the distribution transformers with respect to the customers and to the connection of the network.
Distribution systems are classified according to their connection schemes to the following connection:

2.3.1 Radial distribution system

This system is used only when the substation is located at the center of the consumers where the feeders are radiated from the substation to feed the loads at only one end. Although this connection is the cheapest and simplest one, it is not reliable so in case of failure of one feeder, the supply is cut off to all the loads connected to that feeder.

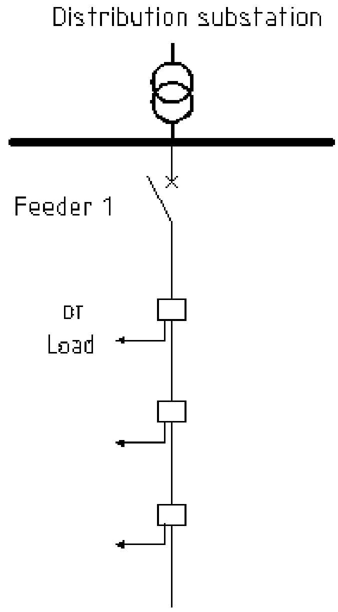


Figure 2.1: Radial distribution system scheme

2.3.2 Parallel distribution system

To solve the problem of reliability in radial distribution systems, parallel distribution system is introduced by doubling the feeder in parallel.

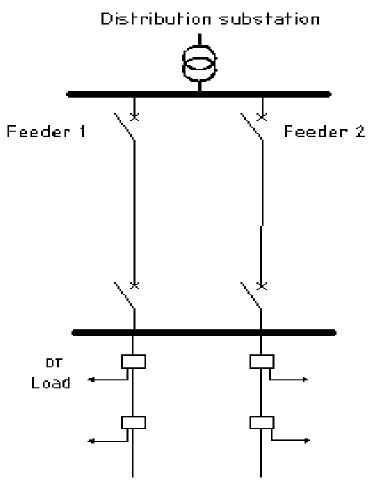


Figure 2.2: Parallel distribution system scheme

2.3.3 Ring main distribution system

In this connection, each distribution transformer is fed with two feeders in opposite directions. The feeders form a loop which starts from the substation bus-bar, runs through the distribution transformers and returns to the substation bus-bars.

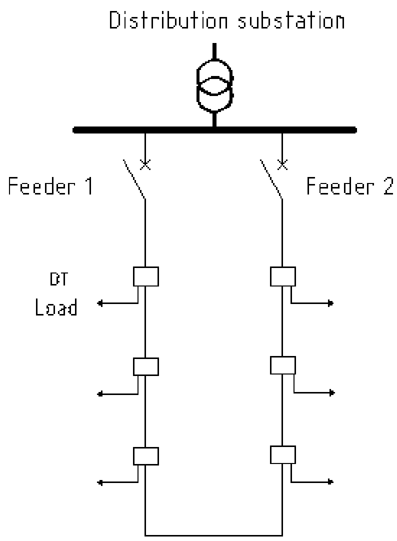


Figure 2.3: Ring main distribution system scheme

2.3.4 Interconnected distribution system

An interconnected distribution system is a ring main supplied by two or more substations. This system ensures reliability in an event of transmission failure.

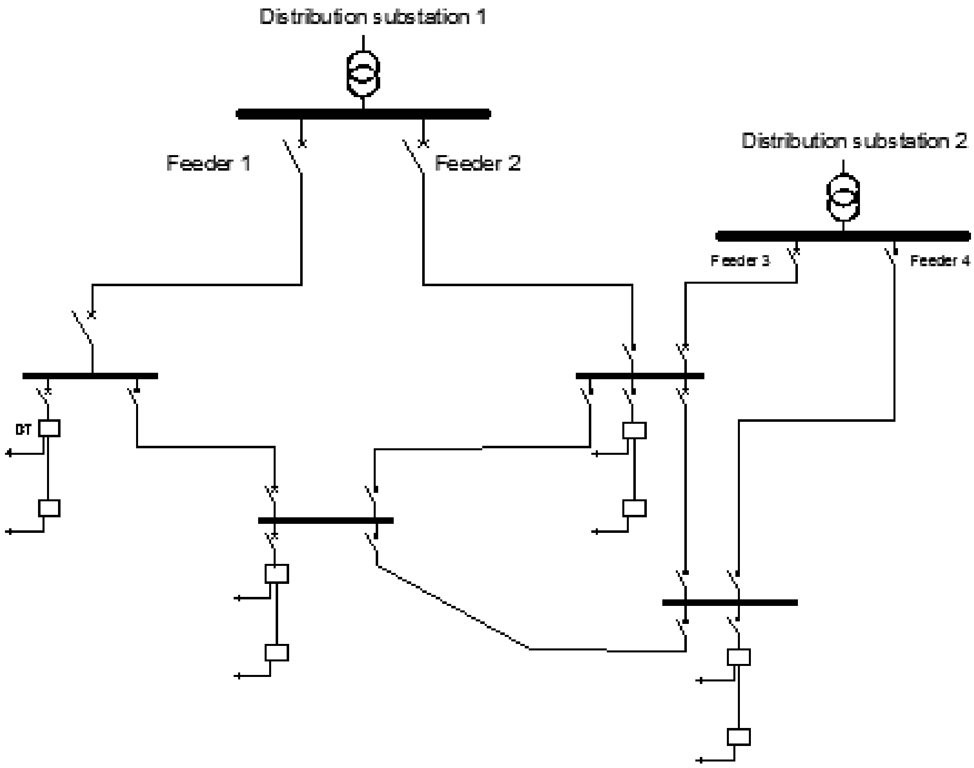


Figure 2.4: Interconnected distribution system scheme

To ensure an optimal and safe operation of the distribution system, the following criteria should be applied:

- The transformers should not operate more than 80% of their full-load (according to Sonelgaz specialists).
- The distribution transformers are centered as much as possible around the customers to reduce the losses (voltage drop),minimize the cost of cables and to balance the system.
- The transformers must be installed in cabinets one meter away from the pavement to ensure an ease and quick access in case of intervention.
- The system connection is ring main which is reliable and cheaper than interconnected system.
- During the normal operation of the system the ring is opened (S6) such that

the two (2) departures share almost the same power. once a failure (F) occurs in a part of the system, this part is isolated by opening its switches (S2-S3) and the loop is closed (S6) to ensure the continuity of the service as shown in figure 2.5

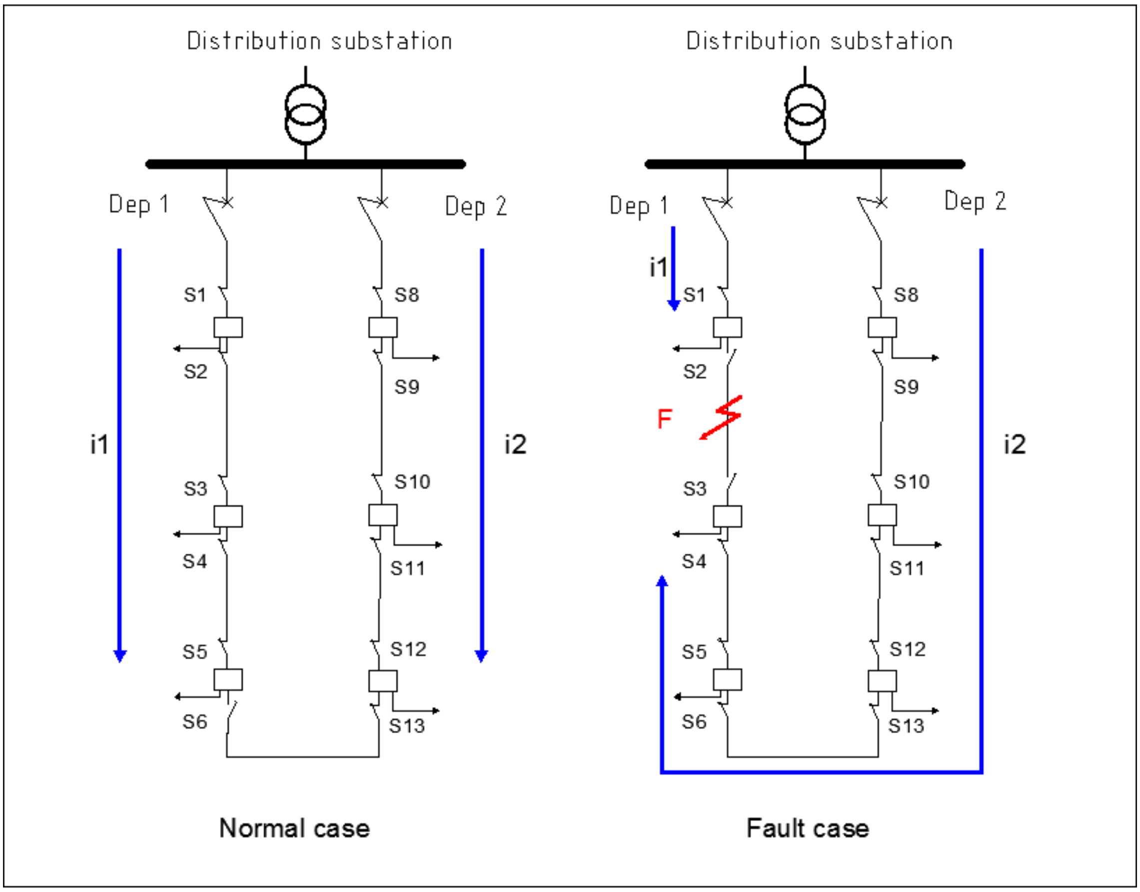


Figure 2.5: Reliability in ring main configuration

- Each transformer has only one arrival and one departure.
- In cities, the primary feeders are underground cables buried next to the pavement for the following reasons:
    1. Protecting them from the hazards of air-crafts and trucks accidents.
    2. Solving the problems of spacing (cities are densely areas) because they require a narrower band of land to install.
    3. Underground cables have small voltage drop compared to overhead cables.

4. Protecting them from weather conditions (storms, snow, fire, lightning...etc)

5. Keeping the landscape proper.

2.4 Cables sizing

The cross-section of the cables is determined based on the current I flowing in the network

$$I = \frac{P}{\sqrt{3} \times V \times \cos\phi} \tag{2.6}$$

Where

P: total power of the network

V: system voltage

Once the current is calculated, the following factors must be taken into consideration to select the right size:

2.4.1 Cable ampacity

Ampacity is defined as the maximum current carrying capacity of any cable. The base value of the ampacity is calculated by the manufacturar using the Neher-McGrath formula [17]

$$I = \sqrt{\frac{T_c - (T_a + \Delta T_d)}{R_{dc}(1 + Y_{ac})R_{ac}}} \tag{2.7}$$

Where:

I : cable current capacity (Amperes)

T_c : conductor temperature (°C)

T_a : ambient temperature (°C)

ΔTd : dielectric loss temperature rise (ºC)

R_{dc} : dc resistance of conductor at temperature Tc

Y_{ac} : component ac resistance resulting from skin effect and proximity effect

2.4.2 Derating Factors

When the installation conditions are different from the base conditions, derating (correction or reduction) factors have to be applied to the base ampacity to reduce it. For underground cables, if the correction is not applied, the cable will overheat as a result of the high thermal resistance created at the location of the conduit.

2.4.3 Short circuit withstanding capability

The selected size of cable has to be evaluated against the short circuit current. The cable must withstand the maximum symmetrical short circuit current of the network for a duration of 1 second. The general formula for cables short circuit current is [18]:

$$I = \frac{K \times A}{\sqrt{t}} \tag{2.8}$$

Where:

I : Effective short circuit current level as r.ms value

K : Depends on the cable conductor and insulation material

A : cable cross section in mm^2

t : short circuit time duration, usually considered 1 second

2.4.4 Voltage drop

The value of the voltage drop in the system should not exceed 3% of the rated voltage (according to Sonelgaz specialists).

For single-phase system [18]:

$$\Delta V\% = \frac{\Delta V}{V_N} \times 100 = \frac{2.L.I(R_L.\cos\phi + X_L.\sin\phi)}{V_N} \times 100 \tag{2.9}$$

For three-phase system [18]:

$$\Delta V\% = \frac{\Delta V}{V_N} \times 100 = \frac{\sqrt{3}.L.I(R_L.\cos\phi + X_L.\sin\phi)}{V_N} \times 100 \qquad (2.10)$$

Where:

Δv% : Percent voltage drop (%)

Δv : Absolute value of voltage drop (V)

V_N : System rated voltage (V)

I : Line or cable current (A)

L : Line or cable length (Km)

R_L : Line or cable resistance at operating temperature (ohm/km)

X_L : Line or cable reactance (ohm/Km)

Cosφ: Load power factor

Voltage drop is directly proportional to the cables impedance. If the voltage drop exceeds the limits (3%), the cross section of the cable must be increased.

Important: in distribution power system design, the voltage drop is evaluated at the furthest busbar from the substation by summing the voltage drops of the cables that connect between each two transformers starting from the substation busbar until the furthest bus.

2.5 Short circuit current calculation

short circuit studies are necessary for any power distribution system to find how much short circuit current flows from the sources to the fault when a symmetrical three-phase short circuit occurs at any location (buses or lines) in the power system. Calculating I_{sc} shows us how to select circuit breakers, what should be their MVA values, current ratings (steady state and transient state) and voltage ratings as well. One line diagrams are not complete unless the short circuit values are solved at various strategic points. No substation equipment,breaker panels, etc., can be purchased without knowledge of the complete short circuit information of the entire power distribution system[13, 16].

Knowing how to calculate short circuit problems is a must for every electrical engineer.

- Transformer fault current

Calculating the Short Circuit Current when there is a Transformer in the circuit, Every transformer has " % " impedance value stamped on the nameplate first the transformer Full Load Amps is calculated

$$FLA = \frac{kVA}{\sqrt{3} \times kV_{LL}} \tag{2.11}$$

So the fault current FC

$$FC = \frac{FLA}{Z\%} \tag{2.12}$$

- Generator fault current

Generator fault current differs from the transformer one, every generator has its subtransient X"

$$kVA = \frac{kW}{PF} \tag{2.13}$$

so the fault curent FC

$$FC = \frac{FLA}{X"} \tag{2.14}$$

2.5.1 System fault current using MVA method

The MVA method is fast and simple as compared to the per unit or ohmic methods. There is no need to convert to an MVA base or worry about voltage levels. This is a useful method to obtain an estimated value of fault currents. The elements of figure 2.6 have to be converted to an MVA values[11].

- Utility MVA at the Primary of the Transformer
- Transformer MVA

$$MVA_{TR} = \frac{MVA}{X_{pu}} \tag{2.15}$$

- Cable

When the cable is added to the circuit, the fault current will decrease to a smaller value. To add a cable to the calculation, use the formula:

$$MVA_{cable} = \frac{kV^2}{Z} \tag{2.16}$$

Combine the MVA'S

- For series:

$$\frac{1}{MVA} = \frac{1}{MVA_1} + \frac{1}{MVA_2} + ... + \frac{1}{MVA_n} \tag{2.17}$$

- For parallel:

$$MVA = MVA_1 + MVA_2 + ... + MVA_n \tag{2.18}$$

After determination the MVA of the system, the fault current of the system is calculated using the following formula

$$I_{fault}(kA) = \frac{MVA}{\sqrt{3} \times kV_{LL}} \tag{2.19}$$

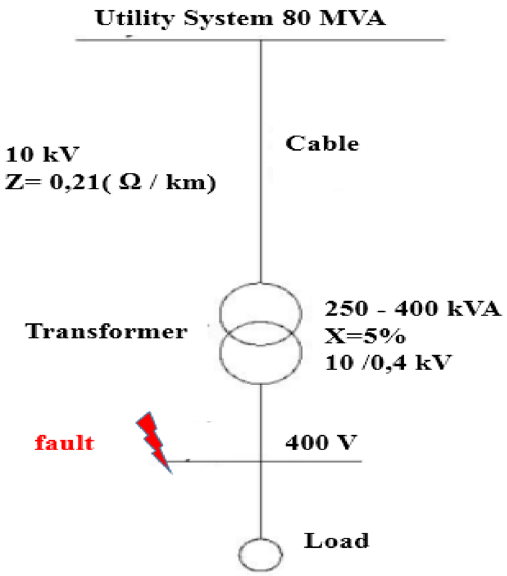


Figure 2.6: one line diagram scheme

2.6 Protection selection

The selection of the protection devices must guarantee safety for personnel and machines and ensure a good service reliability of the installation. The main protective devices in MV systems are: protective relays, circuit breakers, and fuses.

2.6.1 Circuit breakers

A circuit breaker has ratings that an engineer has to understand to make a proper selection. A brief description of these ratings is given below.

Rated operational voltage (Ue): it determines the application limit of an equipment. It is generally expressed as the voltage between phases.

Rated current (In): it is the value of current which characterizes the circuit-breaker itself. Such current is often related to the rated current of the load protected by the circuit breaker.

Rated ultimate short-circuit breaking capacity (Icu): it is the r.m.s. value of the symmetrical component "i_s" of the short-circuit current which is the maximum value that the circuit-breaker is able to break.[10]

$$i_s = \sqrt{2} \times I_{sc}.\sin(\omega.t + \phi_{sc}) \tag{2.20}$$

Rated short-circuit making capacity: it is the maximum peak current which the circuit-breaker must be able to make after the closer of the circuit breaker.[14]

$$Making\ capacity = 2.55 \times symmetrical\ breaking\ current\ (kA) \tag{2.21}$$

2.6.2 Fuses

Fuses are current-sensitive devices that provide reliable protection for discrete components or circuits by melting under current overload conditions. The basic ratings for a fuse selection are:

CURRENT RATING: The nominal amperage value of the fuse. It is established by the manufacturer as a value of current which the fuse can carry.

BREAKING CAPACITY: Also known as interrupting rating or short circuit rating, this is the maximum approved current which the fuse can safely break at rated voltage.

2.6.3 Relays

MV circuit breakers do not open automatically on overcurrent until they receive an order from the protective relays which are the brain of power system. There are many types of relays like overcurrent, distance, differential, under/over-voltage relays...etc. Now these types are integrated in one device called multi-functional relay. The most frequently used are overcurrent relays which are classified by their operating-time characteristics to:

Instantaneous relays: those with no intentional time delay. It trips when the current reaches the pick up value.

Time-delay relays: can be definite-time or inverse-time types

1. **Definite-time**: The current must exceed the setting value and the fault must be continuous at least a time equal to time setting of the relay. It's used when Z_{source} is greater than Z_{Line}.
2. **Normal inverse (OC)**: The tripping time is inversely proportional to the current magnitude. As the current increases, the tripping time decreases.
3. **Inverse definite minimum time OC (IDMT)**: Part of it operate as an inverse OC with low fault currents and part operates as an instantaneous OC with high fault currents.

3 Application case

In this chapter, the method of dimension and design will be applied for the new city of Bejaia " Ighzer Ouzarif"

Figure 3.1: Overhead view of Oued Ghir city and Ighzer Ouzarif city

The city is located in the north of Oued Ghir as illustrated in figure 3.1. It is considered as one of the biggest extensions of Bejaia city with an area of 250 Ha divided to 3 regions:

Region A: includes 2504 apartments, 23 structures, and 4 reserved lands.

Region B: includes 3990 apartments and 19 structures and 1 reserved land.

Region C: includes 2720 apartments, 6 structures, and 1 reserved land.

The ground floors of the buildings are commercial premises, where each ground floor has 8 commercial premises.

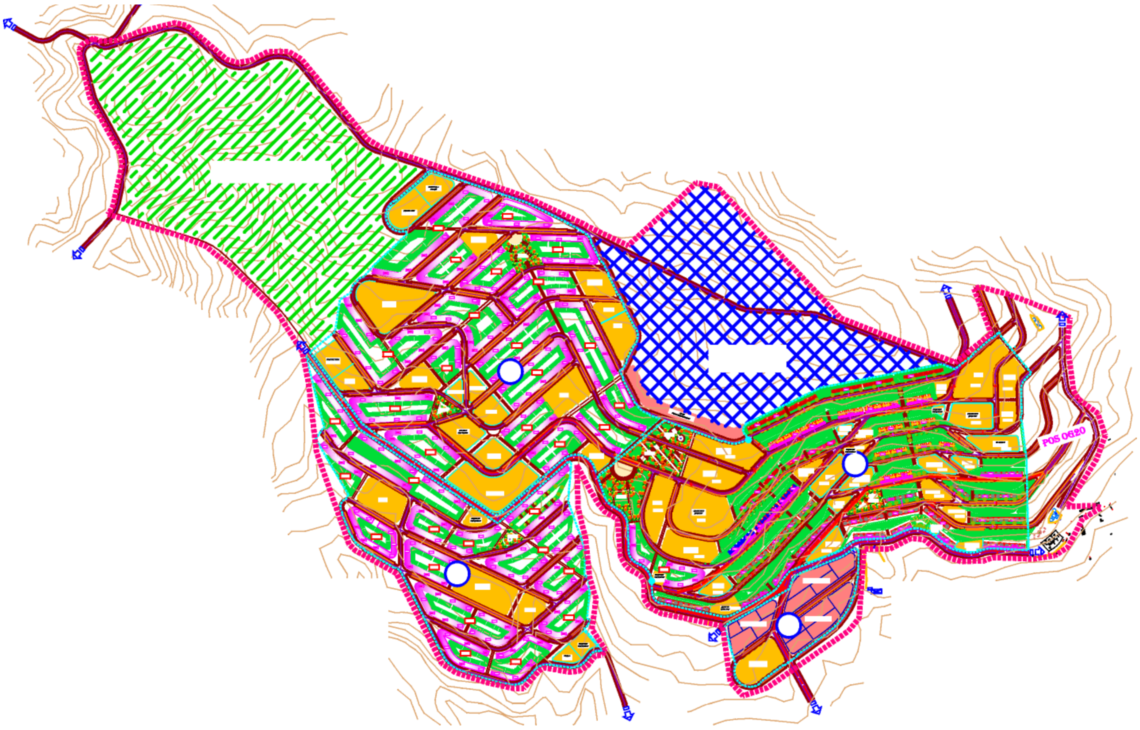


Figure 3.2: Plan of Ighzer Ouzarif city

3.1 Load demand

The total power of the city is calculated based on the following estimations:

- All the apartments are considered 4 pieces apartments.
- All the apartments have the same appliances.
- Power factor is equal to 0.86

The actual operating power of one apartment is calculated using the utilization factors as shown in table 3.1.

Table 3.1: Rated power and operating power of home appliances

Appliances	Max rated power (W)	Max rated power (VA)	UK	Operating power
Kitchen				
Refrigerator	198	230.23	0.6	138.14
2 sockets	2500	2906.98	0.6	1744.19
2 fluorescent lamps	36	36	1	36
Washing machine	2100	2441,86	0.75	1831,4
Living room				
Air-C	1910	2220,93	0.7	1554,651163
TV	75	75	1	75
4 lamps	100	100	1	100
3 sockets	26	26	1	26
Bathroom & toilet				
2 lamps	150	150	1	150
x2 children room				
TV	50	50	1	50
lamp	25	25	1	25
2 sockets	70	70	1	70
Parents room				
Air-c	1425	1656,97	0.7	1159,88
TV	50	50	1	50
lamp	25	25	1	25
2 sockets	70	70	1	70

The real demand is calculated by applying the coincidence factors of table 2.1 to each group of appliances connected to the same circuit breaker as shown in the figure 3.3.

At the main circuit breaker, the value of the simultaneity factor is calculated using the formula (2.1).

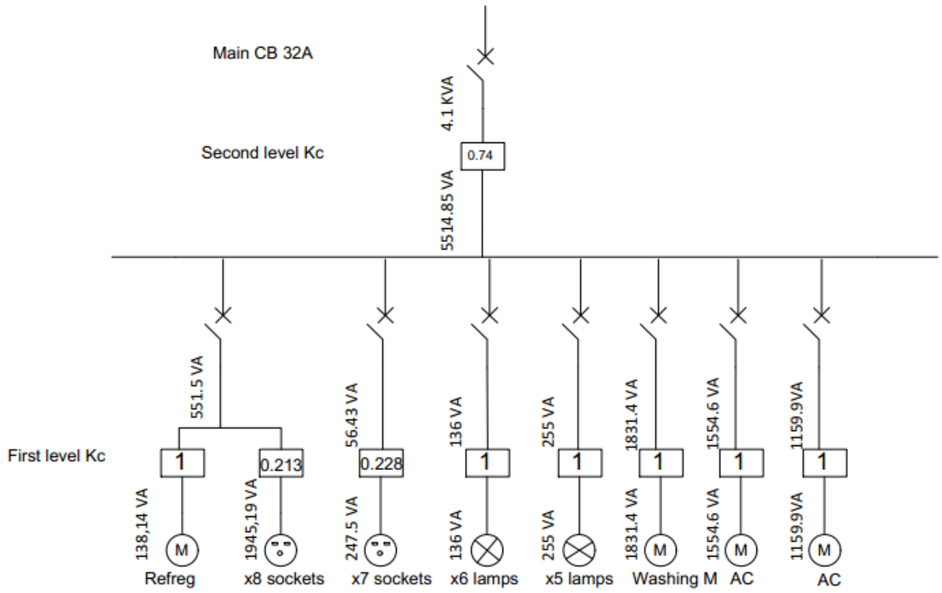


Figure 3.3: Application of coincidence factors for each group of loads

$$Ks = \frac{7630.72}{10278.98} = 0.74$$

After calculating, the power demand of one apartment is found equal to 4.1 kVA. For the commercial premises, the demand is estimated to be 6 kVA.

The total demand of a street is the summation of the apartments demand, the commercial premises demand and the street lighting demand.

$$P_s = (P_a.N + P_c.8.M)0.4 + P_L \tag{3.1}$$

Where

P_a: demand of one apartment

P_c: demand of one commercial premises

N: number of apartments per street

M: number of buildings per street

P_L: lighting demand

8: number of commercial premises by building

0.4: corresponding coincidence factor

In any project, a future planning (extension) needs to be carried out during the design of the system due to the fact of the inflation. According to Sonelgaz, by 2027 there will be around 4.2 millions additional electricity customers [12] which represent a growth rate of 45%. This factor is used to calculate the final demand:

- Final demand = total demand*1.45

The results of the calculations for each region are represented in the next tables:

Table 3.2: Apartments demand for region A

Street n°	Number of buildings / Street	Number of Apartments / Street	Power demand/ Street (kVA)	Lighting+ other Loads	Power of Lighting and other Loads	Final demand (kVA)
1	9	220	533.6	14 poles+ 2p.schools	16.7	790.42
2	2	80	169.6	8 poles	0.4	246.32
3	5	120	292.8	10 poles	0.5	425.06
4	5	200	424	20 poles	1	615.8
5	6	168	390.72	16 Poles+ 2 p.schools	16.8	583.344
6	3	80	188.8	16 Poles	0.8	274.56
7	3	80	188.8	8 Poles	0.4	274.16
8	2	80	169.8	8 Poles	0.4	246.32
9	2	80	169.8	8 Poles	0.4	246.32
10	2	80	169.8	8 Poles	0.4	246.32
11	2	80	169.6	8 Poles	0.4	246.32
12	4	160	339.2	15 Poles+ 2P.schools	16.75	508.59
13	2	80	169.6	10 Poles+ Supermarket	10.5	256.42
14	2	56	130.24	10 Poles	0.5	189.348
15	2	56	130.24	5 Poles+ P.school	8.25	197.098
16	2	56	130.24	12 Poles+ P.school	8.6	197.448
17	4	112	260.48	20 Poles+ Market	31	408.696
18	3	84	195.36	5 Poles	0.25	283.522
19	3	120	254.4	10 Poles	0.5	369.38
20	2	80	169.6	8 Poles	0.4	246.32
21	2	80	169.6	8 Poles+ Creche	6.4	252.32
22	3	120	254.4	10 Poles	0.5	369.38
23	2	80	169.6	8 Poles	0.4	246.32
24	2	56	130.24	15 Poles	0.75	189.598
25	2	56	130.24	5 Poles	0.25	189.098
26	3	120	254.4	10 Poles	0.5	369.38

Table 3.3: Installed power for the structures of region A

Structure	power demand (kVA)	Installed Power(kVA)
Mosque	200	250
Mall	100	250
Hotel	300	400
4 Reserved Land	400	1000
2 Middle Schools	60	500
1 Secondary Schools	30	250
Complex	40	250
Polyclinic	50	250
Maternity	100	250
Youth house	40	250
Central	45	250
Library	50	250
Administration	60	250

Total demand of region A = 9.935 MVA

Table 3.4: Apartments demand for region B

Street n°	Number of buildings / Street	Number of Apartments / Street	Power demand/ Street (kVA)	Lighting+ other Loads	Power of Lighting and other Loads	Final demand (kVA)
1	9	300	664.8	16 Poles	0.8	964.76
2	7	200	462.4	8 Poles +2p.schools	16.4	686.88
3	9	250	582.8	13 Poles	0.65	845.71
4	6	190	426.8	11 Poles	0.55	619.41
5	6	190	426.8	11 Poles	0.55	619.41
6	12	280	689.6	25 Poles	1.25	1001.17
7	14	380	892	30 Poles	1.5	1294.9
8	4	100	240.8	10 Poles	0.5	384.66
9	7	250	544.4	16 Poles+ 2p.schools	16.8	806.18
10	10	250	602	20 Poles+ Creche	7	879.9
11	10	250	602	20 Poles+ 2p.schools	17	889.9
12	9	300	664.8	20 Poles	1	964.96
13	8	270	596.4	20 Poles	1	865.78
14	6	190	426.8	12 Poles	0.6	619.46
15	6	160	377.6	12 Poles+ Supermarket	100.6	648.12
16	3	90	205.2	8 Poles	0.4	297.94
17	5	120	292.8	10 Poles	0.5	425.06
18	7	220	495.2	15 Poles	0.75	718.79

Table 3.5: Installed power for the structures of region B

Structure	Power demand(kVA)	Installed Power(kVA)
Mosque	200	250
Mall	100	250
Middle School	30	250
Secondary School	30	250
Civil Protection	40	250
Sportive Complex	40	250
Touristic Comp	10	250
Central security	45	250
Algeria post	30	250
Cultural Center	20	250
Library	50	250
Media	20	250
Reserved Land	100	250

Total demand of region B = 14.278 MVA

Table 3.6: Apartments demand for region C

Street n°	Number of buildings / Street	Number of Apartments / Street	Power demand/ Street (kVA)	Lighting+ other Loads	Power of Lighting and other Loads	Final demand (kVA)
1	5	140	325.6	8 poles	0.4	472.52
2	10	280	651.2	20 poles	1	945.24
3	3	80	188.8	8 poles	0.4	274.16
4	8	220	514.4	15 poles	0.75	746.63
5	4	160	339.2	12 poles	0.6	492.44
6	5	120	292.8	10 poles	0.5	425.06
7	7	200	462.4	15 poles	0.75	671.23
8	7	220	495.2	15 poles	0.75	718.79
9	13	280	708.8	20 poles	1	1028.76
10	7	160	396.8	12 poles	0.6	575.96
11	14	340	826.4	30 poles+ 2p.schools	17,5	1215.78
12	7	180	429.6	15 poles	0.75	623.67
13	7	160	396.8	15 poles	0.75	576.11
14	6	180	410.4	12 poles	0.6	595.68

Table 3.7: Installed power for the structures region C

Structure	Power demand (kVA)	Installed Power(kVA)
Mosque	200	250
Reserved Land	100	250
Secondary School	30	250
Middle School	30	250
Youth house	40	250

Total demand of region C = 9.762 MVA.

So the total power demand for the system = 9.935 + 14.278 + 9.762 = 33.78 MVA

Note:

For public and private structures, Sonelgaz imposes for each one to use its own transformer (client transformer) regardless to its demand except the primary schools and supermarkets which are allowed to be fed from the public distribution transformers. The difference between client transformer and public transformer will be mentioned in the next section.

3.2 Distribution transformers ratings and optimization

In distribution systems, the ratings of the transformers used by Sonelgaz are:
400 kVA-250 kVA, 10/0.4 kV for urban.
400 kVA-250 kVA, 30/0.4 kV for rural.
Important: for this particular project, Sonelgaz wants to use 30 kV system instead of 10 kV.
Figure 3.4 represents the electrical schemes of client and public distribution transformers.

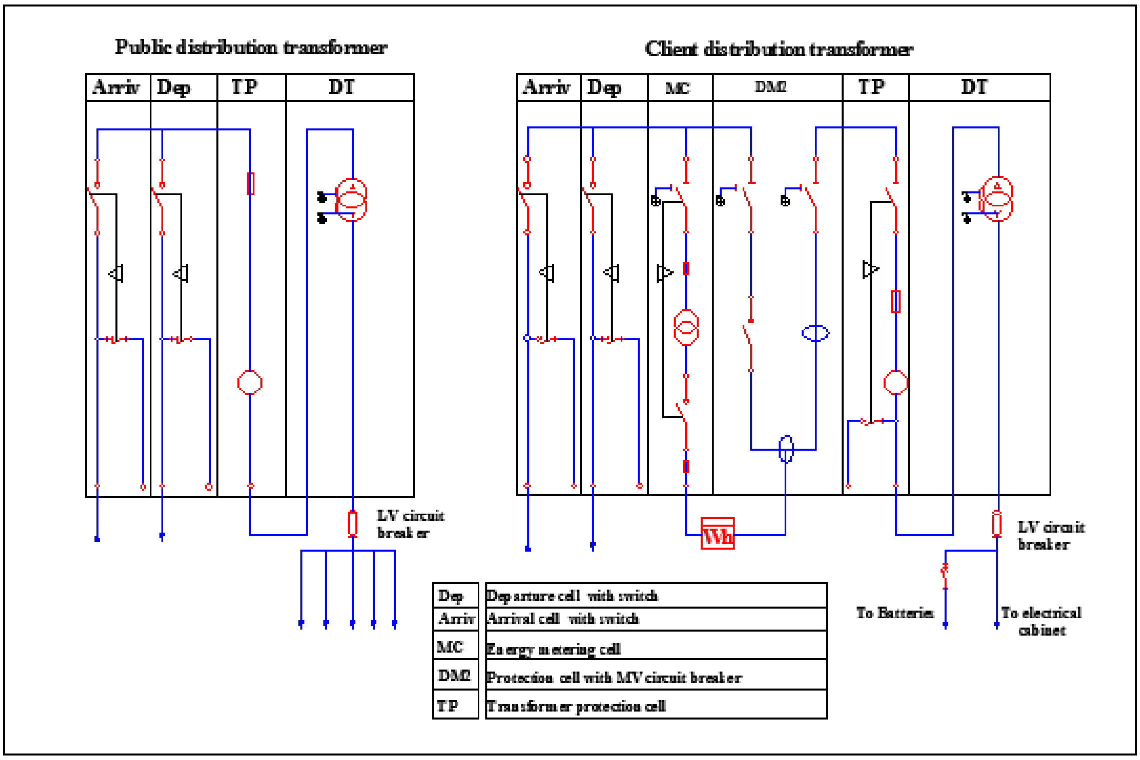


Figure 3.4: Schematic diagram of client and public D.transformers

From the schematic diagram it can be seen that:

- Public D.transformer is equiped with three (3) switchgear cells (arrival, departure, and transformer protection) while client D.transformer is equipped with five (5) switchgear cells (departure, arrival, transformer protection, energy metering, and MV Circuit breaker).

- The transformer protection switchgear of public D.transformer contains only a fuse, whereas the one of client D.transformer contains a fuse plus a disconnector.
- The energy meters of public consumers are installed in the low voltage side (entry of each building).

Now to find the optimal number of D.transformers for each street, the mathematical model constructed in the previous chapter will be applied

$$\begin{cases} Min(F) = \sum_{i=1}^{n} Ci.Ni \\ \quad subject\ to \\ \sum_{i=1}^{n} Ni.Ti >= L \\ \quad Ni <= \frac{L}{Ti} \qquad\qquad i = 1, 2, , n \end{cases} \tag{3.2}$$

Let N1 and N2 be the number of 400 kVA and 250 kVA D.transformers respectively. The cost of each transformer and its installation is C1= 3094 kDA for 400 kVA, and C2= 2746 kDA for 250 KVA (according to Sonelgaz specialists)

Example:

Let's model the problem of 220 apartments of region A:

$$\begin{cases} Min(F) = 3094.N1 + 2746.N2 \\ \quad Subject\ to \\ 320.N1 + 200.N2 >= 790.42 \\ \quad N1 <= \frac{790.42}{320} \\ \quad N2 <= \frac{790.42}{200} \end{cases} \tag{3.3}$$

320 kVA and 200 kVA represent 80% of 400 kVA and 250 kVA respectively. This problem is implemented and solved in MATLAB using the mixed-integer linear Programming function "intlinprog" as shown in appendix A

The solutions are displayed in the following tables:

- **Region A**:

Table 3.8: Number of distribution transformers for region A

Street and structure n°	Apartments and Structure	400 kVA	250 kVA
1	220	2	1
2	80	1	0
3	120	1	1
4	200	2	0
5	168	2	0
6	80	1	0
7	80	1	0
8	80	1	0
9	80	1	0
10	80	1	0
11	80	1	0
12	160	1	1
13	80	1	0
14	56	0	1
15	56	0	1
16	56	0	1
17	112	1	1
18	84	1	0
19	120	0	2
20	80	1	0
21	80	1	0
22	120	0	2
23	80	1	0
24	56	0	1
25	56	0	1
26	120	0	2
27	Mosque	0	1
28	Mall	0	1
29	Hotel	1	0
30	4 Reserved Land	0	4
31	2 Middle Schools	0	2
32	1 Secondary Schools	0	1
33	Complex	0	1
34	Polyclinic	0	1
35	Maternity	0	1
36	Youth house	0	1
37	Central	0	1
38	Library	0	1
39	Administration	0	1

The total number of 400 kVA D.transformers = 22

The total number of 250 kVA D. transformers = 31

- **Region B**:

Table 3.9: Number of distribution transformers for region B

Street and structure n°	Apartments and Structure	400 kVA	250 kVA
1	300	2	2
2	200	1	2
3	250	3	0
4	190	2	0
5	190	2	0
6	280	2	2
7	380	3	2
8	100	0	2
9	250	2	1
10	250	3	0
11	250	3	0
12	300	2	2
13	270	3	0
14	190	2	0
15	160	1	2
16	90	1	0
17	120	1	1
18	220	1	2
19	Mosque	0	1
20	Mall	0	1
21	Middle School	0	1
22	Secondary School	0	1
23	Civil Protection	0	1
24	Sportive Complex	0	1
25	Touristic Comp	0	1
27	Central security	0	1
28	Algeria post	0	1
29	Cultural Center	0	1
30	Library	0	1
31	Media	0	1
32	Reserved Land	0	1

The total number of 400 kVA D.transformers = 34

The total number of 250 kVA D.transformers = 31

- **Region C**:

Table 3.10: Number of distribution transformers for region C

Street and structure n°	Apartments and Structure	400 kVA	250 kVA
1	140	1	1
2	280	3	0
3	80	1	0
4	220	2	1
5	160	1	1
6	120	1	1
7	200	1	2
8	220	1	2
9	280	2	2
10	160	2	0
11	340	4	0
12	180	2	0
13	160	2	0
14	180	2	0
15	Mosque	0	1
16	Reserved Land	0	1
17	Secondary School	0	1
18	Middle School	0	1
19	Youth house	0	1

The total number of 400 kVA distribution transformers = 25

The total number of 250 kVA distribution transformers = 15

3.3 Network optimization

After optimizing the number, i.e. the cost of the D.transformers, the next step is to minimize the electrical losses (voltage drop in the LV system) and provide a quality of supply by well dividing the D.transformers of each street between its buildings based on the demand of the buildings and the transformers ratings (400 kVA or 250 kVA) and centring them to achieve the system balance as shown in figure 3.5 (street 280).

The red and blue squares represent 400 kVA and 250 kVA D.transformers respectively. The same work has been done for all the streets of the city and then drawn on the software AutoCAD with the real dimensions of the city (figure 3.6) in order to design the distribution network and get its exact length.

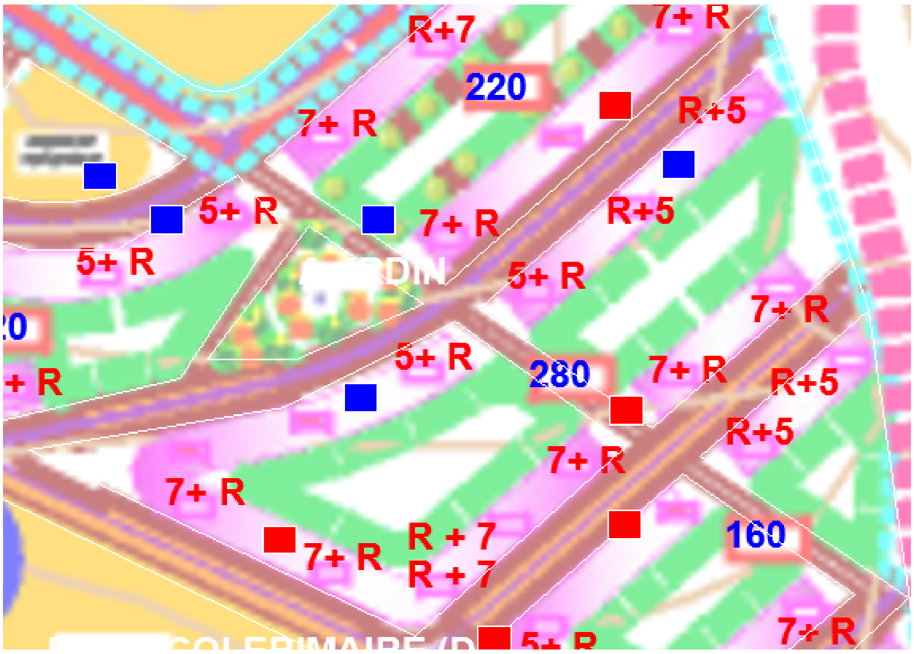


Figure 3.5: The locations of the distribution transformers

Once the transformers are placed, the network must be constructed by connecting the MV cables to the transformers as explained in the previous chapter. In this step, the cost of the cables can be also minimized if the shortest path that covers all the D.transformers is found. Fortunately, there are many algorithms that can solve this kind of problems such as Kruskal's algorithm, Floyd–Warshall algorithm, Johnson's algorithm, Prim's algorithm....etc. For this project Prim's algorithm is going to be used because it's faster than the other algorithms when there is a large number of edges (cables).

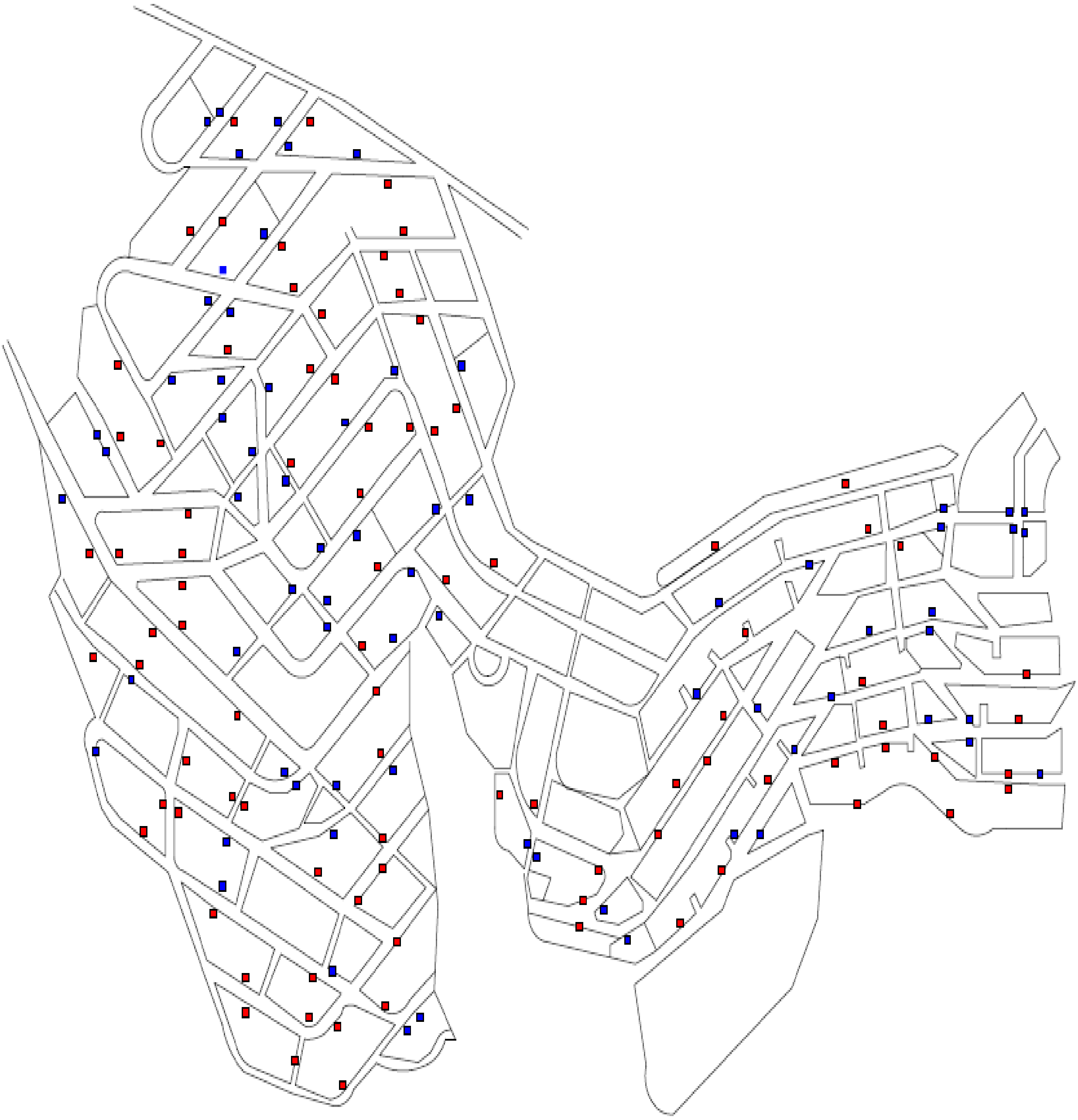


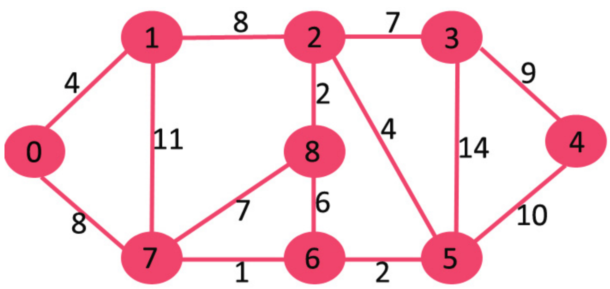
Figure 3.6: The locations of the D.transformers in the city

3.3.1 Prim's algorithm for minimum spanning tree

Given a connected and undirected graph, a minimum spanning tree (MST) of that graph is a subgraph of edges (links) that connects all the vertices (nodes) together without any cycles and with the minimum possible total edge weight (length).

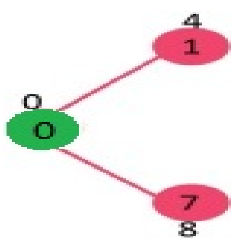
Prim's algorithm is a greedy algorithm that finds the minimum spanning tree of a graph by building this tree one vertex at a time, from an arbitrary starting vertex, at each step adding the cheapest possible connection from the tree to another vertex.

Example:

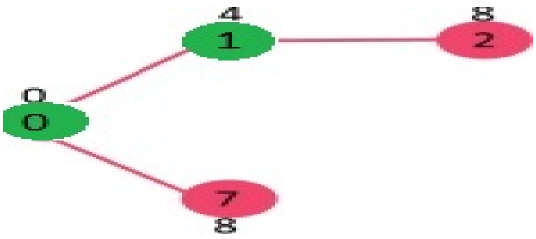


The set MST is initially empty and distances assigned to vertices are {0, inf, inf, inf, inf, inf, inf, inf }.

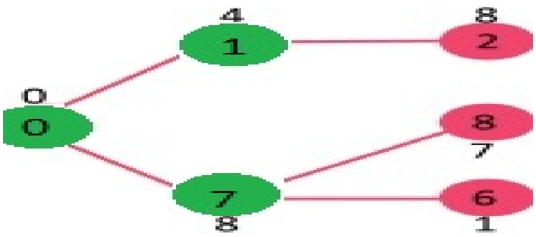
Step 1: Pick the vertex with minimum distance value (vertex 0), and include it in MST. So MST becomes 0. After that, update distance values of its adjacent vertices (vertices 1 and 7). Their distance values are updated as 4 and 8 respectively. The vertices included in MST are shown in green color.



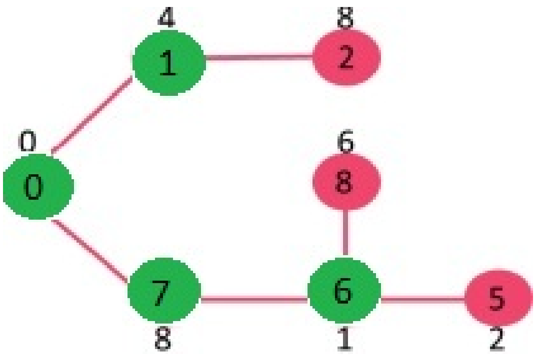
Step 2: Pick the vertex with the minimum distance and not already included in MST (vertex 1) and add it to MST, so MST now becomes {0, 1}. Update the distances of the adjacent vertices of 1. The distance of vertex 2 becomes 8.



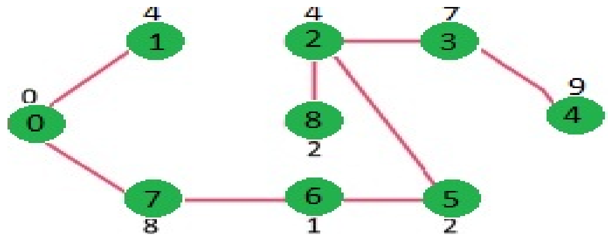
Step 3: Pick the vertex with the minimum distance value. Vertex 7 and vertex 2 can be picked, let's pick vertex 7, so MST now becomes {0, 1, 7}. Update the distance values of adjacent vertices of 7. The distances values of vertex 6 and 8 which are 1 and 7 respectively.



Step 4: Pick the vertex with the minimum distance value. Vertex 6 is picked and the MST now becomes {0, 1, 7, 6}. Update the distance values of adjacent vertices of 6. The distance value of vertex 5 and 8 are updated.



Repeat the above steps until the MST includes all vertices of the graph. Finally, you get the following graph.



In this project, the vertices represent the transformers and the edges represent the electric cables. The initial graph is drawn on AutoCAD as shown in figure 3.7 to get the real distances between the transformers. Each transformer can be connected to more than one transformer in order to increase the probability of finding the best MST of the graph.

Figure 3.7: The Initial graph of the system

For the clearance of the figure, the plan is removed and only the graph is left.

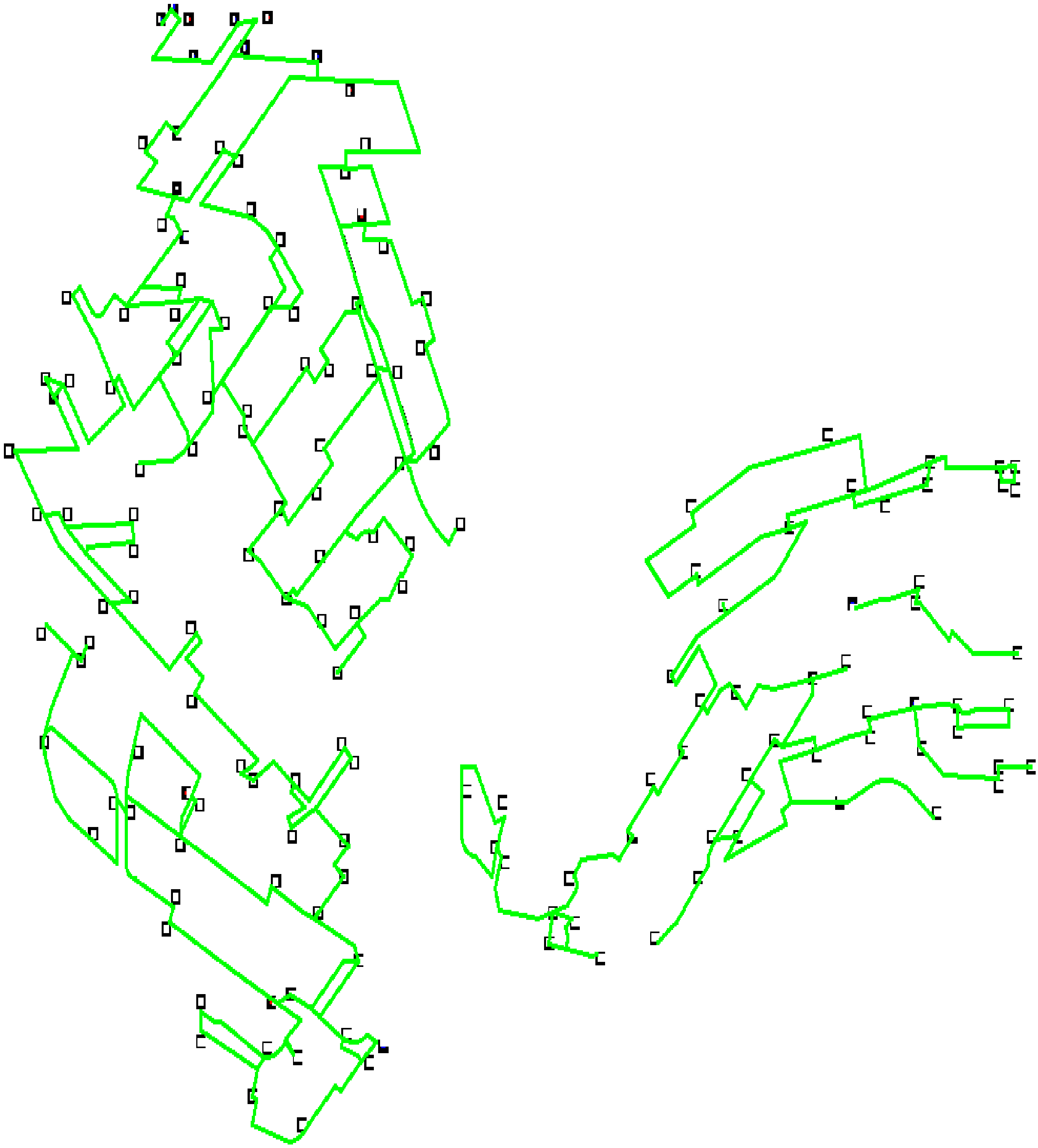


Figure 3.8: The initial graph

The data of the graph are implemented on MATLAB and the MST is obtained using the function "minspantree" of appendix A. The result is shown in figure 3.9

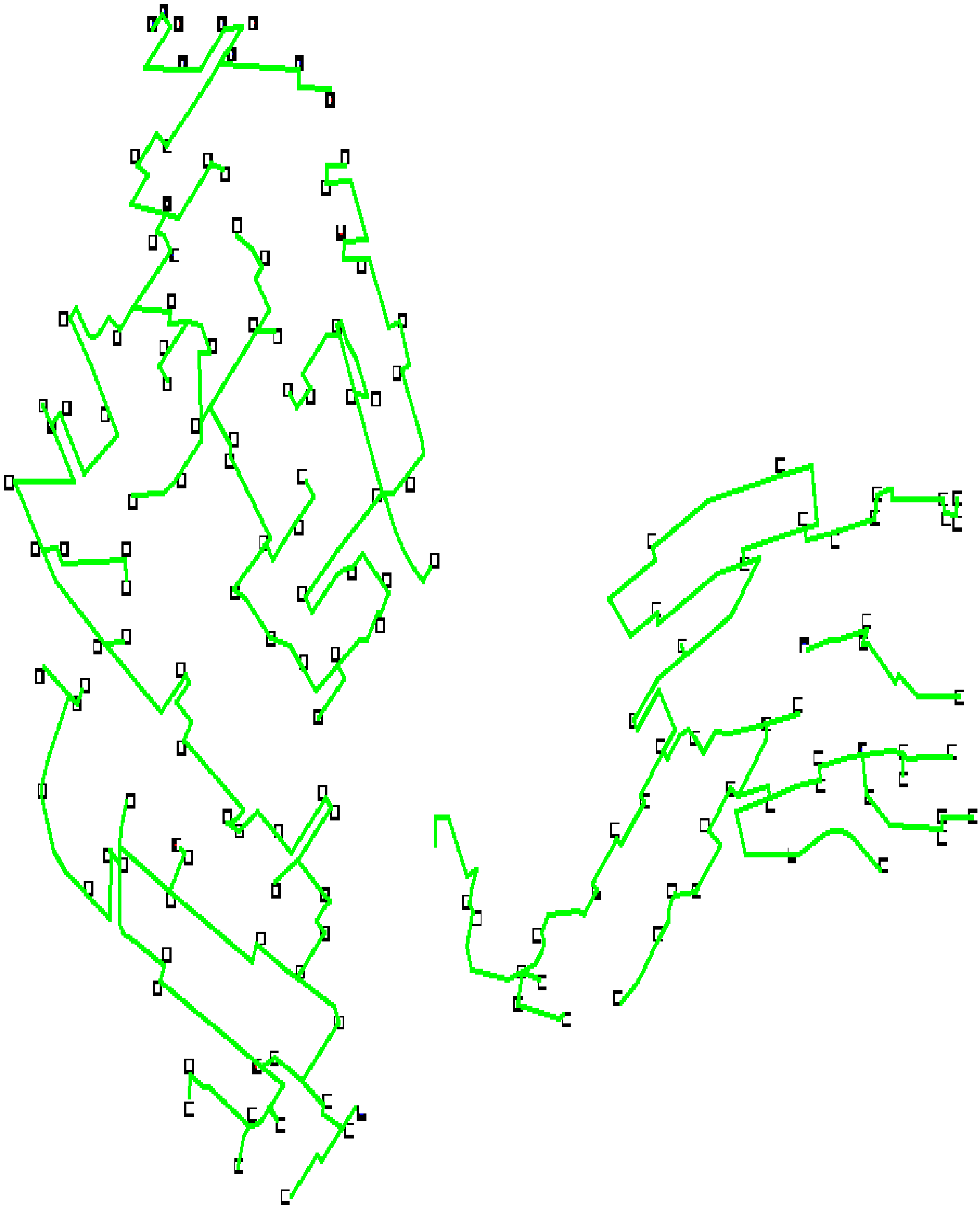


Figure 3.9: The MST of the graph

The MST is obtained after eliminating thirty (30) edges which means that a total length of 1683 m has been minimized.

After finding the MST of the system, the following step is to construct the loops (main-rings) based on the admissible cross-sections of the cables, i.e. Sonelgaz uses 120 mm^2, 150 mm^2, 185 mm^2 and 240 mm^2 cables only. Any cross-section greater than these values is not acceptable. For this, the designer has to take this condition into consideration and finding the minimum number of rings to minimize the cost of the departures switchgears.

Remark:

The MST should be respected as much as possible. However, it can be modified (adding or removing some edges) when it is necessary.

Figure 3.11 shows the designed ring-main distribution system which consists of six (6) departures, each two (2) departures form a ring. The green points indicate the ends of each ring where the transformers are directly connected to the distribution substation.

To feed this distribution system, a 2x40 MVA, 60/30 kV distribution substation has been proposed (figure 3.10). This distribution substation is powered by two (2) 60 kV incomers from the 220/60 kV substation of EL Kseur (10 km away from Oued Ghir).

Remark:

Another solution for the D.substation can be proposed which is 2x 20 MVA, 60/30 kV substation. This system is less costly than the first one, but it is less reliable. For the first solution, in case of failure of one transformer (40 MVA), the second one ensures the continuity of the service for the entire network. However, for the second solution if there is a failure of one transformer (20 MVA), the second one can not power all the network. In this case load shedding should be performed by shedding temporary the non-critical departures to control the flow of power.

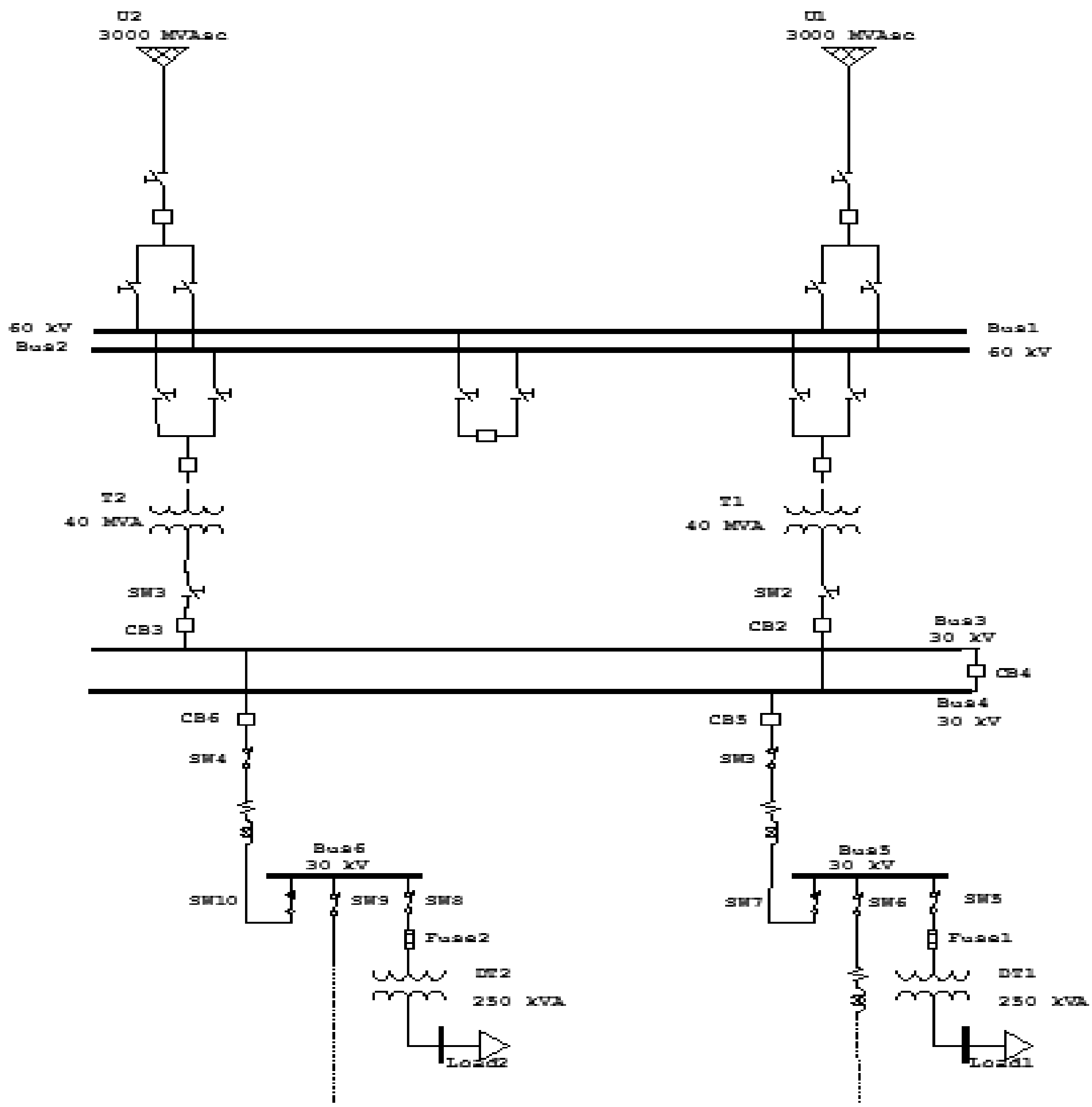


Figure 3.10: One-line diagram of the D.substation

The distribution substation is positioned in the southern-east of the city to get the shortest overhead distance from El-Kseur substation.

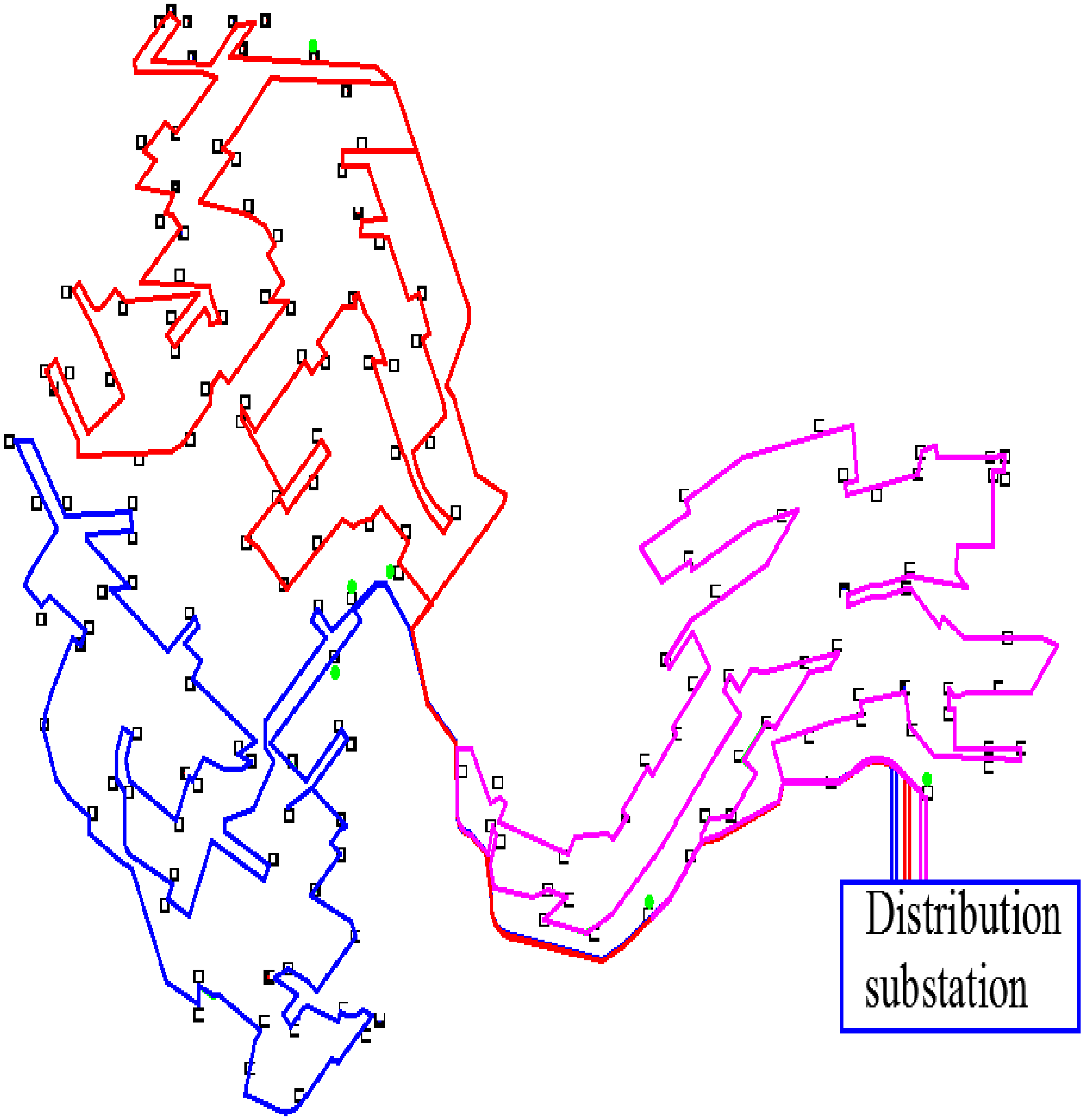


Figure 3.11: The constructed main rings

3.4 Cables sizing

The cross-sections of the cables for each loop are calculated as explained in section 2.4 and the short circuit currents are calculated using the MVA method of section 2.5. The cables are selected from ELSEWEDY CABLES catalogue[3] with the following specifications:

Voltage level: 30kV, V_{Max}= 36 kV

Conductor: Aluminum

Isolation: XLPE

Exterior sheath: PVC

The values of the correction factors of the following parameters are selected from ELSEWEDY catalogue and the international standards IEC 60364-5-52 [9]

a- soil temperature= 35 °C ==> K_1= 1

b- Cables depth= 1m ==> K_2= 1

c- Soil thermal resistivitiy= 2.5 K·m/W ==> K_3= 0.93

When the soil type and geographical location are not specified, the value 2.5 K.m/W is considered necessary as a precaution for worldwide use. [9]

For long-term planning of the cables, all the D.transformers are considered working at 80% of full-load.

When calculating the voltage drop, the most unfavorable (worst) scenario is considered, i.e. the D.transformers are working at 80% of full-load and there is a failure between the D.substation busbar and the nearest D.transformer connected to it. So, the CB will be opened and the ring will be fed from one departure as explained in the previous chapter. In this case, the departure has the maximum length and the voltage drop is evaluated at the furthest point from the substation busbar.

The same thing has been done for I_{sc}. It's calculated uder the worst scenario, i.e. when there is a symmetrical fault at the nearest busbar to the D.substation bus. The results of calculations are shown in table 3.11 and the steps are in appendices C and E.

Table 3.11: Results of cross-sections verification

Loop	Total power (MVA)	Length (Km)	Current (A)	Section (mm^2)	I_{cc} (kA)	$\Delta v\%$
Purple	13.24	3.5	254.8	150	7.42	0.825
Red	15.32	3.23	294.8	185	7.02	1.024
Blue	12.88	3.4	247.8	150	6.9	0.79

Analysis of the results:

1. **Voltage Drop**:

   From the table above, it can be seen that all the values of voltage drop are under the limit (3%). The maximum calculated value is 1.02% in the red ring, which means that the system is operating in safe region.

2. **Short circuit**:

   The calculated short circuit currents are also less than the limits specified by the manufacturer (see [3]).

Therefore, the selected cables satisfy all the criteria and can be used safely.

3.5 Protection devices selection

3.5.1 Circuit breakers

The ratings of the CBs are calculated based on the maximum fault current that can occur in each bus. I_{rated} of CB7, CB8 and CB12 are calculated assuming that only one 40 MVA transformer is in service and it is working at 80% of full-load (the other 40 MVA transformer is assumed out of service)

Table 3.12: Calculation of circuit breakers ratings

Rings	CB	I rated (A)	Rated symetrical breking current(kA)	AC component of I_{sc} (kA)*	Making capacity (kA)
Red	CB1	294.8	7.02	9.92	17.9
	CB2	294.8	6.93	9.8	17.67
Blue	CB3	247.7	6.9	9.75	17.6
	CB4	247.8	6.86	9.7	17.57
Purple	CB5	254.8	7.4	10.46	18.87
	CB6	254.8	7.1	10.1	18.8
Bus main 1	CB8	616.57	7.28	10.29	18.56
Bus main 2	CB7	616.57	7.27	10.29	18.53
MV Buses coupling	CB12	616.57	7.27	10.28	18.53

* Used in ETAP to select the breaking current of the circuit breaker.

3.5.2 Fuses

The current ratings of the fuses depend on the load where the fuse is installed. Considering the case where the D.transformers are loaded at 80% of full-load, the current ratings of the fuse are 6.16 A if it is used to protect a 400 kVA D.transformer and 3.85 A if it is used to protect a 250 kVA D.transformer. The breaking capacity of each fuse depends also on the fault current flowing on the primary side of the D.transformer when there is a short circuit on the busbar of the secondary side.

4 Simulation and discussion

To verify the voltage drop and short circuit calculations, load flow analysis and short circuit analysis should be performed using a simulation software. For this purpose, ETAP 16.0.0 will be used.

4.1 Software ETAP

ETAP is the most comprehensive analysis tool for the design and testing of power systems. Using its standard offline simulation modules, ETAP can utilize real-time operating data for advanced monitoring, real-time simulation, optimization, energy management systems, and high-speed intelligent load shedding. [7]

4.2 Single-line diagram

The one-line diagram of the designed MV distribution system is drawn on ETAP as shown in appendix B.

4.3 Input data

1. **Power grid**: MVA_{sc}= 3000 V_{rated}= 60 kV X/R=1.229 [6]
2. **Substation transformer**: 40 MVA 60/30 kV Δ/Y %Z=9
3. **D.transformers**: 400 & 250 kVA 30/0.4 kV Δ/Y %Z= 4 [2]
4. **Tap changers**: ±5% to compensate the variation of the voltage.
5. **Cables**: material: AL insulation: XLPE 50 Hz U/G buried
6. **Fuses**: V_r= 36 kV size= 6.3 A or 6 A breaking in kA
7. **Circuit breaker**: V_r= 36 kV

Table 4.1: The selected circuit breakers

Element	CB	I_{rated}(A)	Breaking (kA)	Making capacity (kA)
Bus main1	CB8	630	12.5	20
Bus main2	CB7	630	12.5	20
Buses coupling	CB12	630	12.5	20
Bus1	CB1	400	10	20
Bus A1	CB2	400	10	20
Bus2	CB3	400	10	20
Bus A2	CB4	400	10	20
Bus3	CB5	400	12.5	20
Bus A3	CB6	400	12.5	20

The lengths of the cables and the powers of the loads are also entered.

4.4 Load flow analysis

In this section, the normal scenario and the worst scenario of operation will be simulated to see the results.

4.4.1 Worst scenario

Load flow analysis is ran under the worst case (failure between the substation busbar and the nearest bus of each ring to the substation and the D.transformers are loaded at 80% of full-load). For this CB1, CB3 and CB6 are opened and the the departure/arrival switches that connect between each two departures are closed (SW297 at T16 for the red ring, SW355 at T74 for the blue ring, SW166 at T112 for the purple ring). After running the simulation the tap changers on the secondary sides of the substation transformers T1 and T2 are regulated as 2.15% and 3.76% respectively to compensate the voltage variation at the main busbars.
The results are obtained from ETAP report as shown in figure 4.1

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
*Bus HV1	60.000	100.000	0.0	13.602	9.076	0	0	Bus Main 1	13.602	9.076	157.3	83.2	
*Bus HV2	60.000	100.000	0.0	22.767	15.872	0	0	Bus Main 2	22.767	15.872	267.1	82.0	
Bus Main 1	30.000	99.998	-1.7	0	0	0	0	Bus295	13.580	8.474	308.1	84.8	
								Bus HV1	-13.580	-8.474	308.1	84.8	2.150
Bus Main 2	30.000	99.997	-3.0	0	0	0	0	Bus165	11.537	7.185	261.6	84.9	
								Bus427	11.167	6.955	253.2	84.9	
								Bus HV2	-22.704	-14.140	514.8	84.9	3.760
Bus1	30.000	98.857	-1.8	0	0	0	0	Bus351	-0.176	-0.110	4.0	84.8	
								Bus67 (LV)	0.176	0.110	4.0	84.8	
Bus2	30.000	99.155	-2.9	0	0	0	0	Bus400	-0.175	-0.109	4.0	84.8	
								Bus68 (LV)	0.175	0.109	4.0	84.8	
Bus3	30.000	99.124	-2.9	0	0	0	0	Bus216	-0.279	-0.174	6.4	84.9	
								Bus150 (LV)	0.279	0.174	6.4	84.9	

Figure 4.1: Load flow analysis report

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

Bus 1: the furthest bus from the substation in the red ring.

Bus 2: the furthest bus from the substation in the blue ring

Bus 3: the furthest bus from the substation in the purple ring.

Table 4.2: Comparison of the results

$\Delta v\%$	Calculation	Simulation	Error (%)
Bus1	1.024	1.143	11.6
Bus2	0.79	0.84	6.3
Bus3	0.825	0.876	6.1

Discussion: From the table above, it can be seen that the results are very close to each other. According to the simulation, the maximum voltage drop is 1.143% which is below the limit (5%).

4.4.2 Normal scenario

In this case, there is no fault in the system which means that all the CBs of the departures are closed and SW297, SW355 and SW166 are opened. The D.transformers are also loaded with the calculated demands. The results are evaluated at the furthest bus in each departure.

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
*Bus HV1	60.000	100.000	0.0	14.521	9.664	0	0	Bus main 1	14.521	9.664	167.8	83.2	
*Bus HV2	60.000	100.000	0.0	14.925	9.962	0	0	Bus main 2	14.925	9.962	172.7	83.2	
Bus main 1	30.000	100.008	-1.9	0	0	0	0	Bus 296	5.580	3.464	126.4	85.0	
								Bus3333	3.991	2.461	90.2	85.1	
								Bus2222	4.924	3.055	111.5	85.0	
								Bus HV1	-14.496	-8.980	328.1	85.0	2.300
Bus main 2	30.000	100.037	-1.9	0	0	0	0	Bus1111	5.283	3.275	119.6	85.0	
								Bus 303	4.568	2.828	103.4	85.0	
								Bus 202	5.047	3.135	114.3	84.9	
								Bus HV2	-14.899	-9.238	337.2	85.0	2.400
Bus11	30.000	99.804	-1.9	0	0	0	0	Bus326	-0.270	-0.168	6.1	84.9	
								Bus263	0.270	0.168	6.1	84.9	
Bus12	30.000	99.688	-1.9	0	0	0	0	Bus323	-0.269	-0.168	6.1	84.9	
								Bus264	0.269	0.168	6.1	84.9	
Bus13	30.000	99.755	-1.9	0	0	0	0	Bus380	-0.238	-0.148	5.4	85.0	
								Bus376	0.238	0.148	5.4	85.0	
Bus14	30.000	99.792	-1.9	0	0	0	0	Bus449	-0.273	-0.170	6.2	84.9	
								Bus377	0.273	0.170	6.2	84.9	
Bus15	30.000	99.892	-1.9	0	0	0	0	Bus192	-0.164	-0.102	3.7	84.9	
								Bus138	0.164	0.102	3.7	84.9	
Bus16	30.000	99.844	-1.9	0	0	0	0	Bus189	-0.143	-0.088	3.2	85.1	
								Bus139	0.143	0.088	3.2	85.1	

Figure 4.2: Load flow analysis report in the normal scenario

The calculated results are shown in appendix D.

Table 4.3: Comparison of voltage drop result in the normal scenario

Rings	Bus(Δv%)	Calculation	Simulation	Error(%)
Red	Bus11	0.21	0.2	4.7
	Bus12	0.29	0.31	6.8
Blue	Bus13	0.24	0.24	0
	Bus14	0.23	0.21	8.6
Purple	Bus15	0.1	0.11	10
	Bus16	0.18	0.16	11.1

Discussion:

As expected, the voltage drop is much smaller than the worst scenario due to the decrease in the current and the length of each departure which are directly proportional to voltage drop.

4.5 Short circuit analysis

To obtain the worst scenario, a symmetrical fault is applied to Bus1, Bus2 and Bus3 (the nearest buses to the substation for the red, blue and purple rings respectively). The results are shown in figure 4.3

Momentary Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device		Momentary Duty					Device Capability		
ID	kV	ID	Type	Symm. kA rms	X/R Ratio	M.F.	Asymm. kA rms	Asymm. kA Peak	Symm. kA rms	Asymm. kA rms	Asymm. kA Peak
Bus1	30.000	Bus1	Bus	6.925	6.1	1.310	9.073	15.656			
Bus2	30.000	Bus2	Bus	7.066	5.6	1.287	9.092	15.715			
Bus3	30.000	Bus3	Bus	7.367	8.3	1.392	10.253	17.550			

- Method: IEEE - X/R is calculated from separate R & X networks.

Figure 4.3: short circuit analysis report

Discussion:

From table 4.4 it is remarked that the calculated short circuit currents are equal to the simulation result with a small error. The maximum fault current that can occur in the system is equal to 7.367 kA in the red ring while the selected cable can withstand a value of 17.5 kA.

Table 4.4: Comparison of short circuit results

I_{sc} (kA)	Calculation	Simulation	Error(%)
Bus1	7.02	6.925	1.3
Bus2	6.9	7.066	2.4
Bus3	7.42	7.367	0.7

4.6 Conclusion

The results above confirm that the methods of calculation are correct which means that the cables have been selected correctly to ensure a safe operation of the system during the most unfavorable scenario.

General Conclusion

The objective of this project is to help Sonelgaz to dimension and design a MV distribution power system for the new city of Bejaia "Ighzer Ouzarif", commune of Oued Ghir which is still under realization.

Before starting this work, the vision of the planning has been set for a long-term to avoid the degradation in the performance of the system in the future, and the study has been done based on Sonelgaz specifications, international standards and some own approximations.

The design is started first by calculating the demand of the city. Second, the economical factor has been taken into consideration by optimizing the number of distribution transformers needed to power the city and length of the network to minimize the cost of the cables.

Third, the network has been constructed as a ring-main with six (6) departures to provide reliability in case of failure in one part of the system.

Then, the cables have been selected and evaluated against voltage drop and short circuit under the most unfavorable conditions. Based on the obtained results, the protective devices (CBs and fuses) have been also selected to protect personals and machines in a safe way.

After that, two (2) solutions have been provided for the distribution substation with the advantages and the disadvantages of each one so that the client can choose the suitable one for him.

Finally, the designed system has been simulated under different scenarios to compare them with the manual calculations. The results were very close to each other with a small error.

At the end of this project, it can be seen that the MV distribution system has been designed successfully to meet the needs of the customers under the most unfavorable case and with the minimum cost such that the entire system is powered by 158 D.transformers which cost is 462404 kDA.

To sum up, it can be said that this humble work can be enhanced in the future by designing the protective system (current transformers, potential transformers and protective relays) to increase the performances of the system.

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Appendix A

ilyes.m

```
L=input('enter the demand')
N1=ceil(L/320);% Max number of 400 KVA transformer
N2=ceil(L/200);% Max number of 250 KVA transformer
f=[3094;2746];
intcon=[1 2];% vector of positive integers
A=[-320,-200;1 0;0 1];% inequality constrains matrix
b=[-L;N1;N2];
lb=[0,0];
Aeq=[]; % equality constains matrix is empty
beq=[];
ub=[N1,N2];% upper bounds of the solution
[x,output]=intlinprog(f,intcon,A,b,Aeq,beq,lb,ub)
```

Figure A4: linear programming MATLAB code

OUEDGUIR.m

```
s=[];
t=[];
weights=[];
G = graph(s,t,weights);
p = plot(G,'EdgeLabel',G.Edges.Weight);
[T,pred] = minspantree(G,'method','sparse','type','forest');
highlight(p,T)
```

Figure A5: Minimum Spanning Tree (MST) program MATLAB code

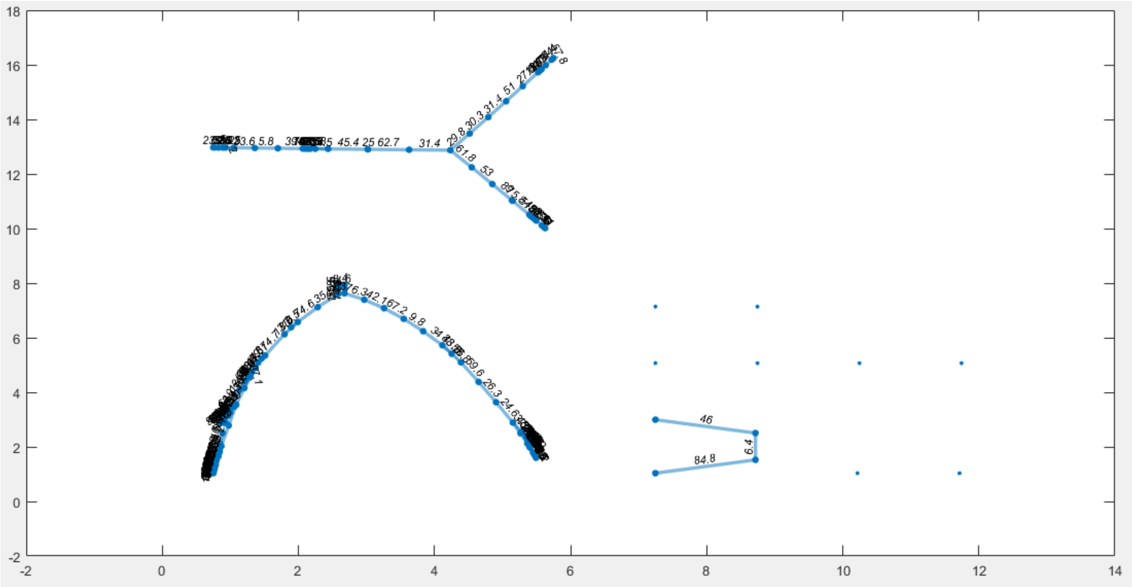

Figure A6: Graph of MST(Minimum Spanning Tree)

Appendix B

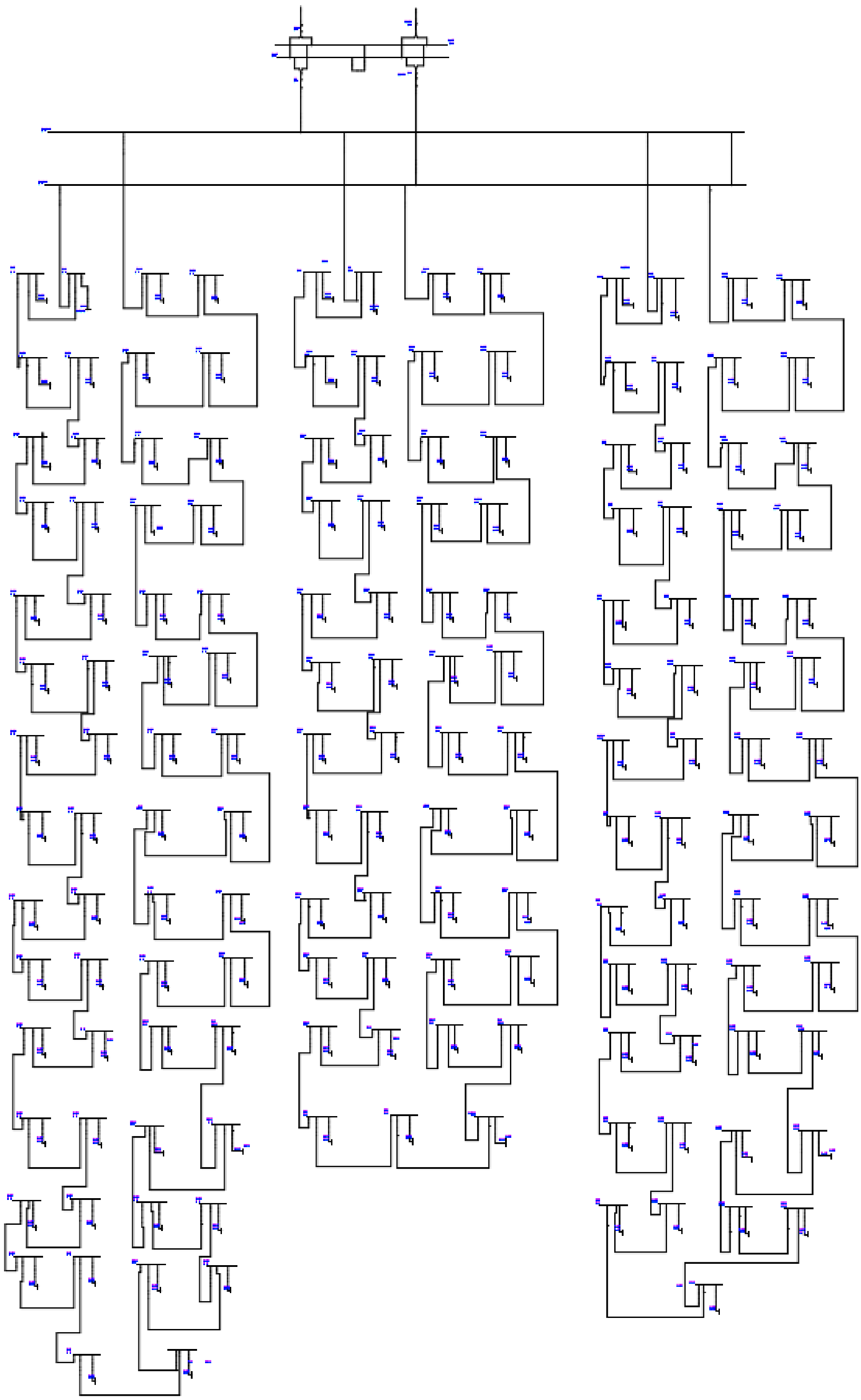

Figure B7: Scheme of distribution network Oued Ghir 30KV

Appendix C

Table C5: Voltage drop purple ring

from-to	current(A)	distance(m)	voltage drop(%)
dep-T166	255.1	266.5	0.113339
T166-T154	248.94	54.6	0.02266
T154-T153	245.09	37	0.015118
T 153-T152	241.24	30.6	0.012307
T152-T137	237.39	51.6	0.020421
T137-T138	233.54	38.5	0.01499
T138-T130	229.69	81.3	0.031132
T130-T131	225.84	39	0.014684
T131-T132	221.99	76.7	0.028386
T132-T165	218.14	186.14	0.067694
T165-T164	214.29	49	0.017505
T164-T163	208.13	64	0.022207
T163-T162	201.97	27.7	0.009327
T162-T160	195.81	78.3	0.025561
T160-T159	191.96	20	0.0064
T159-T158	188.11	78	0.024461
T158-T157	184.26	71.8	0.022056
T157-T161	178.1	81.24	0.024122
T161-T155	171.94	65	0.018632
T155-T135	165.78	45.5	0.012575
T135-T136	159.62	44.3	0.011789
T136-T133	153.46	43.8	0.011206
T133-T134	147.3	75.8	0.018614
T134-T124	143.45	67	0.016023
T124-T122	137.29	103	0.023575
T122-123	133.44	89.8	0.019977
T123-T112	129.59	103.9	0.022447
T112-T113	125.74	116.5	0.024421
T113-T114	119.58	73	0.014553

from-to	current(A)	distance(m)	voltage drop(%)
T114-T121	113.42	36	0.006807
T121-T120	109.57	50.3	0.009188
T120-T115	105.72	24	0.00423
T115-T116	101.87	69	0.011718
T116-T117	98.02	25	0.004085
T117-T118	94.17	21	0.003297
T118-T119	90.32	23	0.003463
T119-T127	86.47	140	0.020182
T127-T125	82.62	60	0.008264
T125-T126	78.77	62.4	0.008194
T126-T129	74.92	98.8	0.01234
T129-T144	68.76	103.4	0.011853
T144-T143	62.6	52.2	0.005448
T143-T147	58.75	23.6	0.002311
T147-T146	54.9	61.3	0.005611
T146-T145	51.05	37.3	0.003175
T145-149	47.2	43.1	0.003392
T149-T148	41.04	76.3	0.00522
T148-T142	34.88	30.2	0.001756
T142-T141	31.03	47.6	0.002462
T141-T140	24.87	19.8	0.000821
T140-T139	18.71	53	0.001653
T139-T151	12.55	96	0.002009
T151-T150	6.39	88.2	0.00094
		total distance	total voltage drop
		3501.08	0.824603

Table C6: Voltage drop blue ring

from-to	current(A)	distance(m)	voltage drop(%)
dep-T71	248.17	610	0.252378
T71-T83	244.32	92.9	0.03784
T83-T84	240.47	62.5	0.025056
T84-T85	234.31	20	0.007813
T85-T88	230.46	67.8	0.026049
T88-T86	226.61	63.3	0.023914
T86-T87	220.45	40.3	0.014811
T87-T90	214.29	38.6	0.01379
T90-T101	208.13	57	0.019778
T101-T100	201.97	72.3	0.024344
T100-T99	198.12	24	0.007927
T99-T105	191.96	53.6	0.017153
T105-T102	185.8	57.9	0.017935
T102-T103	179.64	39.4	0.0118
T103-T104	175.79	26.8	0.007854
T104-T109	171.94	74	0.021212
T109-T108	165.78	74	0.020452
T108-T106	159.62	33.3	0.008861
T106-T98	153.46	64.2	0.016425
T98-T107	147.3	22.5	0.005525
T107-T95	141.14	139.6	0.032848
T95-T77	134.98	76.2	0.017147
T77-T76	131.13	62	0.013554
T76-T74	127.28	21.1	0.004477
T74-T75	121.12	52.7	0.010641
T75-T57	114.96	79.5	0.015237
T57-T39	108.8	49.6	0.008997
T39-T56	104.95	61	0.010673
T56-T55	101.1	69.5	0.011714

from-to	current(A)	distance(m)	voltage drop(%)
T55-T58	94.94	22.4	0.003545
T58-T59	91.09	88	0.013364
T59-T60	84.93	28.2	0.003993
T60-T72	78.77	90.3	0.011858
T72-T73	74.92	56.1	0.007007
T73-T81	68.76	81.2	0.009308
T81-T82	64.91	23.8	0.002575
T82-T80	61.06	63.6	0.006474
T80-T79	54.9	17.5	0.001602
T79-T92	48.74	33.7	0.002738
T92-T78	44.89	73.36	0.00549
T78-T94	38.73	77.6	0.005011
T94-T93	32.57	23	0.001249
T93-T96	26.41	78.3	0.003447
T96-T97	22.56	22	0.000827
T97-T89	16.4	120.4	0.003292
T89-T69	10.24	202.1	0.00345
T69-T68	4.08	48.6	0.000331
		total distance	total voltage drop
		3355.76	0.791769

Table C7: Voltage drop for red ring

from-to	current(A)	distance(m)	voltage drop(%)
dep-T8	295.18	922	0.372834
T8-T7	289.02	81.3	0.03219
T7-T6	282.86	30.1	0.011664
T6-T5	276.7	26.8	0.010159
T5-T4	272.85	54.8	0.020483
T4-T3	269	68.5	0.025243
T3-T2	262.84	22.2	0.007994
T2-T1	258.99	23	0.00816
T1-T11	255.14	142.6	0.049842
T11-T12	248.98	43	0.014667
T12-T13	242.82	68.5	0.022786
T13-T30	238.97	24	0.007857
T30-T29	235.12	27.9	0.008987
T29-T28	231.27	81	0.025663
T28-T27	225.11	54.3	0.016745
T27-T34	221.26	62	0.018793

from-to	current(A)	distance(m)	voltage drop(%)
T34-T33	217.41	34	0.010126
T33-T32	213.56	85.16	0.024915
T32-T31	209.71	63.8	0.018329
T31-T35	203.55	63.1	0.017595
T35-T36	197.39	88.7	0.023985
T36-T37	191.23	27.2	0.007126
T37-T38	187.38	24.5	0.006289
T38-T40	183.53	95.18	0.02393
T40-T42	177.37	51.1	0.012417
T42-T43	173.52	44.4	0.010554
T43-T25	169.67	86.22	0.020041
T25-T26	163.51	27.9	0.00625
T26-T17	157.35	51.7	0.011144
T17-T16	151.19	37.9	0.00785
T16-T15	145.03	83.7	0.01663
T15-T14	138.87	23.3	0.004433
T14-T9	135.02	117.3	0.021697
T9-T21	128.86	122.4	0.021607
T21-T20	122.7	35.1	0.0059
T20-T18	116.54	80.9	0,012916
T18-T22	110.38	34.7	0.005247
T22-T23	104.22	60	0.008566
T23-T50	98.06	40.5	0.005441
T50-T51	91.9	67.2	0.00846
T51-T66	88.05	71.64	0.008641
T66-T52	81.89	71	0.007965
T52-T48	78.04	61	0.006521
T48-T49	71.88	23.1	0.002275
T49-T24	65.72	55.9	0.005033
T24-T47	61.87	60.5	0.005128
T47-T46	55.71	35.2	0.002686
T46-T44	51.86	77.2	0.005485
T44-T45	45,7	19.2	0.001202
T45-T110	41.85	96.5	0.005532
T110-T53	35.69	40.7	0.00199
T53-T54	29.53	45.3	0.001833
T54-T61	25.68	45.2	0.00159
T61-T70	21.83	90.3	0.0027
T70-T63	17.98	68.3	0.001682
T63-T64	11.82	35.7	0.000578
T64-T65	7.97	44.6	0.000487
T65-167	1.81	30.8	7.64E-05
		total distance	total voltage drop
		4150.1	1.026919

Appendix D

Table D8: Voltage drop for red ring Bus11

from-to	current(A)	distance(m)	voltage drop(%)
dep-67	116.86	590.4	0.094517
T67-T65	114.93	30.8	0.004849
T65-T64	109.19	44.6	0.006671
T64-T63	105.53	35.7	0.005161
T63-T70	100.67	68.3	0.009419
T70-T61	100.09	90.3	0.012382
T61-T54	98.16	45.2	0,006078
T54-T53	94.31	45.3	0.005853
T53-T110	88.38	40.7	0.004928
T110-T45	82.81	96.5	0.010947
T45-T44	82.42	19.2	0.002168
T44-T46	76.85	77.2	0.008128
T46-T47	73.13	35.2	0.003526
T47-T24	67.56	60.5	0.005599
T24-T49	63.84	55.9	0.004889
T49-T48	58.19	23.1	0.001841
T48-T52	52.62	61	0.004397
T52-T66	52.04	71	0.005062
T66-T51	47.13	71.64	0.004625
T51-T50	43.85	67.2	0.004037
T50-T23	38.2	40.5	0.002119
T23-T22	37.62	60	0.003092
T22-T18	32.55	34.7	0.001547
T18-T20	26.83	80.9	0.002973
T20-T21	21.11	35.1	0.001015
T21-T9	15.14	122.4	0.002539
T9-T14	9.17	117.3	0.001474
T14-T15	6.53	23.3	0.000208
		Total distance	Total voltage drop
		1730.24	0.21029

Table D9: Voltage drop for red ring Bus12

from-to	current(A)	distance(m)	voltage drop(%)
dep-T8	123.26	922	0.155687
T8-T7	117.83	81.3	0.013123
T7-T6	112.4	30.1	0.004635
T6-T5	106.97	26.8	0.003927
T5-T4	103.25	54.8	0.007751
T4-T3	99.53	68.5	0.00934
T3-T2	93.94	22.2	0.002857
T2-T1	93.55	23	0.002948
T1-T11	93.36	142.6	0.018238
T11-T12	87.44	43	0.005151
T12-T13	81.85	68.5	0.007681
T13-T30	78.19	24	0.002571
T30-T29	77.42	27.9	0.002959
T29-T28	73.76	81	0.008185
T28-T27	67.79	54.3	0.005043
T27-T34	64.13	62	0.005447
T34-T33	60.43	34	0.002815
T33-T32	56.77	85.16	0.006623
T32-T31	53.11	63.8	0.004642
T31-T35	47.24	63.1	0.004084
T35-T36	41.37	88.7	0.005027
T36-T37	35.5	27.2	0.001323
T37-T38	34.73	24.5	0.001166
T38-T40	33.86	95.18	0.004415
T40-T42	27.93	51.1	0.001955
T42-T43	26.97	44.4	0.00164
T43-T25	23.27	86.22	0.002749
T25-T26	17.7	27.9	0.000677
T26-T17	11.73	51.7	0.000831
T17-T16	6.01	37.9	0.000312
		Total distance	Total voltage drop
		2512.86	0.293799

Table D10: Voltage drop for blue ring Bus13

from-to	current(A)	distance(m)	voltage drop(%)
dep-T68	108.84	590	0.107057
T68-T69	105.18	48.6	0.008522
T69-T89	100.02	202.1	0.0337
T89-T97	93.92	120.4	0.018852
T97-T96	87.97	22	0.003226
T96-T93	84.31	78.3	0.011006
T93-T94	78.7	23	0.003018
T94-T78	73.25	77.6	0.009476
T78-T92	69.45	73.36	0.008494
T92-T79	65.79	33.7	0.003696
T79-T80	60.09	17.5	0.001753
T80-T82	55.18	63.6	0.005851
T82-T81	51.9	23.8	0.002059
T81-T73	49.97	81.2	0.006765
T73-T72	43.9	56.1	0.004106
T72-T60	40.05	90.3	0.006029
T60-T59	33.98	28.2	0.001598
T59-T58	27.83	88	0.004083
T58-T55	23.98	22.4	0.000896
T55-T56	18.05	69.5	0.002091
T56-T39	14.39	61	0.001463
T39-T57	10.75	49.6	0.000889
T57-T75	5.3	79.5	0.000702
		Total distance	Total voltage drop
		1999.76	0.245331

Table D11: Voltage drop for blue ring Bus14

from-to	current(A)	distance(m)	voltage drop(%)
dep-T71	111.6	610	0.113492
T71-T83	107.75	92.9	0.016688
T83-T84	103.9	62.5	0.010826
T84-T85	97.76	20	0.00326
T85-T88	93.96	67.8	0.010621
T88-T86	90.16	63.3	0.009515
T86-T87	84.05	40.3	0.005647
T87-T90	78.5	38.6	0.005052
T90-T101	72.95	57	0.006932
T101-T100	66.94	72.3	0.008069
T100-T99	63.09	24	0.002524
T99-T105	57.23	53.6	0.005114
T105-T102	51.68	57.9	0.004989
T102-T103	45.67	39.4	0.003
T103-T104	45.09	26.8	0.002015
T104-T109	44.32	74	0.005468
T109-T108	38.77	74	0.004783
T108-T106	33.03	33.3	0.001834
T106-T98	27.17	64.2	0.002908
T98-T107	21.31	22.5	0.000799
T107-T95	15.57	139.6	0.003624
T95-T77	10.12	76.2	0.001286
T77-T76	6.65	62	0.000687
T76-T74	6.07	21.1	0.000214
		Total distance	Total voltage drop
		1893.3	0.229344

Table D12: Voltage drop for purple ring Bus15

from-to	current(A)	distance(m)	voltage drop(%)
dep-T150	88.4	37.07	0.005463
T150-T151	83.47	88.2	0.012274
T151-T139	78.74	96	0.012602
T139-T140	74.01	53	0,006539
140-T141	69.28	19.8	0,002287
T141-T142	64.55	47.6	0.005122
T142-T148	62.62	30.2	0.003153
T148-T149	57.34	76.3	0.007294
149-T145	52.56	43.1	0.003777
T145-T146	49	37.3	0.0047
T146-T147	45.44	61.3	0.004644
T147-T143	44.48	23.6	0.00175
T143T144	41.2	52,2	0.003585
T144-T129	36.29	103.4	0.006256
T129-T126	31.43	98.8	0.005177
T126-T125	30.47	62.4	0.00317
T125-T127	26.83	60	0.002684
T127-T119	23.03	140	0.005375
T119-T118	22.26	23	0.000854
T118-T117	21.68	21	0.000759
T117-T116	19.75	25	0.000823
T116-T115	19.17	69	0.002205
T115-T120	18.4	24	0.000736
T120-T121	17.53	50.3	0.00147
T121-T114	13.87	36	0.000832
T114-T113	9.15	73	0.001114
T113-T112	3.68	116.5	0.000715
		Total distance	Total voltage drop
		1568.07	0.102992

Table D13: Voltage drop for purple ring Bus16

from-to	current(A)	distance(m)	voltage drop(%)
dep-T166	101.02	266.5	0.044883
T166-T154	96.28	54.6	0.008764
T154-T153	91.54	37	0.005647
T 153-T152	87.98	30.6	0.004488
T152-T137	86.05	51.6	0.07402
T137-T138	82.49	38.5	0.005295
T138-T130	78.64	81.3	0.010659
T130-T131	75	39	0.004876
T131-T132	73.84	76.7	0.009442
T132-T165	73.26	186.14	0.022734
T165-T164	72.49	49	0.005922
T164-T163	67.75	64	0.007229
T163-T162	65.82	27.7	0.00304
T162-T160	60.04	78.3	0.007837
T160-T159	56.38	20	0.00188
T159-T158	52.82	78	0.006869
T158-T157	49.26	71.8	0.005896
T157-T161	43.48	81.24	0.005889
T161-T155	37.7	65	0.004085
T155-T135	31.77	45.5	0.00241
T135-T136	26.47	44.3	0.001955
T136-T133	20.54	43.8	0.0015
T133-T134	14.92	75.8	0.001885
T134-T124	11.16	67	0.001247
T124-T122	5.11	103	0.000877
T122-123	3.18	89.8	0.000476
		Total distance	Total voltage drop
		1866.18	0.183186

Appendix E

Table E14: Short circuit calculation using MVA method

Ring	Utility (MVA)	Transf-ormer (MVA)	Cable (MVA)	Total MVA	Fault current (kA)
Red	3000	444.44	6344.55	364,84	7.03
Blue	3000	444.44	5243.24	360,48	6,95
Purple	3000	444.44	83397.16	385,31	7,42