VIETNAM GENERAL CONFEDERATION OF LABOUR

TON DUC THANG UNIVERSITY

ELECTRICAL – ELECTRONIC DEPARTMENT

PROJECT 1

TECHNICAL DESIGN OF 110KV ELECTRICAL NETWORK – DA1_KTD-M13

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Class : **18H40101**

Course : **22**

HO CHI MINH CITY, 2021

TRƯỜNG ĐH TÔN ĐỨC THẮNG
KHOA ĐIỆN – ĐIỆN TỬ

CỘNG HÒA XÃ HỘI CHỦ NGHĨA VIỆT NAM
Độc lập – Tự do – Hạnh phúc

NHIỆM VỤ ĐỒ ÁN 1

(Ghi chú: Bảng nhiệm vụ này đóng vào trang thứ nhất của đồ án)

HỌ VÀ TÊN : Ninh Thế Vĩnh Cường   MSSV : 418H0363
NGÀNH : Kỹ Thuật Điện   LỚP :

A. Đề tài:

- THIẾT KẾ MẠNG ĐIỆN : 110 KV - DA1_KTD-M13

B. Nhiệm vụ đề tài:

1) Cân bằng công suất trong mạng điện. Xác định dung lượng bù công suất kháng.
2) Đề ra phương án nối dây của mạng điện và chọn các phương án thoả mãn kỹ thuật.
3) So sánh kinh tế chọn phương án hợp lý.
4) Xác định số lượng công suất máy biến áp của trạm phân phối. Sơ đồ nối dây của trạm. Sơ đồ nối dây của mạng điện.
5) Xác định dung lượng bù kinh tế và giảm tổn thất điện năng.
6) Tính toán cân bằng công suất trong mạng điện. Xác định và phân phối thiết bị bù cưỡng bức.
7) Tính toán các tình trạng làm việc của mạng điện lúc phụ tải cực đại, cực tiểu và sự cố.
8) Điều chỉnh điện áp: chọn đầu phân áp của máy biến áp.
9) Các chỉ tiêu kinh tế - kỹ thuật của mạng điện thiết kế.
10) Các bản vẽ A1: sơ đồ nối dây các phương án, sơ đồ nguyên lý của mạng điện thiết kế, các chỉ tiêu kinh tế kỹ thuật.

C. Ngày giao đồ án: /01/2021
D. Ngày nộp đồ án: /04/2021
E. Ngày bảo vệ trước hội đồng: /04/2021
F. Họ và tên giảng viên hướng dẫn: TS. Đinh Hoàng Bách

TP HCM, ngày 06 tháng 01 năm 2021

Trưởng BM. Kỹ Thuật Điện

TS. Đinh Hoàng Bách

Giảng viên hướng dẫn

TS. Đinh Hoàng Bách

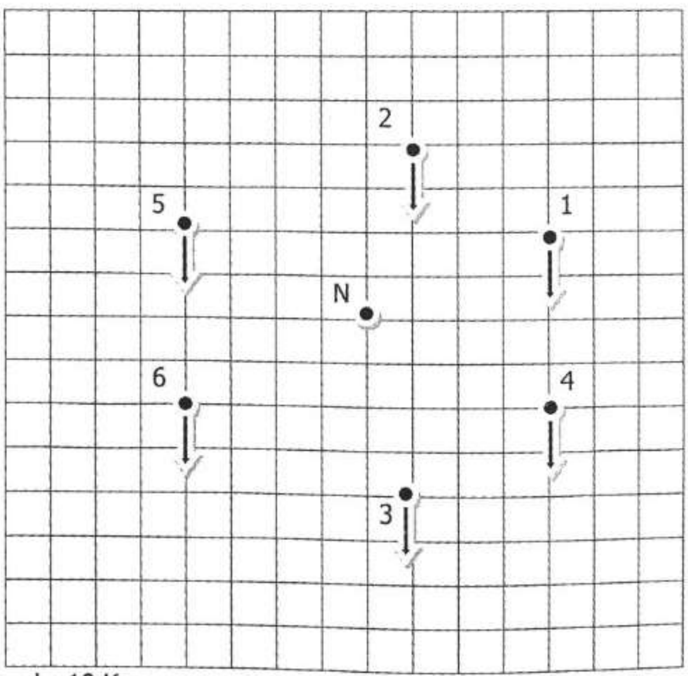
Phụ lục: Số liệu ban đầu:

Nguồn điện	– Đủ cung cấp cho phụ tải với cosφ = 0.9 – Điện áp thanh cái cao áp: 1,1 U_{dm} lúc phụ tải cực đại 1,05 U_{dm} lúc phụ tải cực tiểu __ U_{dm} lúc sự cố					
Phụ tải	1	2	3	4	5	6
P_{max}(MW)	31.5	27.5	22.5	27.5	35	22.5
Cosφ	0,84	0,85	0,82	0,9	0,88	0,86
P_{min}(% P_{max})	40 %	40 %	40 %	40 %	40 %	40 %
T_{max}(giờ/năm)	5000	5000	5000	5000	5000	5000
Yêu cầu cung cấp điện			LT	LT	LT	LT
Điện áp định mức phía thứ cấp trạm phân phối (kV)	22	22	22	22	22	22
Yêu cầu điều chỉnh điện áp phía thứ cấp	±5%	±5%	±5%	±5%	±5%	±5%

– Giá tiền 1 KWh điện năng tổn thất 0,065 $

– Giá tiền 1 KVAr thiết bị bù 5 $

VỊ TRÍ NGUỒN VÀ PHỤ TẢI



|----| : 10 Km

ACKNOWLEDGEMENT

I sincerely thank Dr. Bach H. Dinh and Dr. Van V. Huynh - Lecturer of Ton Duc Thang University. Dr.Bach directly instructed and helped me to implement and complete Project 1 on Technical design of 110kv electrical network. In the process of learning and implementing the project, although many efforts have been made, it is still impossible to avoid shortcomings, large or small. However, in return I have received the dedicated guidance of Dr.Bach helped me overcome the mistakes I often make and encounter in my studies. Dr.Van was the one who directly taught me the subject of "Transmission and Distribution Grid". This project is the result of my study and practice during nearly 6 semesters at Ton Duc Thang University. Therefore, I also sincerely thank all the teachers and faculty of Electrical - Electronic Engineering of Ton Duc Thang University - who participated in teaching and equipped me with the knowledge to help me complete. This project.

Next, I also sincerely thank my family and friends who have always been by my side and encouraged me during this project as well as throughout the study process.

Sincerely

Ho Chi Minh City, 17th April 2021

Author

Ninh The Vinh Cuong

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. BALANCING POWER IN THE NETWORK, DETERMINING RESISTANT CAPACITY COMPENSATION

1.1 Data

Load data is primarily collected to understand the status and needs of large users, forecast consumption demand, and forecast the growth of additional loads in the future. We have the following summary data table:

Source	– Capable of power loads has $\cos\varphi = 0.90$ – Voltage at busbar: + 1.1 $U_{đm}$ at maximum load + 1.05 $U_{đm}$ at minimum load + 1.1 $U_{đm}$ when has problem					
Load	1	2	3	4	5	6
P_{max}(MW)	31.5	27.5	22.5	27.5	35	22.5
$\cos\varphi$	0.84	0.85	0.72	0.90	0.85	0.75
P_{min}(%P_{max})	40%	40%	40%	40%	40%	40%
T_{max}(hours/year)	5000	5000	5000	5000	5000	5000
Demand			Cont	Cont	Cont	Cont
Secondary rated voltage in distribution station (kV)	22	22	22	22	22	22
Request variable in secondary voltage	±5%	±5%	±5%	±5%	±5%	±5%

Table 1.1: Loads' parameters

- Cont : Continuous
- Price for 1 KWh electric wasted : 0.065 $
- Price for 1 KVAr compensation equipment 5$

1.2 Analyze power supplies

The power source is accepted to give adequate dynamic power as per the necessities of the heap with a power factor of 0.9. This proposes that the source may not give the necessary receptive power, and accordingly guaranteeing the responsive power request can be acknowledged during the plan cycle by repaying the responsive power at loads without going from the source.

1.3 Balancing power

There ought to be an equilibrium of dynamic and receptive power in the electrical framework. The complete dynamic and receptive power of the power source should be equivalent to the all out dynamic and responsive power of all heaps in addition to the dynamic and responsive power misfortunes of all components in the electrical organization.

Balance capacity in the power system to consider the supply capacity of the sources for the load through the grid.

1.4 Balancing active power

Balance the power needed to keep the frequency in the electrical system. The active power balance in the system is represented by the following expression:

$$\sum P_F = m\sum P_{pt} + \sum \Delta P_{md} + \sum P_{td} + \sum P_{dt}$$

With:

$\sum P_F$: Total active power generated by the generators of the plants in the system

$\sum P_{dt}$: Total maximum active load of consumers

m: simultaneous coefficients (assuming 0.8)

$\sum P_{md}$: Total active power losses on lines and transformers

$\sum P_{td}$: Total self-consumed capacity of power plants

$\sum P_{dt}$: Total reserve capacity

Deciding the coefficients simultaneously of space should be founded on the genuine circumstance of the heaps.

According to the statistics, the active power loss of the line and transformer in high voltage network is $8 \div 10\% m\sum P_{pt}$. Thus :

$$\sum \Delta P_{md} = 10\% m\sum P_{pt}$$

Self-used capacity of power plants:

Calculated as a percentage of ($m\sum P_{pt} + \sum \Delta P_{md}$)

- Thermal power plant $3 \div 7\%$
- Hydropower plant $1 \div 2\%$

Reserve capacity of the system

- Failure reserve is usually equal to the capacity of the largest unit in the power system.
- Load reserve is estimated for unexpected increase in load: total load.
- Reserve development to meet additional load development 5 - 15 years later.
- Save advancement to meet extra burden improvement 5 - after 15 years.

When all is said in done, hold the framework by 10 - 15% of the all out framework load. In the plan of the subject, it is expected that the power source is adequate to completely supply the dynamic power interest and just adjusted from the high-voltage busbar of the promoter transformer station of the power plant, so the dynamic power equilibrium ought to be determined as follows:

$$\sum P_F = m\sum P_{pt} + \sum \Delta P_{md}$$

From the data of the maximum active power of the loads we can calculate the active power of the emitted source as:

$$\sum P_F = m\sum P_{pt} + \sum \Delta P_{md} = m\sum P_{pt} + 10\% m\sum P_{pt}$$
$$= m\sum P_{pt}(1+10\%)$$
$$= 0.8*(31.5+27.5+22.5+27.5+35+22.5)(1+0.1)$$
$$= 146.52(MW)$$

So we need a source with active power: $\sum P_F = 146.52(MW)$

1.5 Balancing reactive power

In power plants, there is regularly save of dynamic power, so there is likewise save of responsive power. Be that as it may, in the electrical organization the responsive power misfortune is more prominent than the dynamic power misfortune, so while picking the generator limit as per the state of dynamic power balance, the receptive power might be deficient in the electrical organization. . To address the short receptive power, it is more sensible to remunerate responsive power at the devouring burden.

Reactive power balance is identified with voltage. Harming the reactive power equilibrium will prompt voltage changes in the electrical organization. On the off chance that the produced reactive power is more prominent than the reactive power burned-through, the voltage in the electrical organization will increment, in any case, if there is an absence of reactive power, the voltage in the organization will diminish. In this way, to guarantee the nature of the voltage in the buyers in the electrical organization and in the framework, it is important to do a fundamental equilibrium of reactive power.

We have the connection between active power and reactive power as follows:

Load 1:

$$P = 31.5MW \text{ ; } \mathrm{Cos}\varphi = 0{,}84 \ \rightarrow \mathrm{Q} = 31.5 \times \tan(\cos^{-1}(0{,}84)) = 20.35MVAr$$

$$\rightarrow S = \sqrt{31.5^2 + 20.35^2} = 37.5MVA$$

Using similar method for other loads.

	Source	Load 1	Load 2	Load 3	Load 4	Load 5	Load 6
$\sum P(MW)$	166.5	31.5	27.5	22.5	27.5	35	22.5
$\mathrm{Cos}\varphi$		0.84	0.85	0.72	0.9	0.85	0.78
$\sum Q(MVAr)$	112.13	20.35	17.04	21.69	13.32	21.69	18.05
$\sum S(MVA)$	201.66	37.5	32.35	31.25	30.55	41.17	28.84

Table 1.2

Balance reactive power to keep normal voltage in the system. Reactive power balance is represented by the following expression:

$$\sum Q_F + Q_{bu\Sigma} = m\sum Q_{pt} + \sum \Delta Q_B + \sum \Delta Q_L - \sum Q_C + \sum Q_{td} + \sum Q_{dt}$$

With:

+ $\sum Q_F$: total generating capacity of generators. In course design, only design from high-voltage busbar of the plant's booster substation, so only need to balance from the high-voltage busbar.

$$\sum Q_F = \sum P_{pt} \times tg\varphi_F = 146.52 \times tg(\cos^{-1}(0,9)) = 70.33(MVAr)$$

+ $m\sum Q_{pt}$: total reactive load of the electrical network taking into account the concurrent coefficient.
+ $\sum \Delta Q_B$: The total reactive power loss in the transformer can be estimated:

$$\sum \Delta Q_B = (8 \div 12\%)\sum S_{pt} \text{ ;}$$

with $\sum S_{pt} = \sqrt{\sum P_{pt}^2 + \sum Q_{pt}^2} = \sqrt{166.5^2 + 112.14^2} = 201.66(MVA)$

We choose: $\sum \Delta Q_B = 12\%\sum S_{pt} = 0.12 \times 201.66 = 24.2(MVAr)$

+ $\sum \Delta Q_L$: all out reactive limit misfortunes on the line sections of the power organization. With the 110kV power network in the primer computation, it tends to be seen that the reactive power misfortune on the line inductance is equivalent to the reactive power created by the high voltage line capacitance.
+ $\sum Q_{td}$: total self-consumed capacity of the power plant in the system

$$\sum Q_{td} = \sum P_{td} \times tg\varphi_{td}$$

+ $\sum Q_{dt}$: reserve reactive power of the system

$$\sum Q_{dt} = (5 \div 10\%)\sum Q_{pt}$$

In course plan, it is simply important to adjust from the high-voltage busbar of the power plant without the need to figure out Q_{td} and Q_{dt}. From the above power, it is feasible to find the measure of reactive power to be redressed $Q_{bu\Sigma}$. If $Q_{bu\Sigma}$ positive, the system needs to install additional equipment to compensate to can with resistance capacity. The calculation of the exact distribution of the compensation device will be calculated in the exact power balance in the system.

In this segment we just consider giving compensatory ability to loads that are far away from the source and have a low power factor ($\cos\varphi$) or loads with large power consumption. V à for easy calculation, we can temporarily give an amount of $Q_{b,i}$ by $Q_{b\sum}$. Then, we recalculate apparent power and power factor after compensating with the formula:

$$S_i^{'} = \sqrt{P_i^2 + (Q - Q_{bui})^2}\ ;\ \text{Cos}\,\varphi_i^{'} = \frac{P_i}{S_i^{'}}$$

From the expression and the data in the table above we have $Q_{bu\Sigma}$:

$$Q_{bu\Sigma} = m\sum Q_{pt} + \sum \Delta Q_B - \sum Q_F = 0.8\times 112.14 + 24.2 - 70.33 = 43.582(MVAr)$$

⇨ Choose $Q_{bu\Sigma} = 44(MVAr)$

Load 1

$$Q_b = 8MVAr \rightarrow Q_{pt} - Q_{bu} = 20.35 - 8 = 12.35MVAr$$

$$\rightarrow S^{'} = \sqrt{31.5^2 + 12.35^2} = 33.83MVA \rightarrow \text{Cos}\,\varphi^{'} = \frac{31.5}{33.83} = 0,93$$

Load 2

$$Q_b = 7MVAr \rightarrow Q_{pt} - Q_{bu} = 17.04 - 7 = 10.04MVAr$$

$$\rightarrow S^{'} = \sqrt{27.5^2 + 10.04^2} = 29.27MVA \rightarrow \text{Cos}\,\varphi^{'} = \frac{27.5}{29.27} = 0,94$$

Load 3

$$Q_b = 11MVAr \rightarrow Q_{pt} - Q_{bu} = 21.69 - 11 = 10.69MVAr$$

$$\rightarrow S^{'} = \sqrt{22.5^2 + 10.69^2} = 24.91MVA \rightarrow \text{Cos}\,\varphi^{'} = \frac{22.5}{24.91} = 0,90$$

Load 4

Load 4 has the PF of 0.9 then it do not need to be compensated.

Load 5

$$Q_b = 8MVAr \rightarrow Q_{pt} - Q_{bu} = 21.69 - 8 = 13.69MVAr$$

$$\rightarrow S^{'} = \sqrt{35^2 + 13.69^2} = 37.58MVA \rightarrow \text{Cos}\,\varphi^{'} = \frac{35}{37.58} = 0,93$$

Load 6

$$Q_b = 9MVAr \rightarrow Q_{pt} - Q_{bu} = 18.05 - 9 = 9.05MVAr$$

$$\rightarrow S^{'} = \sqrt{22.5^2 + 9.05^2} = 24.25MVA \rightarrow \text{Cos}\,\varphi^{'} = \frac{22.5}{24.25} = 0,93$$

Load	P_{pt} (MW)	$\cos\varphi$	Q_{pt} (MVAr)	Q_b (MVAr)	$Q_{pt} - Q_b$ (MVAr)	S (MVA)	S' (MVA)	$\cos\varphi^{'}$
1	31.5	0.84	20.35	8	12.35	37.5	33.93	0.93
2	27.5	0.85	17.04	7	10.04	32.35	29.27	0.94
3	22.5	0.72	21.69	11	10.69	31.25	24.91	0.9
4	27.5	0.9	13.32	0	13.32	30.55	30.55	0.9
5	35	0.85	21.69	8	13.69	41.17	37.58	0.93
6	22.5	0.78	18.05	9	9.05	28.84	24.25	0.93
Total	166.5			44				

Table 1.3: Load data after preliminary reactive power compensation

The heap information after fundamental pay is utilized in contrasting the choice of the line and transformer limit determination. In the event that, later on, when re-ascertaining the pay gadget dissemination, an uncompensated burden is at first made up for, the wire cross-area and the chose transformer limit should be re-verified.

CHAPTER 2. PROPOSING WIRING METHODS OF ELECTRIC NETWORK AND SELECTING TECHNICAL, ECONOMICAL CODING METHODS

2.1 Load voltage selection

The rated voltage of the electrical network depends on many factors: capacity of each load, distance between loads and the supply, distance between loads, electrical network diagram.

2.1.1 Find the transmission distance

Based on the Pythagorean's theorem we can determine the distance from the source to the loads as follows:

Load 1 (N-1): $\sqrt{40^2+20^2}=44.72(km)$

Load 2 (N-2): $\sqrt{40^2+10^2}=41.23(km)$

Load 3 (N-3): $\sqrt{40^2+10^2}=41.23(km)$

Load 4 (N-4): $\sqrt{40^2+20^2}=44.72(km)$

Load 5 (N-5): $\sqrt{40^2+20^2}=44.72(km)$

Load 6 (N-6): $\sqrt{40^2+20^2}=44.72(km)$

2.1.2 Determine the voltage for each electrical load

The evaluated voltage of the electrical organization is chosen at the same time with the power supply conspire. The fundamental appraised voltage of the electrical organization can be dictated by the estimation of limit per section of the electrical organization.

We rely on Still's formula to find the load voltage U (kV):

$$U = 4.34 \times \sqrt{l + 0.016 \times P}$$

Which: P: transmission power (KW)

L: transmission distance (Km)

Load 1: $U = 4.34 \times \sqrt{L + 0.016 \times P} = 4.34 \times \sqrt{44.72 + 0.016 \times 31500} = 101.66(kV)$

Load 2: $U = 4.34 \times \sqrt{L + 0.016 \times P} = 4,34 \times \sqrt{41.23 + 0.016 \times 27500} = 95.2(kV)$

Load 3: $U = 4.34 \times \sqrt{L + 0.016 \times P} = 4.34 \times \sqrt{41.23 + 0.016 \times 22500} = 86.9(kV)$

Load 4: $U = 4.34 \times \sqrt{L + 0.016 \times P} = 4.34 \times \sqrt{44.72 + 0.016 \times 27500} = 95.55(kV)$

Load 5: $U = 4.34 \times \sqrt{L + 0.016 \times P} = 4.34 \times \sqrt{44.72 + 0.016 \times 35000} = 106.72(kV)$

Load 6: $U = 4.34 \times \sqrt{L + 0.016 \times P} = 4.34 \times \sqrt{44.72 + 0.016 \times 22500} = 87.3(kV)$

From the above calculations we have the following statistics table:

Load	1	2	3	4	5	6
L(Km)	44.72	41.23	41.23	44.72	44.72	44.72
P(MW)	31.5	27.5	22.5	27.5	35	22.5
U(kV)	101.66	95.2	86.9	95.55	106.72	87.3

Table 2.1 Selection of load voltage levels

Compared with the results we have, the voltage level in Vietnam is only 110kV, the closest star with load 5 with the voltage level is 106.72kV. Thus, we will choose 110kV voltage to transmit to this system.

2.2 Choose wiring plan for the electric network

The wiring graph of the electrical network relies upon numerous elements: the number and area of the load, the requirement for a nonstop power supply of each load, the advancement of obtuse loads like the operability of the network.

Inside the plan of the course, we can isolate into numerous districts to supply power to the load hubs dependent on the requirement for continuous power supply. For loads that don't give nonstop power, we just need single wiring, yet the other way around, for loads with persistent power supply, we need to offer double circuit or shut circle wiring alternatives.

According to the power supply requirement of the problem, we will divide it into 2 types of load:

- ❖ Load class 1 includes load 3, load 4, load 5, and load 6 requires continuous power supply. In which we will divide into 2 areas. Area 3 will include load 5 and load 6; area 2 will include load 3 and load 4.
- ❖ Load class 3 includes load 1 and load 2, which are not required for continuous power supply and these loads will be in the area 1.

Separating the loads into three areas limits computation choices and configuration time.

2.2.1 Area 1

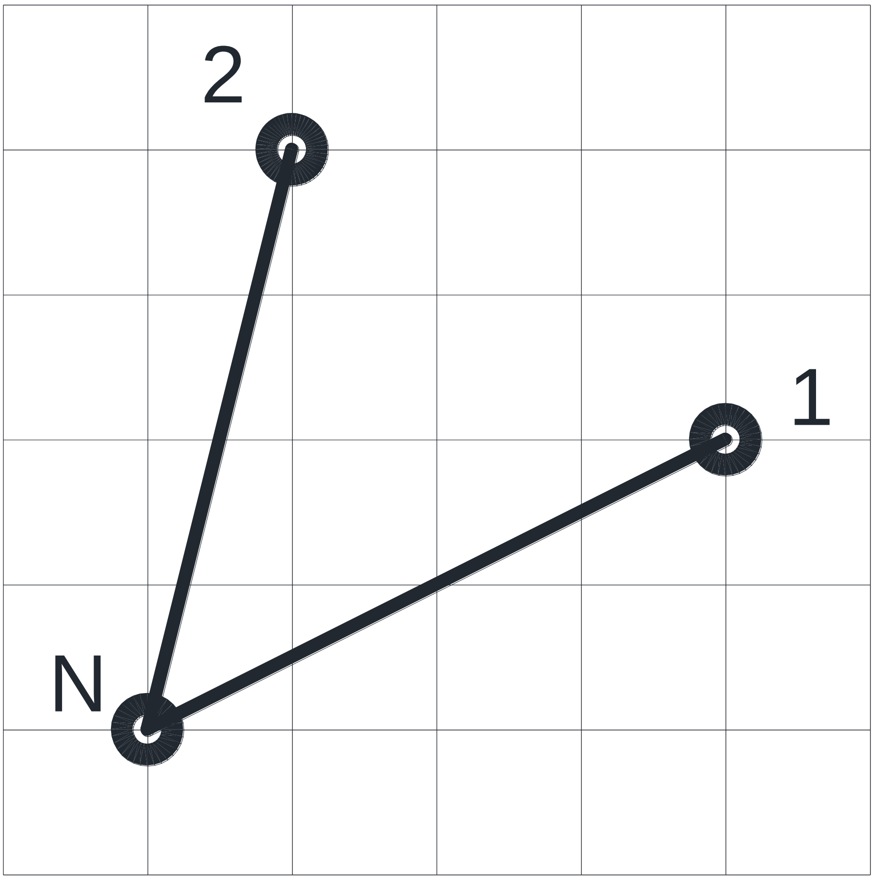


Figure 2.1 Area 1 case 1

Area 1 (case 1)		
Line	N – 1	N – 2
Power (MW)	31.5	27.5
Length (km)	44.72	41.23
$\sum L$ (km)	85.95	

Table 2.2 Area 1 case 1

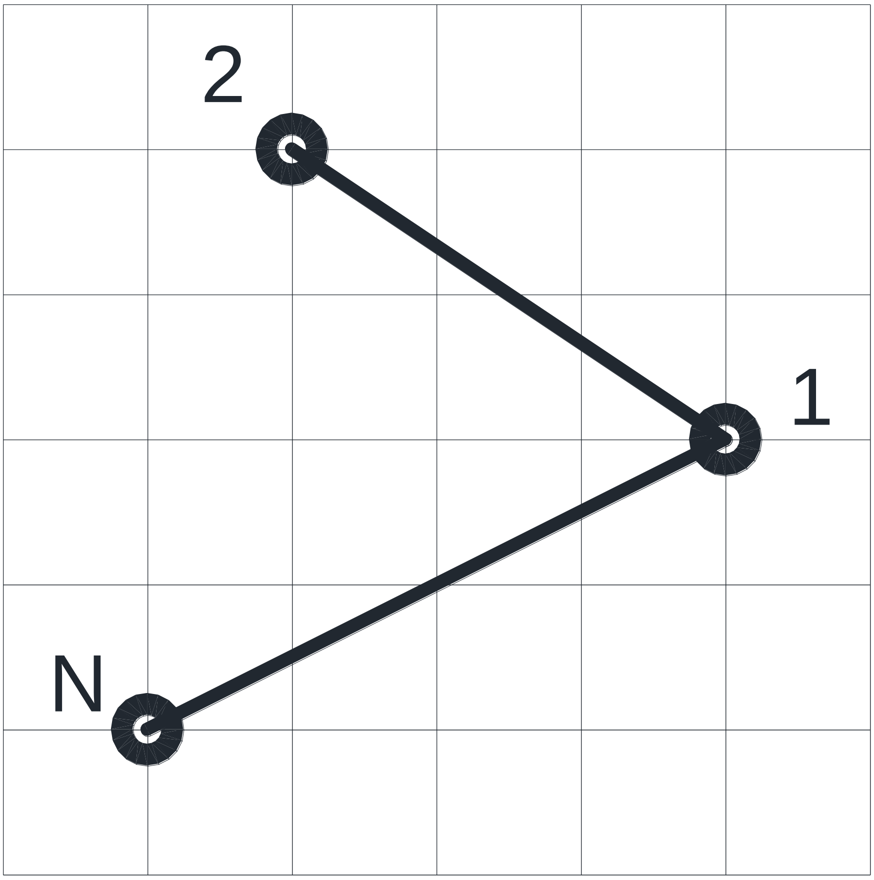


Figure 2.2 Area 1 case 2

Area 1 (case 2)		
Line	N – 1	1 – 2
Power (MW)	59	27.5
Length (km)	44.72	36.05
$\sum L$ (km)	80.77	

Table 2.3 Area 1 case 2

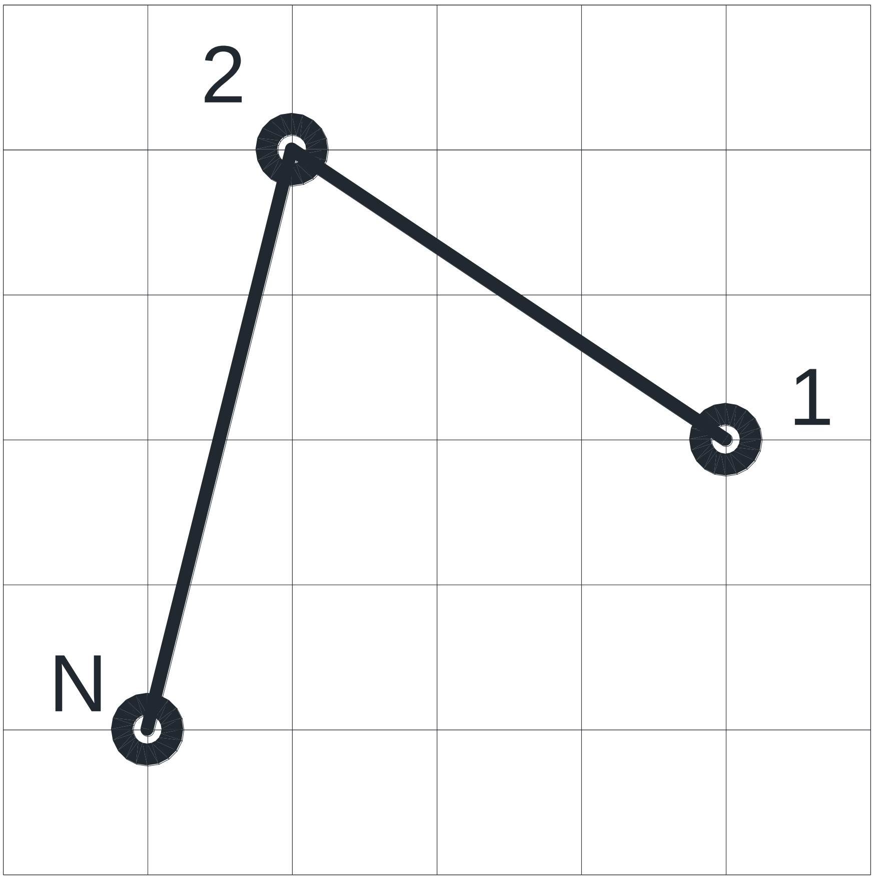


Figure 2.3 Area 1 case 3

Area 1 (case 3)		
Line	N – 2	2 – 1
Power (MW)	59	31.5
Length (km)	41.23	36.05
$\sum L$ (km)	77.28	

Table 2.4 Area 1 case 3

2.2.2 Area 2

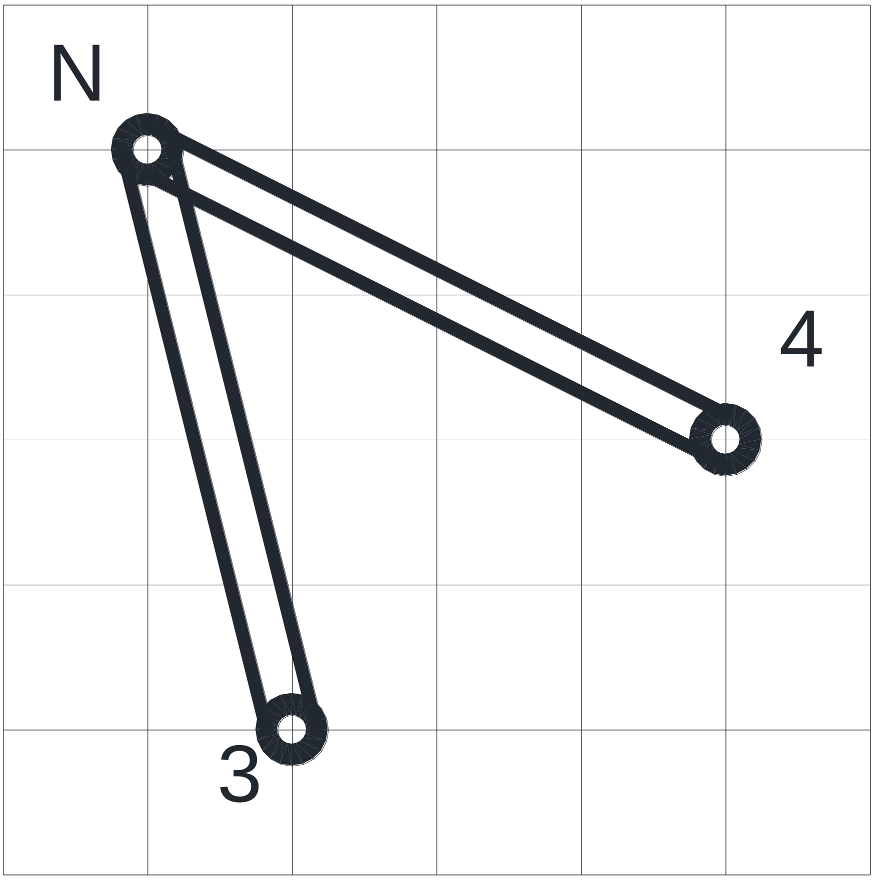


Figure 2.4 Area 2 case 1

Area 2 (case 1)		
Line	N – 3	N – 4
Power (MW)	22.5	27.5
Length (km)	41.23	44.72
$\sum L$ (km)	85.95	

Table 2.5 Area 2 case 1

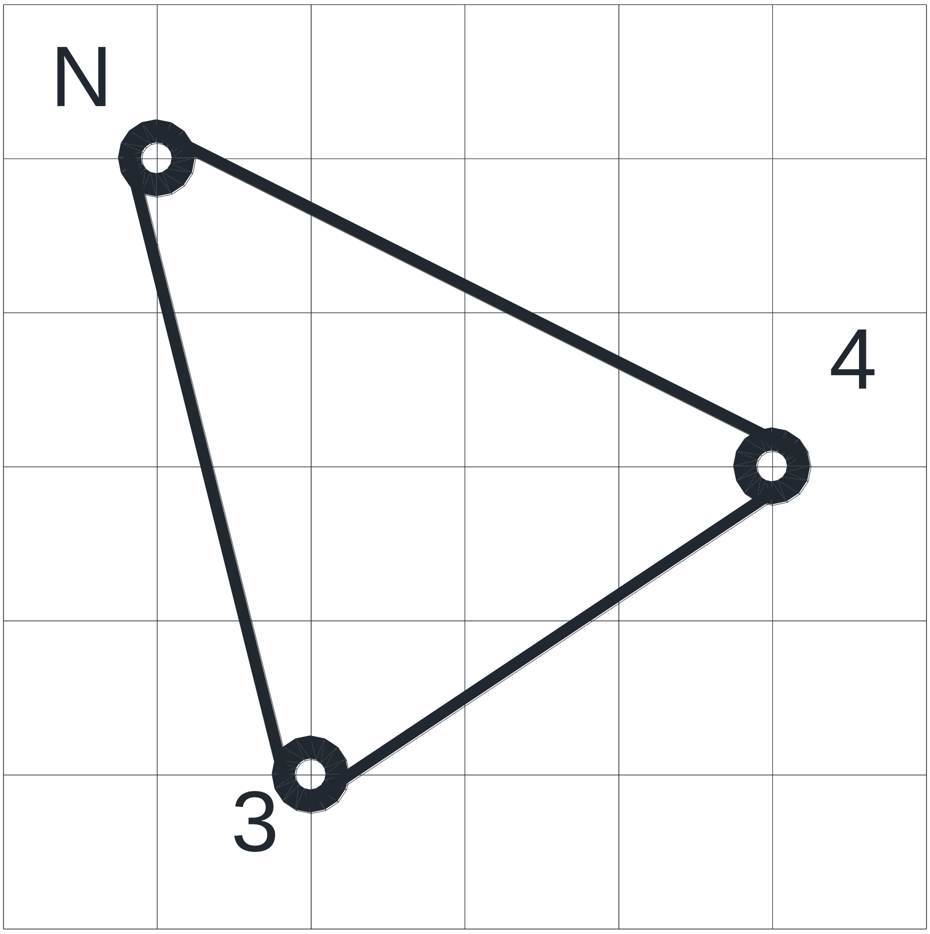


Figure 2.5 Area 2 case 2

Area 2 (case 2)			
Line	N – 3	3 – 4	N – 4
Power (MW)	22.5		27.5
Length (km)	41.23	36.05	44.72
$\sum L$ (km)	122		

Table 2.6 Area 2 case 2

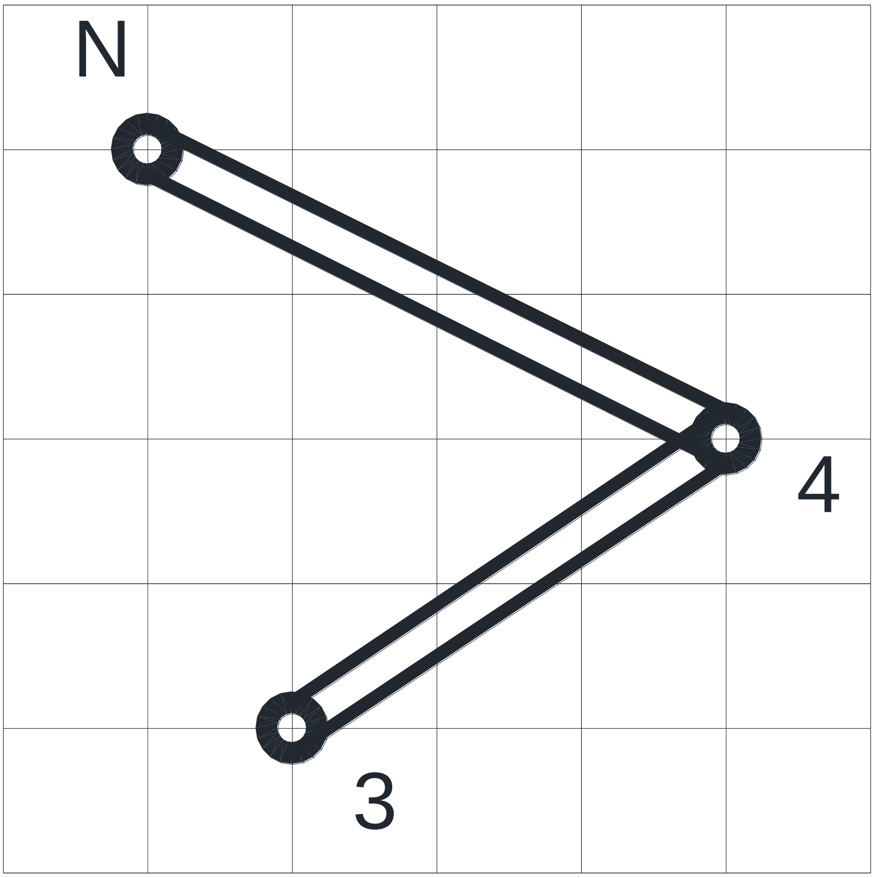


Figure 2.6 Area 2 case 3

Area 2 (case 3)		
Line	N – 4	4 – 3
Power (MW)	50	22.5
Length (km)	44.72	36.05
$\sum L$ (km)	80.77	

Table 2.7 Area 2 case 3

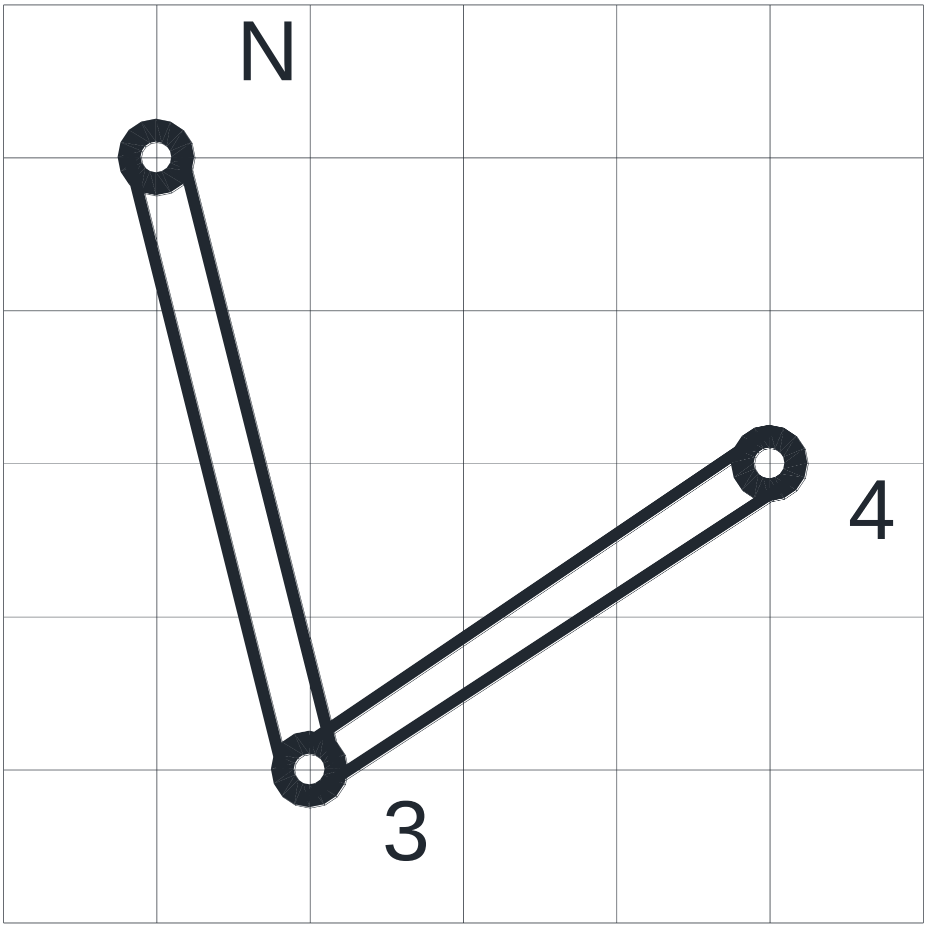


Figure 2.7 Area 2 case 4

Area 2 (case 4)		
Line	N – 3	3 – 4
Power (MW)	50	27.5
Length (km)	44.72	36.05
$\sum L$ (km)	80.77	

Table 2.8 Area 2 case 4

2.2.3 Area 3

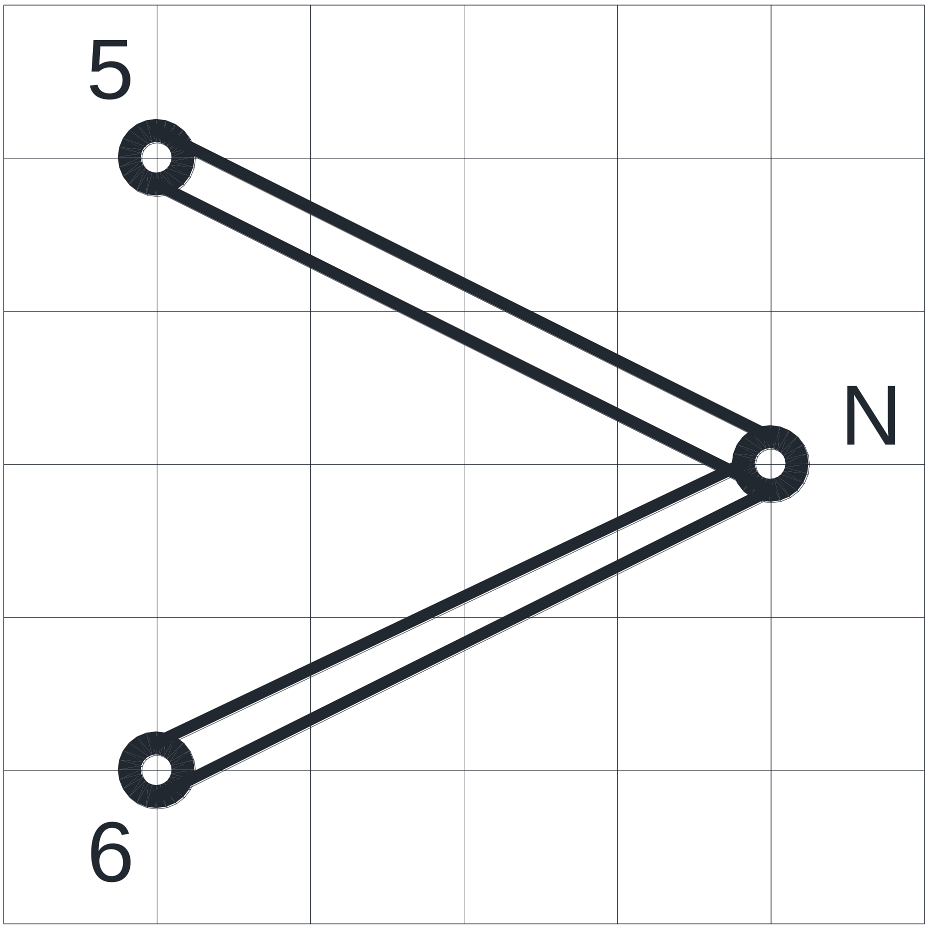


Figure 2.8 Area 3 case 1

Area 3 (case 1)		
Line	N – 5	N – 6
Power (MW)	35	22.5
Length (km)	44.72	44.72
$\sum L$ (km)	89.44	

Table 2.9 Area 3 case 1

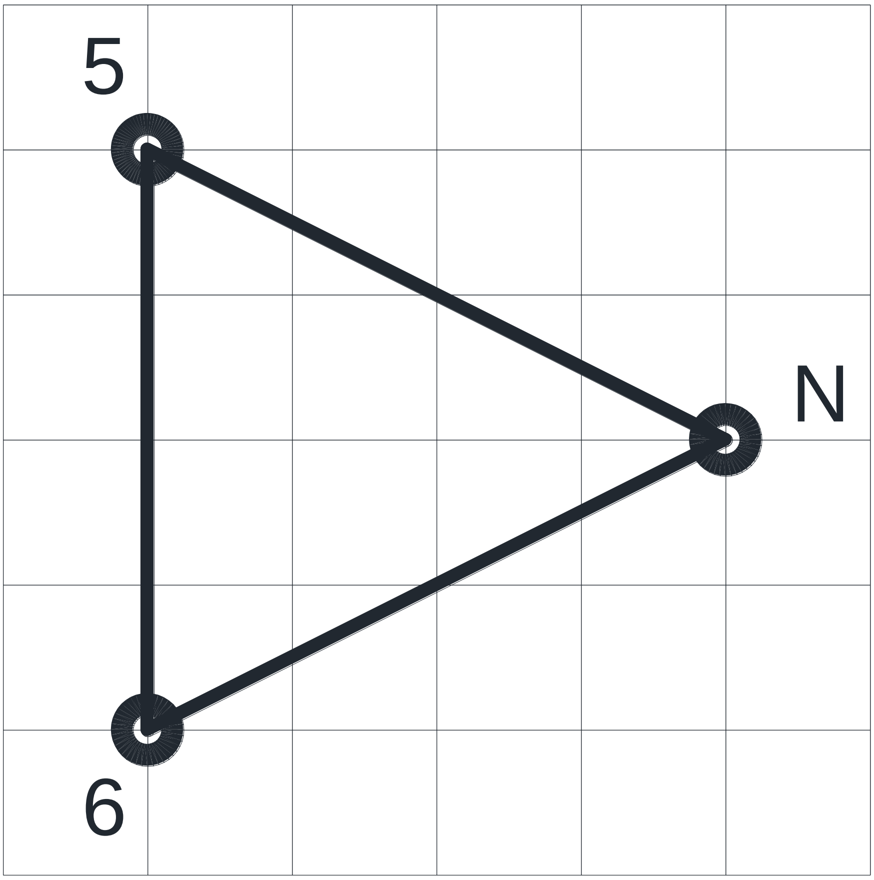


Figure 2.9 Area 3 case 2

Area 3 (case 2)			
Line	N – 5	5 – 6	N – 6
Power (MW)	35		22.5
Length (km)	44.72	40	44.72
$\sum L$ (km)	129.44		

Table 2.10 Area 3 case 2

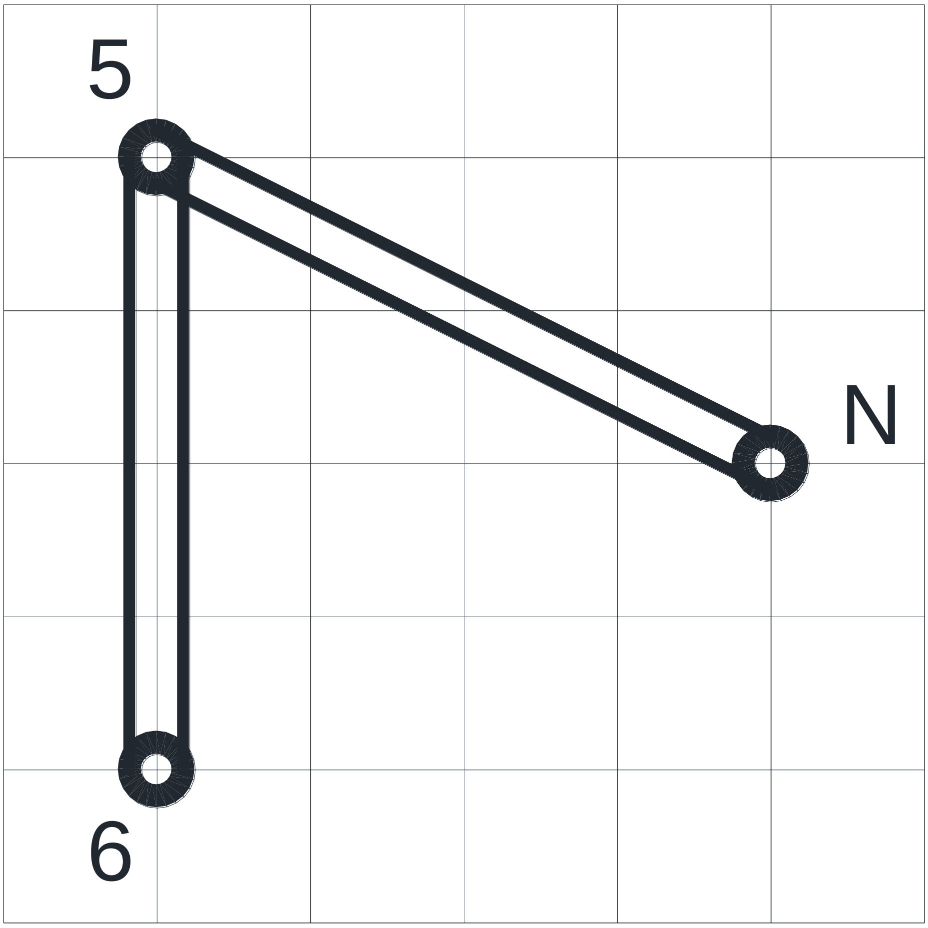


Figure 2.10 Area 3 case 3

Area 3 (case 3)		
Line	N – 5	5 – 6
Power (MW)	57.5	22.5
Length (km)	44.72	40
$\sum L$ (km)	84.72	

Table 2.11 Area 3 case 3

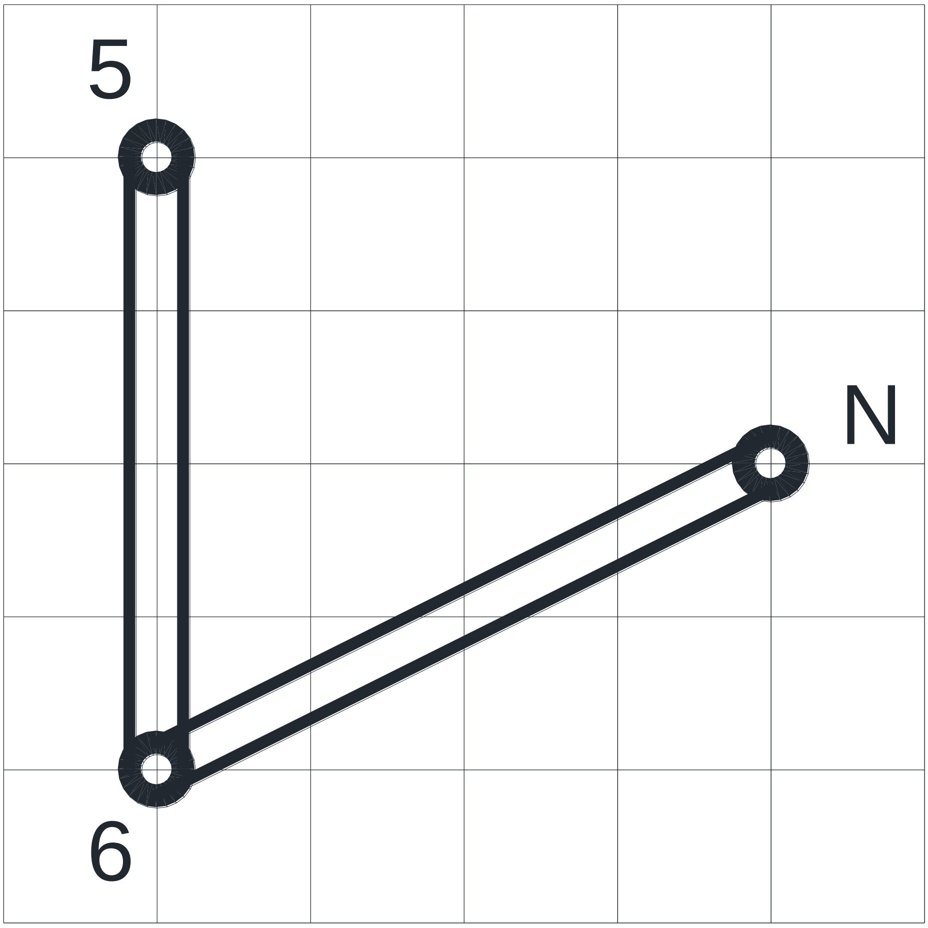


Figure 2.11 Area 3 case 4

Area 3 (case 4)		
Line	N – 6	6 - 5
Power (MW)	57.5	35
Length (km)	44.72	40
$\sum L$ (km)	84.72	

Table 2.12 Area 3 case 3

2.2.4 Select the optimal options

In area 1, I choose case 1 as one option because each line transmit power equal the load attach to. Even problems occur in one line, the other is not affected. In case 2 and case 3, both are interconnecting, the first line always deliver 59MW of power. However, in case 2, the second line only transmits 27.5MW, which is less than other case (31.5MW). Thus, case 2 is a better option, so I choose it as the second one to calculate.

In area 2 and area 3, both area only have one case using single conductor line (case 2), so we choose case 2. In double conductors line cases, only case 1 (in both area), each line take responsibility for each load, thus problems occur in one line will not affact other. So I choose case 1.

Conclusion :

- Area 1 : case 1 and case 2.
- Area 2 : case 1 and case 2.
- Area 3 : case 1 and case 2.

2.3 Calculate technical indicators

2.3.1 Wire selection

2.3.1.1 Area 1 case 1

Choose wire cross-section N – 1

Current flows on the conductor N – 1:

$$I_{N-1} = \frac{S_{N-1}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{33.83}{\sqrt{3} \times 110} \times 10^3 = 177.56(A)$$

With T_{max}=5000 hours, aluminum conductor with steel core, so we have j_{kt}=1,1A/mm^2

$$\rightarrow F_{N-1,KT} = \frac{I_{N-1}}{j_{kt}} = \frac{177.56}{1.1} = 161.42(mm^2) \rightarrow \text{ Select cable AC – 185}$$

Choose wire cross-section N – 2

Current flows on the conductor N – 2:

$$I_{N-2} = \frac{S_{N-2}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{29.27}{\sqrt{3} \times 110} \times 10^3 = 153.62(A)$$

$$\rightarrow F_{N-2,KT} = \frac{I_{N-2}}{j_{kt}} = \frac{153.62}{1.1} = 139.66(mm^2) \rightarrow \text{ Select cable AC – 150}$$

From the book “THIẾT KẾ MẠNG ĐIỆN” by Hồ Văn Hiến, in page 120, we have the permissible current of conductors.

Aluminum conductor with steel core	
Wire code	**Permissible current**
AC – 70	275
AC – 95	335
AC – 120	360
AC – 150	445
AC – 185	515
AC – 240	610

Table 2.13 Permissible current

Aluminum conductor with steel core after temperature correction ***(assume that the ambient temperature is 40oC k=0,81)***		
Wire code	**Permissible current (A)**	**Permissible current after correction (A)**
AC – 70	275	222.75
AC – 95	335	271.35
AC – 120	360	291.6
AC – 150	445	360.45
AC – 185	515	417.15
AC – 240	610	494.1

Table 2.14 Permissble current after correction

Line	Wire	Permissible current
N – 1	AC – 185	417.15
N – 2	AC – 150	360.45

Table 2.15 Permissible current on Line N1 and N2

From the calculated and selected data as above, we have a summary table of section selection for the plan as follows:

Line	High way	S_{max} (MVA)	I_{max} (A)	J_{kt} (mm^2)	F_{KT} (mm^2)	F_{tc} (mm^2)	$I_{hc}=k*I_{cp}$ ($t=40^oC$) (A)	Choose F_{tc} (mm^2)	Wire code
N-1	1	33.83	177.56	1.1	161.43	185	417.15	185	AC-185
N-2	1	29.27	153.62	1.1	139.66	150	291.6	150	AC-150

Table 2.16 Conductors' data of line N – 1 và N – 2

2.3.1.2 Area 1 case 2

Choose wire cross-section N – 1

Current flows on the conductor line N – 1:

$$I_{N-1} = \frac{S_{N-1}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{33.83 + 29.27}{\sqrt{3} \times 110} \times 10^3 = 331.2(A)$$

With T_{max}=5000 hours, aluminum conductor with steel core, thus j_{kt}=1,1A/mm^2

$$\rightarrow F_{N-1,KT} = \frac{I_{N-2}}{j_{kt}} = \frac{331.2}{1.1} = 301.1(mm^2) \rightarrow \text{ Choose } 2 \times \text{ AC} - 185$$

Choose wire cross-section 1 - 2

Current flows on the conductor line 1 - 2:

$$I_{1-2} = \frac{S_{1-2}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{29.27}{\sqrt{3} \times 110} \times 10^3 = 153.64(A)$$

$$\rightarrow F_{1-2,KT} = \frac{I_{1-2}}{j_{kt}} = \frac{153.63}{1.1} = 139.66(mm^2) \rightarrow \text{ Select AC} - 150$$

Line	Conductor	Permissible current
N – 1	2 × AC – 185	2×417.15 = 834.3
1 – 2	AC – 150	360.45

Table 2.17 Permissible current on N – 2 – 1

From the calculated and selected data as above, we have a summary table of section selection for the plan as follows:

Line	High way	S_{max} (MVA)	I_{max} (A)	J_{kt} (mm^2)	F_{KT} (mm^2)	F_{tc} (mm^2)	$I_{hc}=k*I_{cp}$ ($t=40^oC$) (A)	Choosing F_{tc} (mm^2)	Code
N-1	2	63.3	331.2	1.1	301.1	2×185	834.3	2×185	AC-185
1-2	1	29.27	153.63	1.1	139.66	150	360.45	150	AC-150

Table 2.18 Conductors' data of line N – 1 – 2

2.3.1.3 Area 3 case 1

Choose wire cross-section N – 5

Current flows on the conductor N – 5:

$$I_{N-1} = \frac{S_{N-5}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{37.58}{\sqrt{3} \times 110} \times 10^3 = 197.25(A)$$

With T_{max}=5000 hours, aluminum conductor with steel core, so we have j_{kt}=1,1A/mm^2

$$\rightarrow F_{N-5,KT} = \frac{I_{N-1}}{2 \times j_{kt}} = \frac{197.25}{2 \times 1.1} = 89.66(mm^2) \rightarrow \text{ Select cable AC – 95}$$

Choose wire cross-section N – 6

Current flows on the conductor N – 6:

$$I_{N-6} = \frac{S_{N-6}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{24.25}{\sqrt{3} \times 110} \times 10^3 = 127.3(A)$$

$$\rightarrow F_{N-6,KT} = \frac{I_{N-2}}{2 \times j_{kt}} = \frac{127.3}{2 \times 1.1} = 57.85(mm^2) \rightarrow \text{ Select cable AC – 70}$$

Line	Conductor	Permissible current
N – 5	AC - 95	271.35
N - 6	AC - 70	222.75

Table 2.19 Permissible current on N – 5, N – 6

Line	High way	S_{max} (MVA)	I_{max} (A)	J_{kt} (mm^2)	F_{KT} (mm^2)	F_{tc} (mm^2)	$I_{hc}=k*I_{cp}$ ($t=40^oC$) (A)	Choose F_{tc} (mm^2)	Code
N-5	2	37.58	197.25	1.1	89.66	95	271.35	95	AC-95
N-6	2	24.25	127.3	1.1	57.85	70	222.75	70	AC-70

Table 2.20 Conductors' data of line N-5, N-6

Table 2.3.6: Conductors' data of line N – 5, N - 6

2.3.1.4 Area 3 case 2

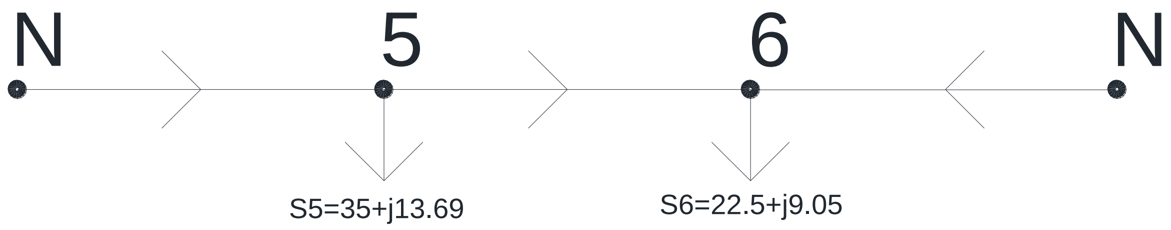


Figure 2.12 Area 3 case 2 flattened

I assume using same conductors for all the line in this area, thus power flow on line N-5 are:

$$P_{N-5} = \frac{P_5(l_{5-6} + l_{N-6}) + P_6 l_{N-6}}{l_{N-5} + l_{5-6} + l_{N-6}} = \frac{35 \times (40 + 44.72) + 22.5 \times (44.72)}{40 + 44.72 + 44.72} = 30.68(MW)$$

$$Q_{N-5} = \frac{Q_5(l_{5-6} + l_{N-6}) + Q_6 l_{N-6}}{l_{N-5} + l_{5-6} + l_{N-6}} = \frac{13.69 \times (40 + 44,72) + 9.05 \times (44,72)}{40 + 44,72 + 44,72} = 12.09(MVAr)$$

Power being delivered in line 5-6

$$P_{5-6} = P_{N-5} - P_5 = 35 - 30.68 = 4.32MW$$
$$Q_{5-6} = Q_{N-5} - Q_5 = 13.69 - 12.09 = 1.6MVAr$$

Power being transmitted in line N-6

$$P_{N-6} = P_6 + P_{5-6} = 22.5 + 4.32 = 26.82MW$$
$$Q_{N-6} = Q_6 + Q_{5-6} = 9.05 + 1,6 = 10.65MVAr$$

Current flow on line N – 5:

$$I_{N-5} = \frac{S_{N-5}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{\sqrt{30.68^2 + 12.09^2}}{\sqrt{3} \times 110} \times 10^3 = 173.1(A)$$

Current flow on line 5 – 6:

$$I_{5-6} = \frac{S_{5-6}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{\sqrt{4.32^2 + 1.6^2}}{\sqrt{3} \times 110} \times 10^3 = 24.18(A)$$

Current flow on line N – 6:

$$I_{N-6} = \frac{S_{N-6}}{\sqrt{3}U_{dm}} \times 10^3 = \frac{\sqrt{26.82^2 + 10.65^2}}{\sqrt{3} \times 110} \times 10^3 = 151.46(A)$$

With T_{max}=5000 hours, aluminum conductor with steel core, we have j_{kt}=1,1A/mm^2

$$\rightarrow F_{N-5,KT} = \frac{I_{N-5}}{j_{kt}} = \frac{173.1}{1,1} = 157.3(mm^2) \rightarrow \text{select AC} - 185$$

$$\rightarrow F_{5-6,KT} = \frac{I_{5-6}}{j_{kt}} = \frac{24.18}{1,1} = 22(mm^2) \rightarrow \text{select AC} - 70$$

$$\rightarrow F_{N-6,KT} = \frac{I_{N-6}}{j_{kt}} = \frac{151.46}{1,1} = 137.7(mm^2) \rightarrow \text{select AC} - 150$$

Line	**Conductor**	**Permissible current (A)**
N – 5	AC - 185	417.15
5 – 6	AC – 70	222.75
N - 6	AC - 150	360.45

Table 2.21 Permissible current on N – 5 – 6 – N

❖ Consider when one line breakdown:

➢ When line N – 5 broke down:

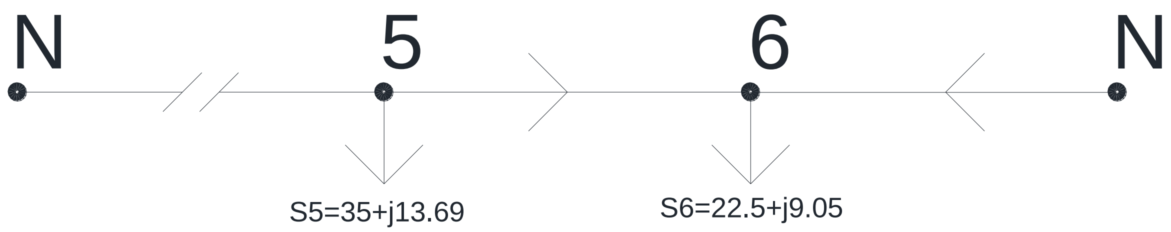


Figure 2.13 Area 3 case 2 when N-5 break

➢ When line N – 6 broke down:

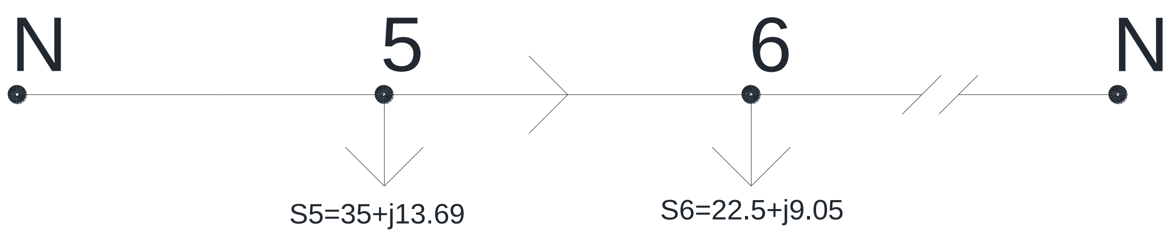


Figure 2.14 Area 3 case 2 when N-6 break

$\rightarrow$In both scenarios, the first line always transmits 57.5MW of power. However, when N-5 broke down, the trouble current is larger than the other case because power transmit on 5-6 at the moment is 35MW. Thus, we only consider the N-5 breakdown situation.

➢ Forced current on line N – 6 when N – 5 broke down:

$$I_{N-5,cb} = \frac{S_5 + S_6}{\sqrt{3}U_{dm}} \times 10^3 = \frac{\sqrt{P_5^2 + Q_5^2} + \sqrt{P_6^2 + Q_6^2}}{\sqrt{3} \times 110} \times 10^3$$

$$= \frac{\sqrt{35^2 + 13.69^2} + \sqrt{22.5^2 + 9.05^2}}{\sqrt{3} \times 110} = 324.5(A)$$

- Forced current on line 5 – 6:

$$I_{5-6,cb} = \frac{S_5}{\sqrt{3}U_{dm}} \times 10^3 = \frac{\sqrt{P_5^{\ 2} + Q_5^{\ 2}}}{\sqrt{3} \times 110} \times 10^3 = \frac{\sqrt{35^2 + 13.69^2}}{\sqrt{3} \times 110} = 197.25(A)$$

- Consider line N – 6: $I_{N-6,cb}$=324.5(A)<$I_{N-6,hc}$=417.15(A)$\rightarrow$in line N – 6, choosing conductor AC – 150 will ensure operating conditions at fault.
- Consider line 5 – 6: : $I_{5-6,cb}$=197.25(A)<$I_{5-6,hc}$=222,75(A)$\rightarrow$in line 5 – 6, choosing conductor AC – 70 will ensure operating conditions at fault.

From the calculated and selected data as above, we have a summary table of section selection for the plan as follows:

Line	**High way**	**S_{max} (MVA)**	**I_{max} (A)**	**J_{kt} (mm^2)**	**F_{KT} (mm^2)**	**F_{tc} (mm^2)**	**I_{hc}=k*I_{cp} (t=40^{o}C) (A)**	**Choose F_{tc} (mm^2)**	**Code**
N-5	1	32.97	173.1	1.1	157.3	185	417.15	185	AC-185
5-6	1	4.6	24.18	1.1	22	70	222.75	70	AC-70
N-6	1	28.86	151.46	1.1	137.7	150	360.45	150	AC-150

Table 2.22 Conductors' data of line N-5-6

2.3.1.5 Area 2 case 1

Because Area 2 and Area 3 are similar, I using same method of calculation for this area.

Line	Conductor	Permissible current
N – 3	AC – 70	222.75
N - 4	AC - 95	271.35

Table 2.23 Permissible current on N – 3, N – 4

Line	High way	S_{max} (MVA)	I_{max} (A)	J_{kt} (mm^2)	F_{KT} (mm^2)	F_{tc} (mm^2)	I_{hc}=k*I_{cp} (t=40°C) (A)	Choose F_{tc} (mm^2)	Code
N-3	2	24.9	130.74	1.1	59.43	70	222.75	70	AC-70
N-4	2	30.55	160.38	1.1	72.9	95	271.35	95	AC-95

Table 2.24 Conductors' data of line N – 3, N – 4

2.3.1.6 Area 2 case 2

Because Area 2 and Area 3 are similar, I using same method of caculation for this area.

Line	Conductor	Permissible current
N – 3	AC – 150	360,45
3 – 4	AC – 70	222,75
N – 4	AC – 150	360,45

Table 2.25 Permissble current on N-3-4

Line	High way	S_{max} (MVA)	I_{max} (A)	J_{kt} (mm^2)	F_{KT} (mm^2)	F_{tc} (mm^2)	$I_{hc}=k*I_{cp}$ ($t=40^oC$) (A)	Choose F_{tc} (mm^2)	Code
N-3	1	27.7	145.31	1.1	132.1	150	360.45	150	AC-150
3-4	1	2.7	14..57	1.1	13.25	70	222.75	70	AC-70
N-4	1	27.7	145.8	1.1	131.8	150	360.45	150	AC-150

Table 2.26 Conductors’ data of line N-3-4

2.3.1.7 Summarize wire selections

Case	Line	Highway	S_{max} (MVA)	I_{max} (A)	F_{kt} (mm2)	Wire code	Note
1-1	N – 1	1	33.93	177.56	161.43	AC-185	Star
	N – 2	1	29.27	153.62	139.66	AC-150	
1-2	N – 1	2	63.2	331.2	301.1	AC-185	Inter-connection
	1 - 2	1	33.93	121..61	139.66	AC-150	
2-1	N – 3	2	24.9	130.74	59.43	AC-70	Star
	N – 4	2	30.55	160.388	72.9	AC-95	
2-2	N – 3	1	27.7	145.3	132.1	AC-150	Ring
	3 – 4	1	2.77	14.57	13.25	AC-70	
	N – 4	1	27.78	145.8	131.8	AC-150	
3-1	N – 5	2	37.58	197.25	89.66	AC-95	Star
	N – 6	2	24.25	127.3	57.85	AC-70	
3-2	N -5	1	32.97	173.1	157.3	AC-185	Ring
	5 – 6	1	4.6	24.18	22	AC-70	
	N - 6	1	28.86	151.46	137.7	AC-150	

Table 2.27 Wires selections

2.3.2 Electrical capacity selection and line parameter calculation

2.3.2.1 Selection of pillars for single circuit lines

Because the sections N - 1, N - 2 we use a single highway, we choose reinforced concrete pillars with code DT20 (refer to the book of electrical network design by Ho Van Hien at PL5.5, page 154)

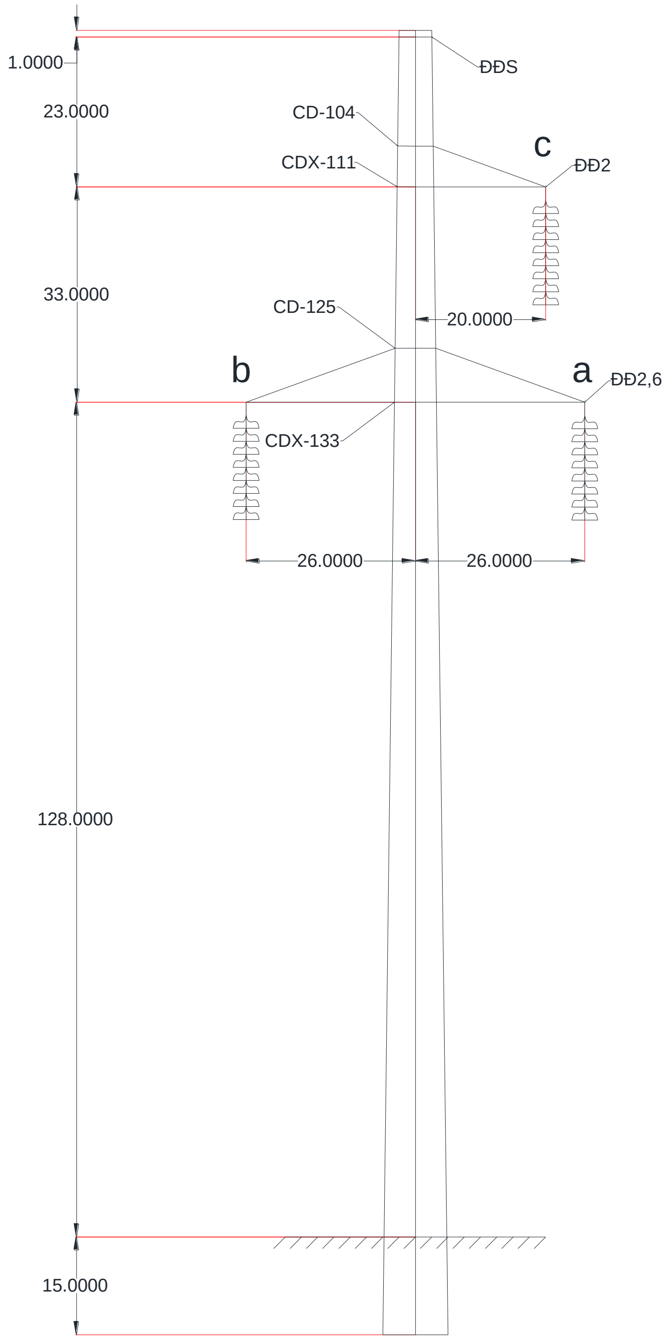


Figure 2.15 Reinforced concrete pillar DT20

2.3.2.2 Calculation of parameters of resistance, inductance, capacitance for single-circuit lines:

Based on the reinforced concrete pillar code DT20 we can calculate the following distances:

$$D_{ab} = 2,6 + 2,6 = 5,2(m)$$
$$D_{ac} = \sqrt{3,3^2 + 0,6^2} = 3,35(m)$$
$$D_{bc} = \sqrt{3,3^2 + 4,6^2} = 5,66(m)$$

⇨ The geometric mean distance D_m is:

$$D_m = \sqrt[3]{D_{ab} \times D_{ac} \times D_{bc}} = \sqrt[3]{5,2 \times 3,35 \times 5,66} = 4,62(m)$$

➢ **Line N – 1 uses wire AC – 185:**

Look up the annexes in the electrical network design book of Mr. Ho Van Hien, we have the following parameters:

+ AC wire - 1 85 has 28 aluminum fibers and 7 steel fibers (PL2.5 / 119)

+ The wire wire has outer diameter d = 19 (mm), so the outer radius of the wire is r = 8.5 mm (PL2.1 / 116)

+ Equivalent resistance at 20^{o}C is: r_0 = 0,17 Ω / km (PL2.1/116)

+ The average radius of the cable : r’ = 0.768(mm) (Table 2.5/25). Thus the average self-radius is : $r' = 0.768 \times r = 0.768 \times 8.5 = 6.528(mm)$

+ Line reactance:

$$X_0 = 2\pi f \times 2 \times 10^{-4} \times \ln \frac{D_m}{r'} = 2\pi \times 50 \times 2 \times 10^{-4} \times \ln \frac{4.62}{6.528 \times 10^{-3}} = 0.405(\Omega / km)$$

+ Line capacity:

$$b_0 = \frac{2\pi f}{18 \times 10^6 \times \ln \frac{D_m}{r}} = \frac{2\pi \times 50}{18 \times 10^6 \times \ln \frac{4.62}{8.5 \times 10^{-3}}} = 2,82 \times 10^{-6} (1/\Omega.km)$$

Other single conductor lines use the same method.

Case	Line	High way	Code	Length	R_0	X_0	B_0 $*10^{-6}$	R= $R_0.l$	X= X_0*l	Y= $B_0.l$ $*10^{-6}$
1-1	N – 1	1	AC-185	44.72	0.17	0.405	2.82	7.6	18.1	126.1
	N – 2	1	AC-150	41.23	0.21	0.41	2.77	8.66	16.9	114.2
1-2	1 - 2	1	AC-150	36.05	0.21	0.41	2.77	7.57	14.8	99.85
2-2	N – 3	1	AC-150	41.23	0.21	0.41	2.77	8.66	16.9	114.2
	3 – 4	1	AC-70	36.05	0.46	0.441	2.6	16.58	15.9	93.73
	N – 4	1	AC-150	44.72	0.21	0.41	2.77	9.4	18.33	123.87
3-2	N – 5	1	AC-185	44.72	0.17	0.405	2.82	7.6	18.1	126.1
	5 – 6	1	AC-70	40	0.46	0.441	2.6	18.4	17.64	104
	N – 6	1	AC-150	44.72	0.21	0.41	2.77	9.4	18.33	123.87

Table 2.28 Single conductor lines parameter

2.3.2.3 Selection of pillars for double circuit lines

In this alternative , for sections N - 3 and N - 4, we use dual highways according to the problem, so we choose the steel pillar code Y110-2 + 9 (refer to the electrical network design book by Ho Van Hien at PL5.12, page 161).

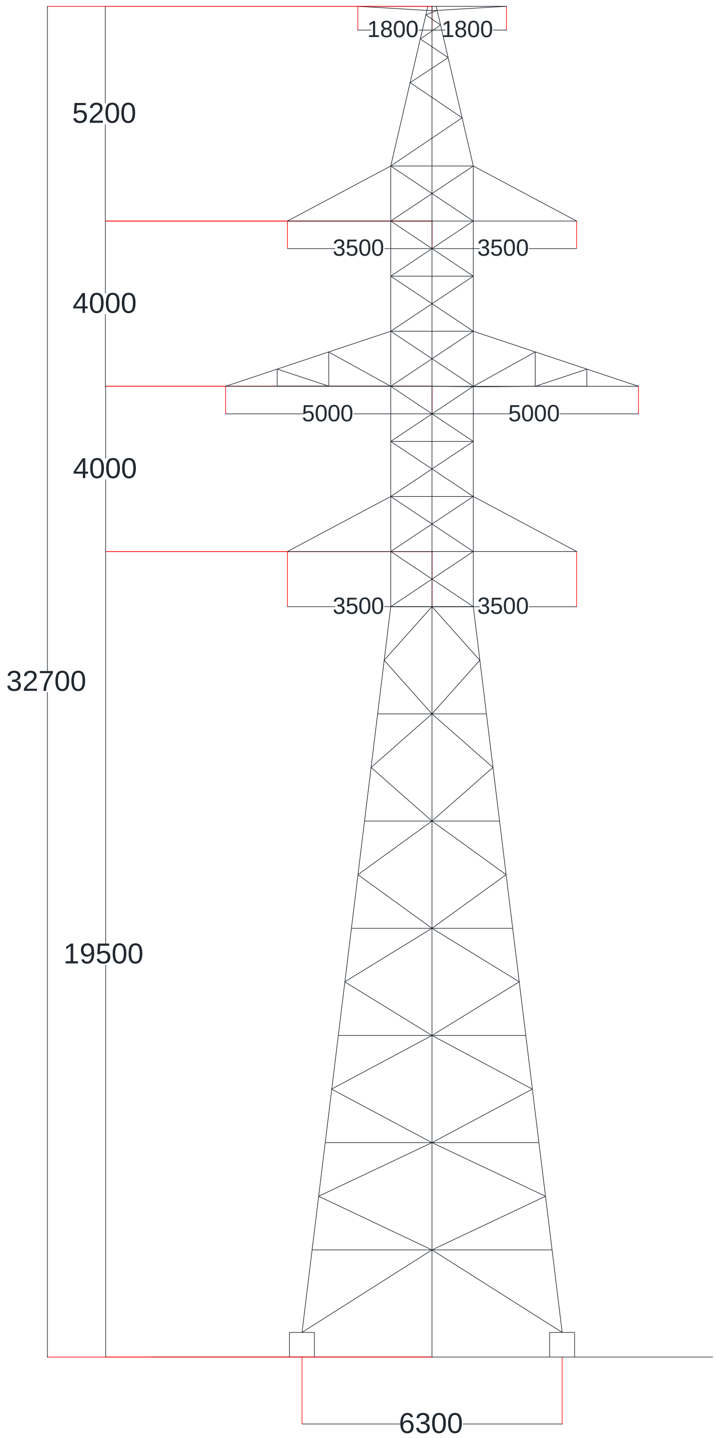


Figure 2.16 Steel pillar Y110-2 + 9

2.3.2.4 Calculation of resistance, inductance, and capacitance parameters of dual circuit lines

Based on the steel pillar code Y110-2 + 9 we can calculate the distances behind:

$$D_{ab} = D_{bc} = D_{a'b'} = D_{b'c'} = \sqrt{(5-3,5)^2 + 4^2} = 4,27(m)$$
$$D_{ac} = D_{a'c'} = 4 + 4 = 8(m)$$
$$D_{ab'} = D_{a'b} = D_{bc'} = \sqrt{(3,5+5)^2 + 4^2} = 9,39(m)$$
$$D_{ac'} = D_{a'c} = 3,5 + 3,5 = 7(m)$$
$$D_{aa'} = D_{cc'} = \sqrt{(4+4)^2 + (3,5+3,5)^2} = 10,63(m)$$
$$D_{bb'} = 5 + 5 = 10(m)$$

Geometric average distances

+ Between phase A and B:

$$D_{AB} = \sqrt[4]{D_{ab} \times D_{a'b} \times D_{ab'} \times D_{a'b'}} = \sqrt[4]{4,27 \times 9,39 \times 9,39 \times 4,27} = 6,33(m)$$

+ Between phase C and B:

$$D_{BC} = \sqrt[4]{D_{bc} \times D_{b'c} \times D_{bc'} \times D_{b'c'}} = \sqrt[4]{4,27 \times 9,39 \times 9,39 \times 4,27} = 6,33(m)$$

+ Between phase A and C:

$$D_{CA} = \sqrt[4]{D_{ac} \times D_{a'c} \times D_{ac'} \times D_{a'c'}} = \sqrt[4]{8 \times 7 \times 7 \times 8} = 7,48(m)$$

$\rightarrow$ The Geometric average distances between phase of the permutation double highway:

$$D_m = \sqrt[3]{D_{AB} \times D_{BC} \times D_{AC}} = \sqrt[3]{6,33 \times 6,33 \times 7,48} = 6,69(m)$$

- **Line N – 4 use conductor AC – 95:**

Look up the annexes in the electrical network design book of Mr. Ho Van Hien, we have the following parameters:

+ AC - 95 wire has 6 aluminum fibers and 1 steel thread (PL2.5 / 119)

+ Wire has outer diameter d = 13.5 (mm), so the outer radius of the wire is r = 6.75mm (PL2.1 / 116)
+ Equivalent resistance at 20^oC is: $r_0 = 0{,}33\,\Omega/km$ (PL2.1/116), because N – 4 là is a double highway, thus $r_0 = \dfrac{0{,}33}{2} = 0{,}165(\Omega/km)$
+ The average radius of the cable is r’ = 0,726(mm) (Table 2.5/25). So the self-radius is: $r' = 0{,}726 \times r = 0{,}726 \times 6{,}75 = 4{,}9(mm)$

Calculate the geometric mean radius:

+ Between conductors of phase A

$$D_{SA} = \sqrt{r' \times D_{aa'}} = \sqrt{4{,}9 \times 10^{-3} \times 10{,}63} = 0{,}23(m)$$

+ Between conductors of phase B

$$D_{SB} = \sqrt{r' \times D_{bb'}} = \sqrt{4{,}9 \times 10^{-3} \times 10} = 0{,}22(m)$$

+ Between conductors of phase C

$$D_{SC} = \sqrt{r' \times D_{cc'}} = \sqrt{4{,}9 \times 10^{-3} \times 10{,}63} = 0{,}23(m)$$

$\rightarrow$ The geometric mean radius of a double highway with permutation:

$$D_S = \sqrt[3]{D_{SA} \times D_{SB} \times D_{SC}} = \sqrt[3]{0{,}23 \times 0{,}22 \times 0{,}23} = 0{,}23(m)$$

+ Reactance of line N – 4:

$$X_0 = 2\pi f \times 2 \times 10^{-4} \times \ln\frac{D_m}{D_S} = 2\pi \times 50 \times 2 \times 10^{-4} \times \ln\frac{6{,}69}{0{,}23} = 0{,}21(\Omega/km)$$

Recalculate the geometric mean radius:

+ Between conductors of phase A:

$$D'_{SA} = \sqrt{r \times D_{aa'}} = \sqrt{6{,}75 \times 10^{-3} \times 10{,}63} = 0{,}27(m)$$

+ Between conductors of phase B:

$$D'_{SB} = \sqrt{r \times D_{bb'}} = \sqrt{6,75 \times 10^{-3} \times 10} = 0,26(m)$$

+ Between conductors of phase C:

$$D'_{SC} = \sqrt{r \times D_{cc'}} = \sqrt{6,75 \times 10^{-3} \times 10,63} = 0,27(m)$$

→ The geometric mean radius of a double highway with permutation:

$$D'_S = \sqrt[3]{D'_{SA} \times D'_{SB} \times D'_{SC}} = \sqrt[3]{0,27 \times 0,26 \times 0,27} = 0,27(m)$$

+ Line's capacitance N – 4:

$$b_0 = \frac{2\pi f}{18 \times 10^6 \times \ln \dfrac{D_m}{D'_S}} = \frac{2\pi \times 50}{18 \times 10^6 \times \ln \dfrac{6,69}{0,27}} = 5,44 \times 10^{-6} (1/\Omega.km)$$

- **Section N - 4 uses conductor AC - 95 at fault:**

Look up the annexes in the electrical network design book of Mr. Ho Van Hien, we have the following parameters:

+ AC - 95 wire has 6 aluminum fibers and 1 steel thread (PL2.5 / 119)
+ Wire has outer diameter d = 13.5 (mm), so the outer radius of the wire is r = 6.75mm (PL2.1 / 116)
+ Equivalent resistance at 20^{o}C is r_0 = 0,33 Ω / km (PL2.1/116)
+ Geometric mean radius r' = 0,726(mm) (Bảng 2.5/25). Mean self-radius: $r' = 0,726 \times r = 0,726 \times 6,75 = 4,9(mm)$
+ Reactance:

$$X_0 = 2\pi f \times 2 \times 10^{-4} \times \ln \frac{D_m}{r'} = 2\pi \times 50 \times 2 \times 10^{-4} \times \ln \frac{6,69}{4,9 \times 10^{-3}} = 0,45(\Omega / km)$$

+ Line's capacitance:

$$b_0 = \frac{2\pi f}{18\times10^6 \times \ln\frac{D_m}{r}} = \frac{2\pi\times50}{18\times10^6\times\ln\frac{6,69}{6,75\times10^{-3}}} = 2,52\times10^{-6}(1/\Omega.km)$$

Other double conductors lines use the same method

$\rightarrow$ Summarize to a table of the calculation results of resistance, inductance, and capacitance of the lines (for dual-line, we will set up a table showing the calculation results of resistance, inductance. Resistance, capacitance at calculation break down).

Line	High way	Wire code	Length	R_0 (Ω/km)	X_0 (Ω/km)	B_0 $*10^{-6}$ $(1/\Omega.km)$	$R=R_0.l$ (Ω)	$X=X_0*l$ (Ω)	$Y=B_0.l$ $*10^{-6}$ $(1/\Omega)$
N-1	2	AC-185	41.23	0.085	0.204	5.6	3.5	8.41	230.89
N-3	2	AC-70	41.23	0.23	0.218	5.27	9.48	9	217.28
N-4	2	AC-95	44.72	0.165	0.213	5.4	7.388	9.53	241.5
N-5	2	AC-95	44.72	0.165	0.213	5.4	7.388	9.53	241.5
N-6	2	AC-70	44.72	0.23	0.218	5.27	10.28	9.75	235.67

Table 2.29 Line parameters at normal operation

Line	High way	Wire code	Length	R_0	X_0	B_0 $*10^{-6}$	R= $R_0.l$	X= X_0*l	$Y=B_0.l$ $*10^{-6}$
N-1	2	AC-185	41.23	0.17	0.42	2.71	7	17.32	111.73
N-3	2	AC-70	41.23	0.46	0.464	2.47	18.96	19.13	101.84
N-4	2	AC-95	44.72	0.33	0.453	2.53	14.75	20.26	113.14
N-5	2	AC-95	44.72	0.33	0.453	2.53	14.75	20.26	113.14
N-6	2	AC-70	44.72	0.46	0.464	2.47	20.57	20.75	110.46

Table 2.30 Line parameters at fault operation

2.3.3 Total power losses and voltage drops calcuation

2.3.3.1 Star circuit

- **Line N – 1:**

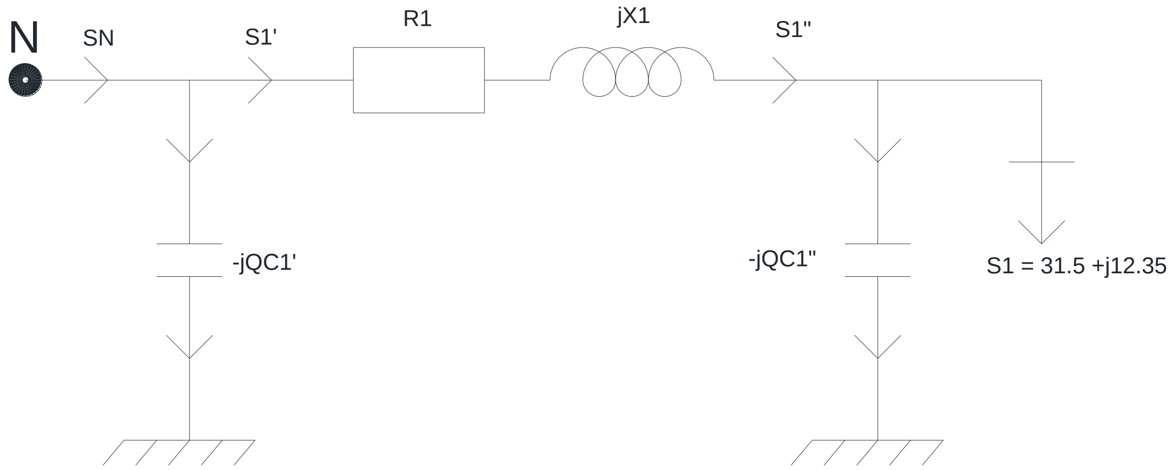


Figure 2.17

$$\Delta Q"_{C1} = \Delta Q'_{C1} = U^2 \times \frac{b_0 \times l}{2} = 110^2 \times \frac{126.1 \times 10^{-6}}{2} = 0,763(MVAr)$$

+ Power at the end of impedance R_1+jX_1 of line N – 1:

$$S"_1 = -j\Delta Q"_{C1} + S_1 = -j0.763 + (31.5 + j12.35) = 31.5 + j11.6(MVA)$$

+ Power losses on N – 1:

$$\Delta S_1 = \frac{(P"_1)^2 + (Q"_1)^2}{U^2_{dm}} \times (R_1 + jX_1) = \frac{31.5^2 + 11.6^2}{110^2} \times (7.6 + j18.1) = 0.707 + j1.685(MVA)$$

+ Power at the start of line impedance N – 1:

$$S'_1 = S"_1 + \Delta S_1 = 31.5 + j11.6 + 0.707 + j1.685 = 32.207 + j13.285(MVA)$$

+ Sending power N – 1:

$$S_N = S'_1 - j\Delta Q'_{C1} = 32.207 + j13.285 - j0.763 = 32.207 + j12.522(MVA)$$

+ Voltage drop on N – 1:

$$\Delta U_1 = \frac{P"_1 \times R_1 + Q"_1 \times X_1}{U_{dm}} = \frac{31.5 \times 7.6 + 11.6 \times 18.1}{110} = 4.085(kV)$$

+ Percent voltage drop on N – 1:

$$\Delta U_1\% = \frac{\Delta U_1}{U_{dm}} \times 100 = \frac{4,085}{110} \times 100 = 3.73\%$$

$\rightarrow \Delta U_{N-1}^{bt}\% = 3.73\% \leq 10\% \rightarrow$ **Satisfied technical requirements.**

- **Line N – 2:**

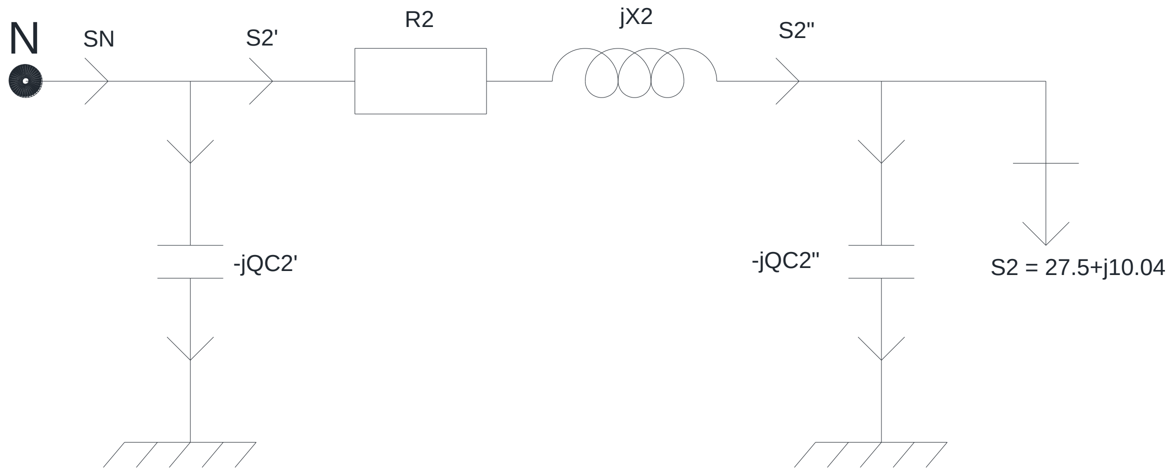


Figure 2.18

The line N – 2 has the similar calculations with line N – 1.

Other area with similar circuit use the same method.

From the results calculated above, we have a summary table of voltage losses and power losses of all the lines as:

No.	**Line**	**Highway**	**Wire code**	$\Delta P(MW)$	$\Delta P_{SC}(MW)$	$\Delta U\%$	$\Delta U_{SC}\%$
1	N – 1	1	AC – 185	0.707		3.73	
2	N – 2	1	AC – 150	0.604		3.27	
3	N – 3	2	AC – 70	0.465	0.952	2.46	5.12
4	N – 4	2	AC – 95	0.547	1.116	2.61	5.46
5	N – 5	2	AC – 95	0.841	1.71	3.11	6.48
6	N – 6	2	AC - 70	0.479	0.98	2.52	5.26

Table 2.31 Power losses of all lines in start circuits

⇨ The calculation results of $\Delta U\%$ all satisfy the following requirements

⇨ **Normal operation** $\Delta U_{\max}\% \leq 10\%$ **.**

2.3.3.2 Interconnection circuit

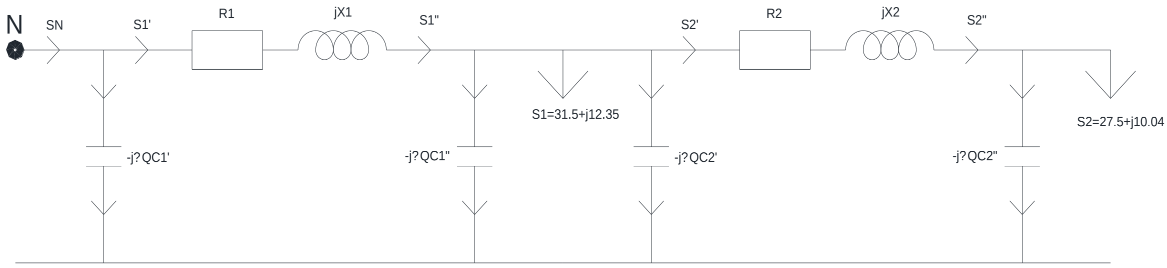


Figure 2.19

❖ **At normal operation**

➢ **Line N – 1 – 2:**

$$\Delta Q''_{C1} = \Delta Q'_{C1} = U^2 \times \frac{b_0 \times l}{2} = 110^2 \times \frac{230.89 \times 10^{-6}}{2} = 1.39(MVAr)$$

$$\Delta Q''_{C2} = \Delta Q'_{C2} = U^2 \times \frac{b_0 \times l}{2} = 110^2 \times \frac{99.85 \times 10^{-6}}{2} = 0.6(MVAr)$$

+ Power at the end of the impedance R_2+jX_2 of line 1– 2:

$$S''_2 = -j\Delta Q''_{C2} + S_2 = -j0.6 + (27.5 + j10.04) = 27.5 + j9.44(MVA)$$

+ Voltage drop of line 2 – 1:

$$\Delta U_{1-2} = \frac{P''_2 \times R_2 + Q''_2 \times X_2}{U_{dm}} = \frac{27.5 \times 7.57 + 9.44 \times 14.8}{110} = 3.18(kV)$$

+ Percent voltage drop of 2 – 1:

$$\Delta U_{1-2}\% = \frac{\Delta U_{1-2}}{U_{dm}} \times 100 = \frac{3.18}{110} \times 100 = 2.89\%$$

$\rightarrow \Delta U_{1-2}^{bt}\% = 2.89\% \leq 10\% \rightarrow$ **Technical requirements are satisfied.**

+ Power losses on line 1 – 2:

$$\Delta S_2 = \frac{(P''_2)^2 + (Q''_2)^2}{U^2_{dm}} \times (R_2 + jX_2) = \frac{27.5^2 + 9.44^2}{110^2} \times (7.67 + j14.8) = 0.535 + j1.03(MVA)$$

+ Power at start end of line 1 – 2:

$$S'_2 = S''_2 + \Delta S_2 = 27.5 + j9.44 + 0.535 + j1.03 = 28.035 + j10.47(MVA)$$

+ Power at the end of impedance R_1+jX_1 of line N - 1:

$$S''_1 = -j\Delta Q''_{C1} + S_1 + (-j\Delta Q'_{C2}) + S'_2 = 28.035 + j10.47 + 31.5 + j12.35 - j1.39 - j0.6$$
$$= 59.535 + j20.93(MVA)$$

+ Voltage drop of line N – 1:

$$\Delta U_{N-1} = \frac{P''_1 \times R_1 + Q''_1 \times X_1}{U_{dm}} = \frac{59.535 \times 3.5 + 20.93 \times 8.41}{110} = 3.49(kV)$$

+ Percent voltage drop of line N – 1:

$$\Delta U_{N-2}\% = \frac{\Delta U_{N-2}}{U_{dm}} \times 100 = \frac{3.49}{110} \times 100 = 3.17\%$$

$\rightarrow \Delta U^{bt}_{N-1}\% = 3.17\% \leq 10\% \rightarrow$ **Satisfied all technical requirements.**

+ Power losses on line N – 1:

$$\Delta S_1 = \frac{(P''_1)^2 + (Q''_1)^2}{U^2_{dm}} \times (R_1 + jX_1) = \frac{59.535^2 + 20.93^2}{110^2} \times (3.5 + j8.41)$$
$$= 1.15 + j2.76(MVA)$$

+ Power before the impedance of line N – 1:

$$S'_1 = S''_1 + \Delta S_{2-1} = 59.535 + j20.93 + 1.15 + j2.76 = 60.685 + j23.69(MVA)$$

+ Sending power of N – 1:

$$S_N = S'_1 - j\Delta Q'_{C1} = 60.685 + j23.69 - j1.39 = 60.685 + j22.3(MVA)$$

+ Total Voltage drop:

$\rightarrow \Delta U^{bt}_{N-1-2}\% = 6.06\% \leq 10\% \rightarrow$ **Satisfied all technical requirements.**

⇨ **From the results calculated above, we have a summary table of voltage loss and power loss of all lines as follows:**

No.	**Line**	**Highway**	**Wire code**	$\Delta P(MW)$	$\Delta U\%$
1	N – 1	2	AC-185	1.15	6.06
2	1 - 2	1	AC-150	0.535	2.89

Table 2.32 Power losses of all lines in interconnection circuit

❖ **At fault operation**

$$\Delta Q"_{C1} = \Delta Q'_{C1} = U^2 \times \frac{b_0 \times l}{2} = 110^2 \times \frac{111.73 \times 10^{-6}}{2} = 0.67(MVAr)$$

$$\Delta Q"_{C2} = \Delta Q'_{C2} = U^2 \times \frac{b_0 \times l}{2} = 110^2 \times \frac{99.85 \times 10^{-6}}{2} = 0.6(MVAr)$$

+ Power at the end of the impedance R_2+jX_2 of line 1– 2:

$$S"_2 = -j\Delta Q"_{C2} + S_2 = -j0.6 + (27.5 + j10.04) = 27.5 + j9.44(MVA)$$

+ Voltage drop of line 2 – 1:

$$\Delta U_{1-2} = \frac{P"_2 \times R_2 + Q"_2 \times X_2}{U_{dm}} = \frac{27.5 \times 7.57 + 9.44 \times 14.8}{110} = 3.18(kV)$$

+ Percent voltage drop of 2 – 1:

$$\Delta U_{1-2}\% = \frac{\Delta U_{1-2}}{U_{dm}} \times 100 = \frac{3.18}{110} \times 100 = 2.89\%$$

+ Power losses on line 1 – 2:

$$\Delta S_2 = \frac{(P"_2)^2 + (Q"_2)^2}{U^2_{dm}} \times (R_2 + jX_2) = \frac{27.5^2 + 9.44^2}{110^2} \times (7.67 + j14.8) = 0.535 + j1.03(MVA)$$

+ Power at start end of line 1 – 2:

$$S'_2 = S"_2 + \Delta S_2 = 27.5 + j9.44 + 0.535 + j1.03 = 28.035 + j10.47(MVA)$$

+ Power at the end of impedance R_1+jX_1 of line N - 1:

$$S''_1 = -j\Delta Q''_{C1} + S_1 + (-j\Delta Q'_{C2}) + S'_2 = 28.035 + j10.47 + 31.5 + j12.35 - j0.67 - j0.6$$
$$= 59.535 + j21.55 (MVA)$$

+ Voltage drop of line N – 1:

$$\Delta U_{N-1} = \frac{P''_1 \times R_1 + Q''_1 \times X_1}{U_{dm}} = \frac{59.535 \times 7 + 21.55 \times 17.32}{110} = 7.18 (kV)$$

+ Percent voltage drop of line N – 1:

$$\Delta U_{N-2}\% = \frac{\Delta U_{N-2}}{U_{dm}} \times 100 = \frac{7.18}{110} \times 100 = 6.53\%$$

+ Power losses on line N – 1:

$$\Delta S_1 = \frac{(P''_1)^2 + (Q''_1)^2}{U^2_{dm}} \times (R_1 + jX_1) = \frac{59.535^2 + 21.55^2}{110^2} \times (7 + j17.32)$$
$$= 2.32 + j5.74 (MVA)$$

+ Power before the impedance of line N – 1:

$$S'_1 = S''_1 + \Delta S_{2-1} = 59.535 + j21.55 + 2.32 + j5.74 = 61.855 + j27.29 (MVA)$$

+ Sending power of N – 1:

$$S_N = S'_1 - j\Delta Q'_{C1} = 61.855 + j27.29 - j0.67 = 61.855 + j26.62 (MVA)$$

+ Total Voltage drop:

$\rightarrow \Delta U^{bt}_{N-1-2}\% = 9.72\% \le 20\% \rightarrow$ **Satisfied all technical requirements.**

No.	**Line**	**Highway**	**Wire code**	$\Delta P(MW)$	$\Delta U_{SC}\%$
1	N – 1	1	AC-185	0.535	6.53
2	1 - 2	1	AC-150	2.32	2.89

Table 2.33 Power losses of all lines in interconnection circuit at fault

2.3.3.3 Ring circuit

- Consider N – 5 – 6 – N at normal operation

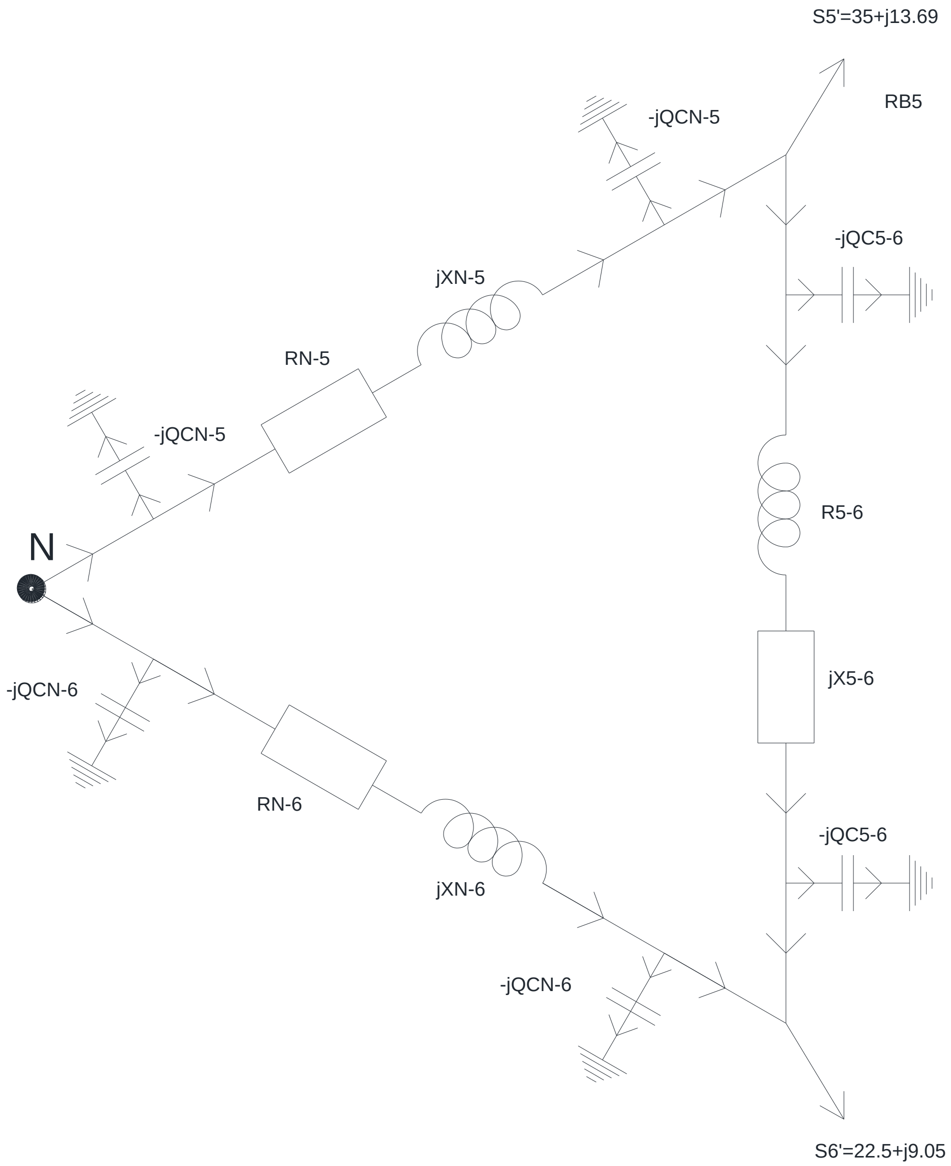


Figure 2.20

+ Power is generated by half of the line capacitance:

$$j\Delta Q_{CN-5} = j\frac{b_0 \times l}{2} \times U_{dm}{}^2 = j\frac{126.1 \times 10^{-6}}{2} \times 110^2 = j0.763(MVAr)$$

$$j\Delta Q_{CN-6} = j\frac{b_0 \times l}{2} \times U_{dm}{}^2 = j\frac{104 \times 10^{-6}}{2} \times 110^2 = j0.75(MVAr)$$

$$j\Delta Q_{C5-6} = j\frac{b_0 \times l}{2} \times U_{dm}{}^2 = j\frac{123.87 \times 10^{-6}}{2} \times 110^2 = j0.63(MVAr)$$

\+ Power at node 5 and 6

$$S_5 = P_5 + jQ_5 = 35 + j13.69(MVA)$$
$$S_6 = P_6 + jQ_6 = 22.5 + j9.05(MVA)$$
$$S'_5 = S_5 - j\Delta Q_{CN-5} - j\Delta Q_{C5-6} = 35 + j13.69 - j0,763 - j0,63 = 35 + j12.297(MVA)$$
$$S'_6 = S_6 - j\Delta Q_{CN-6} - j\Delta Q_{C5-6} = 22.5 + j9.05 - j0,75 - j0,63 = 22.5 + j7.67(MVA)$$

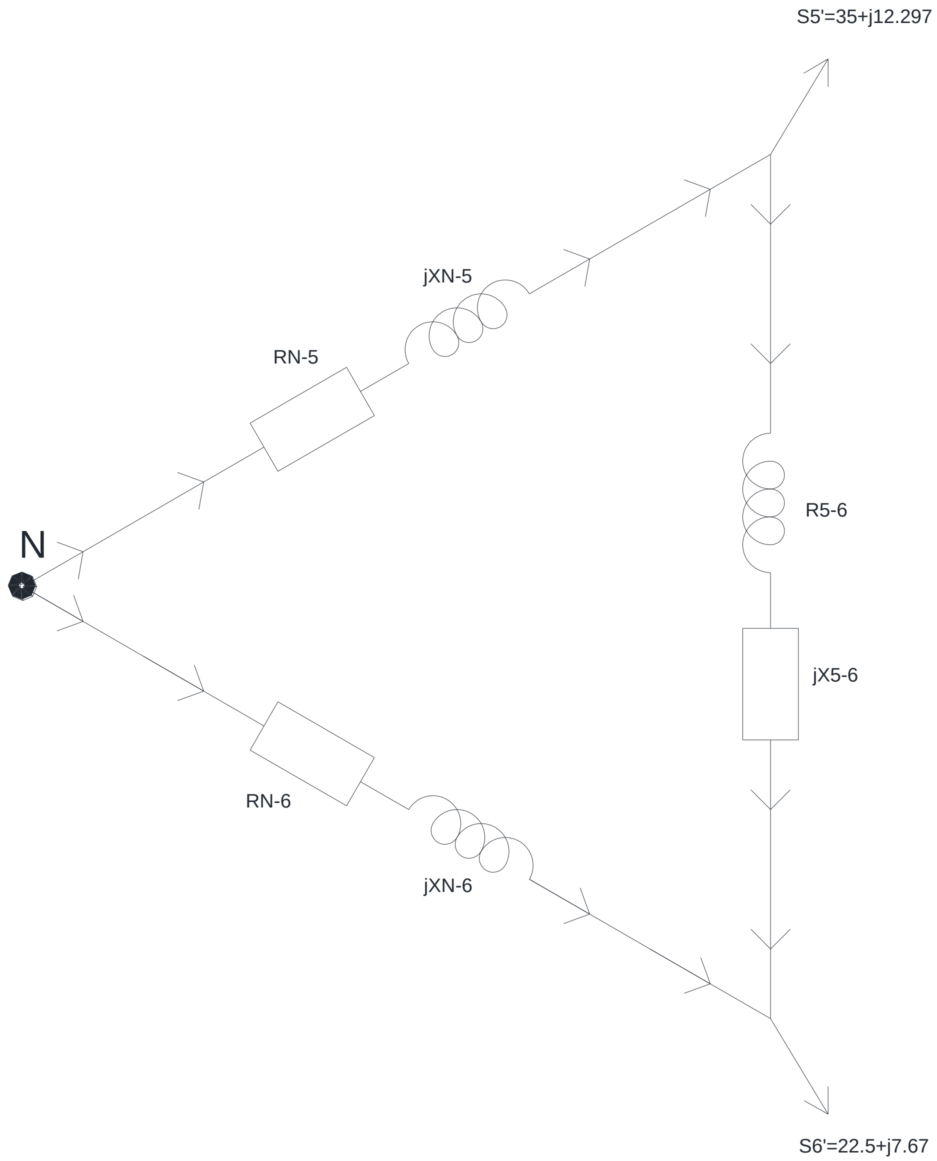


Figure 2.21

Apply the approximate power distribution in terms of impedance to calculate the power current on the lines connected to the source:

$$Z_{N-5} = R_{N-5} + jX_{N-5} = 7.6 + j18.1(\Omega)$$
$$Z_{N-6} = R_{N-6} + jX_{N-6} = 9.4 + j18.42(\Omega)$$
$$Z_{5-6} = R_{5-6} + jX_{5-6} = 18.4 + 17.64(\Omega)$$

+ Power being delivered on line N – 5:

$$\overset{*}{S}_{N-5} = \frac{\overset{*}{S'}_5 \times (Z_{56} + Z_{N6}) + \overset{*}{S'}_6 \times (Z_{N6})}{Z_{N5} + Z_{56} + Z_{N6}}$$
$$= \frac{(35 - j12.297) \times (27.8\text{+j}36.06) + (22.5 - j7.67) \times (9.4 + j18.42)}{35.4 + j64.16}$$
$$= 31.294 - j12.212(MVA)$$
$$\rightarrow S_{N-5} = 31.294 + j12.212MVA)$$

+ Power being delivered on line 6 – 5:

$$S_{6-4} = S_{N-5} - S'_5 = (35 + j12.297) - (31.294 + j12.212) = 3.706 + j0.085(MVA)$$

+ Power being delivered on line N – 6:

$$S_{N-6} = S'_6 + S_{6-5} = (22.5 + j7.67) + (3.706 + j0.085) = 26.2 + j7.755$$

+ Power losses on N – 5:

$$\Delta S_{N-5} = \frac{(P_{N-5})^2 + (Q_{N-5})^2}{U^2_{dm}} \times (R_{N-5} + jX_{N-5}) = \frac{31.294^2 + 12.212^2}{110^2} \times (7.6 + j18.1)$$
$$= 0,708 + j1.688(MVA)$$

Similar calculations for N-6 and 6-5.

+ Voltage drop on N – 5:

$$\Delta U_{N-5} = \frac{P_{N-5} \times R_{N-5} + Q_{N-5} \times X_{N-5}}{U_{dm}} = \frac{31.294 \times 7.6 + 12.212 \times 18.1}{110} = 4.17(kV)$$

+ Percent voltage drop on N – 5:

$$\Delta U_{N-5}\% = \frac{\Delta U_{N-5}}{U_{dm}} \times 100 = \frac{4.17}{110} \times 100 = 3.8\%$$

$\rightarrow \Delta U_{N-5}^{bt}\% = 3,87\% \leq 10\% \rightarrow$ **Satisfied Technical requirement.**

Similar calculations for N-6 and 6-5, and also the area 2 case 2.

No.	Line	Power losses (MW)	Voltage drop (kV)	Voltage drop (%)
1	**N-5**	0.708	4.17	3.8
	6-5	0.021	0.633	$5.75*10^{-3}$
	N-6	0.58	3.52	3.2
2	**N-3**	0.512	3.595	3.27
	3-4	$6.04*10^{-3}$	0.322	$2.93*10^{-3}$
	N-4	0.495	3.723	3.38

Table 2.34 Power losses and voltage drop on N-5-6, N-3-4 at normal operation

- **Consider N – 5 – 6 – N at fault operation when N-6 breakdown:**
- **Line N – 5 – 6:**

$$\Delta Q''_{C6} = \Delta Q'_{C6} = U^2 \times \frac{b_0 \times l}{2} = 110^2 \times \frac{123.87 \times 10^{-6}}{2} = 0.75(MVAr)$$

$$\Delta Q''_{C5} = \Delta Q'_{C5} = U^2 \times \frac{b_0 \times l}{2} = 110^2 \times \frac{126.1 \times 10^{-6}}{2} = 0.763(MVAr)$$

+ Power at the end of R_6+jX_6 of line 5 – 6:

$$S''_6 = -j\Delta Q''_{C6} + S_6 = 22.5 + j9.05 - 0.j75 = 22.5 + j8.3(MVA)$$

+ Voltage drop on line 5 – 6:

$$\Delta U_{5-6} = \frac{P"_6 \times R_6 + Q"_6 \times X_6}{U_{dm}} = \frac{22.5 \times 9.4 + 8.3 \times 18.42}{110} = 5.1(kV)$$

+ Percent voltage drop on line 5 – 6:

$$\Delta U_{5-6}\% = \frac{\Delta U_{5-6}}{U_{dm}} \times 100 = \frac{5.1}{110} \times 100 = 4.63\%$$

+ Power losses on line 5 – 6:

$$\Delta S_{5-6} = \frac{(P"_6)^2 + (Q"_6)^2}{U^2{}_{dm}} \times (R_6 + jX_6) = \frac{22.5^2 + 8.3^2}{110^2} \times (9.4 + j18.42)$$
$$= 0.875 + j0.0838(MVA)$$

+ Power at the end of R_5+jX_5 of line N – 5:

$$S"_5 = +S_5 + S_6 + \Delta S_6 - j\Delta Q'_{C6} - j\Delta Q"_{C5}$$
$$S"_5 = 22.5 + j8.3 + 35 + 13.69 + 0.875 + 0.838 - j0.763 - j0.75$$
$$S"_5 = 58.375 + j21.315$$

+ Voltage drop on N – 5:

$$\Delta U_{N-5} = \frac{P"_5 \times R_5 + Q"_5 \times X_5}{U_{dm}} = \frac{58.375 \times 7.6 + 21.315 \times 18.1}{110} = 7.54(kV)$$

+ Voltage drop on N – 5:

$$\Delta U_{N-5}\% = \frac{\Delta U_{N-5}}{U_{dm}} \times 100 = \frac{7.54}{110} \times 100 = 6.85\%$$

+ Power losses on N – 5:

$$\Delta S_{N-5} = \frac{(P"_5)^2 + (Q"_5)^2}{U^2{}_{dm}} \times (R_5 + jX_5) = \frac{58.375^2 + 21.315^2}{110^2} \times (7.6 + j18.1)$$
$$= 2.426 + j5.77(MVA)$$

+ Power before resistance of line N – 5:

$$S'_5 = S''_5 + \Delta S_{N-5} = 58.372 + j21.315 + 2.426 + j5.77 = 60.8 + j27.085(MVA)$$

+ Sending power on line N – 5:

$$S_N = S'_5 - j\Delta Q'_{C5} = 60.8 + j27.085 - 0.763 = 60.8 + j26.322(MVA)$$

+ Voltage drop at fault:

$$\Delta U_{N-5-6}\% = \Delta U_{N-5}\% + \Delta U_{5-6}\% = 6.85\% + 4.63\% = 11.48\%$$

$\rightarrow \Delta U^{sc}_{N-5-6}\% = 15,39\% \le 20\% \rightarrow$ **Satisfied technical requirement at fault.**

Similar calculations at fault when N-5 breakdown.

No.	Line	High way	Wire code	$\Delta P(MW)$	$\Delta U_{SC}\%$	Ghi chú
1	N-5	1	AC-185	2.426	**6.85**	N-6 breakdown
	5-6	1	AC-70	0.875	**4.63**	
2	N-6	1	AC-150	3.13	**7.2**	N-5 breakdown
	5-6	1	AC-70	2.117	**7.96**	

Table 2.35 Power losses of area 3 ring at fault

Other ring circuits use similar method of calculating.

⇨ **From the results calculated ,we have a summary table of voltage loss and power loss of all lines as follows:**

No.	Line	High way	Wire code	$\Delta P(MW)$	$\Delta U_{SC}\%$	Note
1	N-3	1	AC-150	2.267	**6.93**	N-4 breakdown
	3-4	1	AC-70	1.25	**5.43**	
2	N-4	1	AC-150	2.416	**6.93**	N-3 breakdown
	3-4	1	AC-70	0.834	**4.41**	
3	N-5	1	AC-185	2.426	**6.85**	N-6 breakdown
	5-6	1	AC-70	0.875	**4.63**	
4	N-6	1	AC-150	3.13	**7.2**	N-5 breakdown
	5-6	1	AC-70	2.117	**7.96**	

Table 2.36 Power losses of all lines in ring circuits at fault

⇨ **Conclusion:** The calculation results all satisfy the following requirements.

At normal operation

$$\Delta U_{\max}\% \leq 10\%$$

And at fault operation

$$\Delta U_{\max}\% \leq 20\%$$

2.3.3.4 Summarize total power losses

No.	Line	Power loss (MW)	Voltage drop (kV)	Voltage drop (%)
1	**N-3**	0.512	3.595	3.27
	3-4	$6.04*10^{-3}$	0.322	$2.93*10^{-3}$
	N-4	0.495	3.723	3.38
2	**N-5**	0.708	4.17	3.8
	6-5	0.021	0.633	$5.75*10^{-3}$
	N-6	0.58	3.52	3.2

Table 2.37 Power losses of all lines in ring circuits at normal operation

No.	Line	High way	Wire code	$\Delta P(MW)$	$\Delta U_{SC}\%$	Note
1	N-3	1	AC-150	2.267	**6.93**	N-4 breakdown
	3-4	1	AC-70	1.25	**5.43**	
2	N-4	1	AC-150	2.416	**6.93**	N-3 breakdown
	3-4	1	AC-70	0.834	**4.41**	
3	N-5	1	AC-185	2.426	**6.85**	N-6 breakdown
	5-6	1	AC-70	0.875	**4.63**	
4	N-6	1	AC-150	3.13	**7.2**	N-5 breakdown
	5-6	1	AC-70	2.117	**7.96**	

Table 2.38 Power losses of all lines in ring circuits at fault operation

2.3.4 Ceramic insulators

Ceramic insulators (also known as Porcelain bushing) are an indispensable part in high-voltage electrical networks, especially overhead high-voltage lines often use ceramic chains hanging at intermediate piers and tensioned porcelain chains at middle piers. The number of ceramic bowls depends on the voltage level.

In the scope of this project design, because the voltage of the electrical network is 110kV, we choose a ceramic insulator with the number of bowls of 8.

The structure of the beam and the electric pillar, the capacitance distributed between the ceramic insulators makes the voltage distribution across the ceramic chains uneven. So the maximum voltage distributed across the ceramic bowl closest to the wire is about 21%.

The voltage E between wire and ground is: $\frac{e_l}{E} = 0,21$.

Performance of ceramic insulators chain:

$$\eta = \frac{E}{n \times e_l} = \frac{1}{n(e_l / E)} = \frac{1}{8 \times 0,21} = 0,595 = 59,5\%$$

In this project, we choose ceramic insulators $\Pi\Phi - 6A$ with a wet test voltage of 32kV at 50Hz. So chain of 8 ceramic insulators will withstand the voltage is:

$$E_{fa} = \frac{32}{0,21} = 152,38(kV) \rightarrow \mathrm{E_{line}} = 152,38\sqrt{3} = 263,92(kV)$$

We have the wire voltage of the electrical network is:

$$U = 110\sqrt{2} = 155,56(kV)$$

After comparing the two results calculated above, we can see that the number of selected ceramic insulators satisfies the insulation requirements of the 110kV grid..

2.3.5 Indicators on resistant capacity by line electricity

We have the formula to calculate the characteristic resistance or pulse resistance of the line is:

$$R_C = \sqrt{\frac{x_0}{b_0}}(\Omega)$$

+ For single line resistance, it is approximate $400\,\Omega$
+ For dual line resistance, it is approximate $200\,\Omega$

Natural capacity or SIL resistance is:

$$SIL = \frac{U^2_{dm}}{R_C}(MW)$$

Reactive capacity is generated by line capacitance per 100km line length:

$$Q_{C(100)} = U^2_{dm}(100 \times b_0)(MVAr)$$

Design criteria is

$$Q_{C(100)} \leq 0,125 \times SIL$$

Because it only require x_0 and b_0, thus only wire code is needed

Wire code	X_0	b_0 $(*10^{-6})$	$R_C = \sqrt{\frac{x_0}{b_0}}(\Omega)$	$SIL = \frac{U^2_{dm}}{R_C}$ (MW)	$Q_{C(100)} = U^2_{dm}(100 \times b_0)$ $(MVAr)$	$0,125 \times SIL$
AC-70	0.441	2.6	411.84	29.38	3.146	3.6725
AC-95	0.453	2.53	423.14	28.595	3.0613	3.5744
AC-150	0.412	2.53	403.54	29.985	3.0613	3.7481
AC-185	0.405	2.82	378.97	31.929	3.4122	3.9911

Table 2.39 Resistant capacity of single conductor lines

Wire code	X_0	b_0	$R_C = \sqrt{\frac{x_0}{b_0}}(\Omega)$	$SIL = \frac{U^2_{dm}}{R_C}$ (MW)	$Q_{C(100)} = U^2_{dm}(100 \times b_0)$ $(MVAr)$	$0{,}125 \times SIL$
AC-70	0.218	5.27	203.39	59.493	6.3767	7.4366
AC-95	0.213	5.4	198.61	60.925	6.534	7.6156
AC-185	0.204	5.6	190.86	63.39	6.776	7.92

Table 2.40 Resistant capacity of dual conductors lines

Case	Line	High way	Wire code	$R_C = \sqrt{\frac{x_0}{b_0}}(\Omega)$	$SIL = \frac{U^2_{dm}}{R_C}$ (MW)	$Q_{C(100)} = U^2_{dm}(100 \times b_0)$ $(MVAr)$	$0{,}125 \times SIL$
1-1	N-1	1	AC-185	378.97	31.929	3.4122	3.9911
	N-2	1	AC-150	403.54	29.985	3.0613	3.7481
1-2	N-1	2	AC-185	190.86	63.39	6.776	7.92
	1-2	1	AC-150	403.54	29.985	3.0613	3.7481
2-1	N-3	2	AC-70	203.39	59.493	6.3767	7.4366
	N-4	2	AC-95	198.61	60.925	6.534	7.6156
2-2	N-3	1	AC-150	403.54	29.985	3.0613	3.7481
	3-4	1	AC-70	411.84	29.38	3.146	3.6725
	N-4	1	AC-150	403.54	29.985	3.0613	3.7481
3-1	N-5	2	AC-95	198.61	60.925	6.534	7.6156
	N-6	2	AC-70	203.39	59.493	6.3767	7.4366
3-2	N-5	1	AC-185	378.97	31.929	3.4122	3.9911
	5-6	1	AC-70	411.84	29.38	3.146	3.6725
	N-6	1	AC-150	403.54	29.985	3.0613	3.7481

Table 2.41 Resistant capacity of every cases

⇨ **From the data summary table 2.34 we can see that all the lines meet the design criteria** $Q_{C(100)} \leq 0{,}125 \times SIL$.

2.3.6 Corona effect

The phenomenon of ionisation of surrounding air around the conductor due to which luminous glow with hissing noise is rise is known as the corona effect.

When the electric field around the surface of the wire exceeds the electrical strength, a corona effect will occur, at this time the electricity of the air is about 21kV / cm. In this electric field, the air is strongly ionized and its electrical strength in the area around the wire is considered to be eliminated, at that time the air is considered to be conducting. This causes the line loss to be increased.

Critical voltage for corona effect:

$$U_0 = 21{,}1.m_0.\delta.r.2{,}303.\log\frac{D}{r}(kV)$$

With

m_0: form factor of the wire surface (m_0 = 1 for round conductors)

δ: air density factor with $\delta = \frac{3.92 \times b}{273 + t}$

which b: air pressure, b = 76 cmHg

t: celsius degree, t = 40°C

=> $\delta = \frac{3.92 \times 76}{273 + 40} = 0.952$

D: Geometric mean distance between phase (cm)

r: conductor’s radius (cm)

Grid’s phase voltage: $U_{fa} = \frac{110}{\sqrt{3}} = 63.51(kV)$

❖ **Line N – 5: Conductor AC – 150, r = 8.5mm=0.85cm**

$$U_0 = 21.1 \times 1 \times 0.952 \times 0.85 \times 2.303 \times \log \frac{462}{0.85} = 107.55(kV)$$

Case	Line	High way	Wire code	Radius	Geometric mean distance between phase	Critical voltage
1-1	N-1	1	AC-185	0.95	462	118.08
	N-2	1	AC-150	0.85	462	107.55
1-2	N-1	2	AC-185	0.95	669	125.99
	1-2	1	AC-150	0.85	462	107.55
2-1	N-3	2	AC-70	0.57	669	81.442
	N-4	2	AC-95	0.675	669	94.152
2-2	N-3	1	AC-150	0.85	462	107.55
	3-4	1	AC-70	0.57	462	76.7
	N-4	1	AC-150	0.85	462	107.55
3-1	N-5	2	AC-95	0.675	669	94.152
	N-6	2	AC-70	0.57	669	81.442
3-2	N-5	1	AC-185	0.95	462	118.08
	5-6	1	AC-70	0.57	462	76.7
	N-6	1	AC-150	0.85	462	107.55

Table 2.42 Critical voltage of all lines to create corona effect

Based on data summary 2.42 we can see the minimum critical voltage. So there is no corona effect loss due to

$$U_{fa} = \frac{110}{\sqrt{3}} = 63.51(kV) < U_{0\min} = 76.7(kV) .$$

2.4 Calculate economical indicators

2.4.1 Calculation of the annual total consumer charge for each method

The economic indicator used to compare options is the annual calculated costs, determined by the formula:

$$Z = (a_{vh} + a_{tc}) \times K + c \times \Delta A$$

Where:

- K: Investment for electric network
- a_{vh}: Power network operation and repair coefficient.

  For the transmission lines on steel poles a_{vh}=7%

  For the transmission lines on reinforced concrete poles a_{vh}=4%
- a_{tc}: Coefficient of return of sub-investment (difference between options). With atc = 1/Ttc and Ttc = 5÷8 years is the standard time to recover sub-investment depending on the state's use policy. Normally atc = 0.125 - 0.2, select atc = 0,125.
- c: The cost of 1 kWh of lost power is c = 0.065 ($/kWh) = 65($/MWh)
- ΔA: Electrical power loss, $\Delta A = \Delta P_{\Sigma} \times \tau$

  where ΔP_{Σ}: The total power losses for each area were calculated before

  τ: time of maximum power loss. Can be approximate by formula:

  $$\tau = (0,124 + \frac{T_{\max}}{10^4})^2 \times 8760 = (0,124 + \frac{5000}{10^4})^2 \times 8760 = 3410,93 \text{(hours/year)}$$

Conductor	Highway	Cost per 1 km length (10^3\$)	Mass (kg/km/phase)
AC – 70	1	15.4	275
AC – 95	1	16	286
AC – 150	1	17.3	617
AC - 185	1	18	771
AC – 70	2	32.1	275
AC – 95	2	33.2	286
AC – 150	2	35.7	617
AC - 185	2	37.3	771

Table 2.43 Cost per length and mass of each line

2.4.1.1 Area 1 case 1

Line	Highway	Conductor	Length (km)	Cost of 1 km length ($10^3$$)	Total cost ($)
N – 1	1	AC – 185	44.72	18	804 960
N - 2	1	AC - 150	41.23	17.3	713 279
The total cost of the area's line investment K=					**1 518 239**

Table 2.44 Investment cost of Area 1 case 1

Power loss

$$\Delta P_{\Sigma} = 1.311(MW)$$
$$\tau = 3410.93$$

⇨ $\Delta A = \Delta P_{\Sigma} \times \tau = 1.311 \times 3410.93 = 4471.73$ (MWh/year)

⇨ **Cost annually:**

⇨ $Z = (a_{vh\_betong} + a_{tc}) \times K + c \times \Delta A = (4\% + 0{,}125) \times 1518239 + 65 \times 4471.73$
$= 541171.885$

No.	Line	Highway	Wire code	Length (km)	Mass (kg/km/phase)	Mass of 3 phase (ton)
1	N – 1	1	AC – 185	44.72	771	103.437
2	N - 2	1	AC - 150	41.23	617	76.31
Total amount of non-ferrous metal used						**179.747**

Table 2.45 Non-ferrous metal used of Area 1 case 1

⇨ **From the calculation results, we make the table of economic indicators for Area 1 as follows:**

indicators	**Unit**	**Value**
Investment K	$	1 518 239
Power loss ΔA	MWh	4471.73
$\Delta U\%$ **max**	%	3.73
Non-ferrous metal used	Ton	179.747
Cost annually Z	$	541 171.885

Table 2.46 Summary of economic indicators of Area 1 case 1

2.4.1.2 Area 1 case 2

Line	Highway	Conductor	Length (km)	Cost of 1 km length ($10^3$$)	Total cost ($)
N – 1	2	AC – 185	44.72	37.3	1 668 056
1 – 2	1	AC - 150	36.05	17.3	713 279
The total cost of the area's line investment K=					**2 381 335**

Table 2.47 Investment cost of Area 1 case 2

Power loss

$$\Delta P_{\Sigma} = 1.685(MW)$$
$$\tau = 3410.93$$

⇨ $\Delta A = \Delta P_{\Sigma} \times \tau = 1.685 \times 3410.93 = 5747.42$ (MWh/year)

⇨ **Cost annually:**

$$Z = (a_{vh\_betong} + a_{tc}) \times K_{betong} + (a_{vh\_thep} + a_{tc}) \times K_{thep} + c \times \Delta A$$
⇨ $$= (4\% + 0,125) \times 713279 + (7\% + 0,125) \times 1668056 + 65 \times 5747.42$$
$$= 816544.255$$

No.	Line	Highway	Wire code	Length (km)	Mass (kg/km/phase)	Mass of 3 phase (ton)
1	N – 1	2	AC – 185	44.72	771	206.87
2	1 - 2	1	AC - 150	36.05	617	66.73
Total amount of non-ferrous metal used						**273.6**

Table 2.48 Non-ferrous metal used of Area 1 case 2

⇨ **From the calculation results, we make the table of economic indicators for Area 1 as follows:**

indicators	Unit	Value
Investment K	$	2 381 335
Power loss ΔA	MWh	5747.42
$\Delta U\%$ **max**	%	8.95
Non-ferrous metal used	Ton	273.6
Cost annually Z	$	816 544.255

Table 2.49 Summary of economic indicators of Area 1 case 2

2.4.1.3 Area 2 case 1

Line	Highway	Conductor	Length (km)	Cost of 1 km length ($10^3$$)	Total cost ($)
N – 3	2	AC – 70	41.23	32.1	1 323 483
N – 4	2	AC - 95	44.72	33.2	1 484 704
The total cost of the area's line investment K=					**2 808 187**

Table 2.50 Investment cost of Area 2 case 1

Power loss

$$\Delta P_{\Sigma} = 1.012(MW)$$
$$\tau = 3410.93$$

⇨ $\Delta A = \Delta P_{\Sigma} \times \tau = 1.012 \times 3410.93 = 3451.86$ (MWh/year)

⇨ **Cost annually:**

$$Z = (a_{vh\_thep} + a_{tc}) \times K_{thep} + c \times \Delta A$$
⇨ $$= (7\% + 0{,}125) \times 2808187 + 65 \times 3451.86$$
$$= 771967.365$$

No.	Line	Highway	Wire code	Length (km)	Mass (kg/km/phase)	Mass of 3 phase (ton)
1	N – 3	2	AC – 70	41.23	275	68
2	N – 4	2	AC - 95	44.72	386	103.57
Total amount of non-ferrous metal used						**171.57**

Table 2.51 Non-ferrous metal used on Area 2 case 1

⇨ **From the calculation results, we make the table of economic indicators for Area 2 as follows:**

indicators	Unit	Value
Investment K	$	2 808 187
Power loss ΔA	MWh	3451.86
$\Delta U\%$ **max**	%	2.61
Non-ferrous metal used	Ton	171.57
Cost annually Z	$	771 967.365

Table 2.52 Summary of economic indicators of Area 2 case 1

2.4.1.4 Area 2 case 2

Line	Higway	Conductor	Length (km)	Cost of 1 km length ($10^3$$)	Total cost ($)
N – 3	1	AC – 150	41.23	17.3	713 279
3 – 4	1	AC – 70	36.05	12.6	454 230
N - 4	1	AC - 150	44.72	17.3	773 656
The total cost of the area's line investment K=					**1 941 165**

Table 2.53 Investment cost of Area 2 case 2

Power loss

$$\Delta P_{\Sigma} = 1.013(MW)$$
$$\tau = 3410.93$$

⇨ $\Delta A = \Delta P_{\Sigma} \times \tau = 1.013 \times 3410.93 = 3455.27$ (MWh/year)

⇨ **Cost annually:**

$$Z = (a_{vh\_betong} + a_{tc}) \times K_{betong} + c \times \Delta A$$
⇨ $$= (4\% + 0,125) \times 1941165 + 65 \times 3455.27$$
$$= 544884.775$$

No.	Line	Highway	Wire code	Length (km)	Mass (kg/km/phase)	Mass of 3 phase (ton)
1	N – 3	1	AC – 150	41.23	617	76.316
2	3 – 4	1	AC – 70	36.05	275	29.741

3	N – 4	1	AC - 150	44.72	617	82.776
Total amount of non-ferrous metal used						**188.834**

Table 2.54 Non-ferrous metal used of Area 2 case 2

⇨ **From the calculation results, we make the table of economic indicators for Area 2 as follows:**

indicators	Unit	Value
Investment K	$	1 941 165
Power loss ΔA	MWh	3455.27
$\Delta U\%$ **max**	%	3.38
Non-ferrous metal used	Ton	188 .834
Cost annually Z	$	544 884.775

Table 2.55 Summary of economic indicators of Area 2 case 2

2.4.1.5 Area 3 case 1

Line	Highway	Conductor	Length (km)	Cost of 1 km length (10^3\$)	Total cost (\$)
N – 5	2	AC – 95	44.72	33.2	1 484 704
N – 6	2	AC - 70	44.72	32.1	1 435 512
The total cost of the area's line investment K=					**2 920 216**

Table 2.56 Investment cost of Area 3 case 1

Power loss

$$\Delta P_{\Sigma} = 1.32(MW)$$
$$\tau = 3410.93$$

⇨ $\Delta A = \Delta P_{\Sigma} \times \tau = 1.32 \times 3410.93 = 4502.432$ (MWh/year)

⇨ **Cost annually:**

⇨ $$Z = (a_{vh\_thep} + a_{tc}) \times K_{thep} + c \times \Delta A$$
$$= (7\% + 0,125) \times 2920216 + 65 \times 34502.432$$
$$= 862100.2$$

No.	Line	Highway	Wire code	Length (km)	Mass (kg/km/phase)	Mass of 3 phase (ton)
1	N – 5	2	AC – 95	4.72	386	103.303
2	N – 6	2	AC - 70	44.72	275	73.788
Total amount of non-ferrous metal used						**177.09**

Table 2.57 Non-ferrous metal used of Area 3 case 1

⇨ **From the calculation results, we make the table of economic indicators for Area 3 as follows:**

indicators	Unit	Value
Investment K	$	2 920 216
Power loss ΔA	MWh	4502.432
$\Delta U\%$ **max**	%	3.11
Non-ferrous metal used	Ton	177.09
Cost annually Z	$	862 100.2

Table 2.58 Summary of economic indicators of Area 3 case 1

2.4.1.6 Area 3 case 2

Line	Highway	Conductor	Length (km)	Cost of 1 km length (10^3\$)	Total cost (\$)
N – 5	1	AC – 185	44.72	18	804 960
5 – 6	1	AC – 70	40	16.4	616 000
N - 6	1	AC - 150	44.72	17.3	773 656
The total cost of the area's line investment K=					**2 194 616**

Table 2.59 Investment cost of Area 3 case 2

Power loss

$$\Delta P_{\Sigma} = 1.309(MW)$$
$$\tau = 3410.93$$

⇨ $\Delta A = \Delta P_{\Sigma} \times \tau = 1.309 \times 3410.93 = 4464.912$ (MWh/year)

⇨ **Cost annually:**

$$Z = (a_{vh\_betong} + a_{tc}) \times K_{betong} + c \times \Delta A$$

⇨ $= (4\% + 0,125) \times 2194616 + 65 \times 4464.912$

$= 652330.92$

No.	Line	Highway	Wire code	Length (km)	Mass (kg/km/phase)	Mass of 3 phase (ton)
1	N – 6	1	AC – 185	44.72	771	103.437
2	5 – 6	1	AC – 70	40	275	33
3	N – 6	1	AC - 150	44.72	617	82.776
Total amount of non-ferrous metal used						219.214

Table 2.60 Non-ferrous metal used of Area 3 case 2

⇨ **From the calculation results, we make the table of economic indicators for Area 2 as follows:**

Indicators	Unit	Value
Investment K	$	2 194 616
Power loss ΔA	MWh	4464.912
$\Delta U\%$ **max**	%	3.8
Non-ferrous metal used	Ton	219.214
Cost annually Z	$	652 330.92

Table 2.61 Summary of economic indicators of Area 3 case 2

2.4.2 Probability of electrical supply network 's disturbance

Parameter	Probability of fault in a year λ (times/year)	Incident recovery time (fix) r_{sc} (hours/times)	Periodic repair time r_{ts} (hours/year)
Transformer 110kV	0,01	90	25
Line 110kV	0,6	8 to 10	20
Cutting machine	0,0012	15	
Isolation knife	0,006	15	

Table 2.62 Times for maintain, fixing parameters of network

2.4.2.1 PROBABILITY OF SINGLE CONDUCTOR ELECTRICAL SUPPLY NETWORK'S DISTURBANCE

Area 3 case 2 is a single conductor line network, thus :

❖ **Probability to stop power supply due to line repair:**

Line N – 5: $f_d = \dfrac{r_{tsd}}{8760} \times \dfrac{l}{100} = \dfrac{20}{8760} \times \dfrac{44,72}{100} = 1,021 \times 10^{-3}$

Line 5 – 6: $f_d = \dfrac{r_{tsd}}{8760} \times \dfrac{l}{100} = \dfrac{20}{8760} \times \dfrac{40}{100} = 0,913 \times 10^{-3}$

Line N – 6: $f_d = \dfrac{r_{tsd}}{8760} \times \dfrac{l}{100} = \dfrac{20}{8760} \times \dfrac{44,72}{100} = 1,021 \times 10^{-3}$

❖ **The probability of one line failure:**

Line N – 5: $q_d = \dfrac{r_{scd} \times \lambda_d}{8760} \times \dfrac{l}{100} = \dfrac{0,6 \times 8}{8760} \times \dfrac{44,72}{100} = 0,245 \times 10^{-3}$

Line 5 – 6: $q_d = \dfrac{r_{scd} \times \lambda_d}{8760} \times \dfrac{l}{100} = \dfrac{0,6 \times 8}{8760} \times \dfrac{40}{100} = 0,219 \times 10^{-3}$

Line N – 6: $q_d = \frac{r_{scd} \times \lambda_d}{8760} \times \frac{l}{100} = \frac{0,6 \times 8}{8760} \times \frac{44,72}{100} = 0,245 \times 10^{-3}$

❖ **Isolation knife failure probability of the whole area:**

$$q_{dcl} = \frac{\lambda_{cl} \times r_{sc.cl}}{8760} = \frac{0,006 \times 15}{8760} = 0,0103 \times 10^{-3}$$

\+ **The probability of cutting machine failure in the whole area**

$$q_{mc} = \frac{\lambda_{mc} \times r_{sc.mc}}{8760} = \frac{0,0012 \times 15}{8760} = 0,002 \times 10^{-3}$$

❖ **Transformer failure probability:**

$$q_{ba} = \frac{\lambda_{ba} \times r_{sc.ba}}{8760} = \frac{0,01 \times 90}{8760} = 0,103 \times 10^{-3}$$

❖ **Probability of power outage in the whole area:**

Line N – 5:

$$h = q_{dcl} + q_{mc} + q_{dcl} + q_d + f_d + q_{dcl} + q_{mc} + q_{dcl} + (q_{dcl} + q_{ba} + q_{mc})^2$$
$$= 0,0103 + 0,002 + 0,0103 + 0,245 + 1,021 + 0,0103 + 0,002 + 0,0103 + (0,0103 + 0,103 + 0,002)^2$$
$$= 1,311 \times 10^{-3}$$

Line 5 – 6:

$$h = q_{dcl} + q_{mc} + q_{dcl} + q_d + f_d + q_{dcl} + q_{mc} + q_{dcl} + (q_{dcl} + q_{ba} + q_{mc})^2$$
$$= 0,0103 + 0,002 + 0,0103 + 0,219 + 0,913 + 0,0103 + 0,002 + 0,0103 + (0,0103 + 0,103 + 0,002)^2$$
$$= 1,177 \times 10^{-3}$$

Line N – 6:

$$h = q_{dcl} + q_{mc} + q_{dcl} + q_d + f_d + q_{dcl} + q_{mc} + q_{dcl} + (q_{dcl} + q_{ba} + q_{mc})^2$$
$$= 0,0103 + 0,002 + 0,0103 + 0,245 + 1,021 + 0,0103 + 0,002 + 0,0103 + (0,0103 + 0,103 + 0,002)^2$$
$$= 1,311 \times 10^{-3}$$

⇨ **Probability of stopping power supply in area 3 case 2:**

$$1,311\times10^{-3}+1,177\times10^{-3}+1,311\times10^{-3}=3,799\times10^{-3}$$

Similar calculations apply for other single conductor line network.

No.	Case	Line	Fault probability
1	Area 1 case 1	N – 1, N – 2	$2.554*10^{-3}$
2	Area 2 case 2	N – 3 – 4	$3.625*10^{-3}$
3	Area 3 case 2	N – 3 – 5	$3.845*10^{-3}$
4	Area 1 case 2	1 – 2	$1.065*10^{-3}$

Table 2.63 Probability of power supply disturbance of single conductor lines

2.4.2.2 Probability of dual conductor electrical supply network's disturbance

Area 2 case 1 is a dual conductors line network, thus

❖ **The probability of repairing each circuit:**

Line N – 3: $fd=\frac{r_{tsd}}{8760}\times\frac{l}{100}=\frac{20}{8760}\times\frac{41,23}{100}=0,941\times10^{-3}$

Line N – 4: $fd=\frac{r_{tsd}}{8760}\times\frac{l}{100}=\frac{20}{8760}\times\frac{44,72}{100}=1,021\times10^{-3}$

❖ **Probability of a separate line failure (assuming 10% of the failure is a breakdown of both lines)**

Line N – 3: $q_d^{'}=\frac{(1-0,1)\times\lambda_d\times r_{sc.d}}{8760}\times\frac{l}{100}=\frac{(1-0,1)\times0,6\times8}{8760}\times\frac{41,23}{100}=0,203\times10^{-3}$

Line N – 4: $q_d^{'}=\frac{(1-0,1)\times\lambda_d\times r_{sc.d}}{8760}\times\frac{l}{100}=\frac{(1-0,1)\times0,6\times8}{8760}\times\frac{44,72}{100}=0,22\times10^{-3}$

❖ **The probability of failure on both lines at the same time:**

Line N – 3: $q_d^{''}=\frac{0,1\times\lambda_d\times r_{sc.d}}{8760}\times\frac{l}{100}=\frac{0,1\times0,6\times8}{8760}\times\frac{41,23}{100}=0,022\times10^{-3}$

Line N – 4: $q_d^{''} = \frac{0,1\times\lambda_d\times r_{sc.d}}{8760}\times\frac{l}{100} = \frac{0,1\times 0,6\times 8}{8760}\times\frac{44,72}{100} = 0,024\times 10^{-3}$

- **Isolation knife failure probability of the whole area:**

$$q_{dcl} = \frac{\lambda_{cl}\times r_{sc.cl}}{8760} = \frac{0,006\times 15}{8760} = 0,0103\times 10^{-3}$$

The probability of cutting machine failure in the whole area

$$q_{mc} = \frac{\lambda_{mc}\times r_{sc.mc}}{8760} = \frac{0,0012\times 15}{8760} = 0,002\times 10^{-3}$$

- **Transformer failure probability:**

$$q_{ba} = \frac{\lambda_{ba}\times r_{sc.ba}}{8760} = \frac{0,01\times 90}{8760} = 0,103\times 10^{-3}$$

- **Probability of power outage in the whole area:**

Line N – 3:

$$h = q_d^{''} + 2\times k(f_d + 4\times q_{dcl} + 2\times q_{mc})\times q_d^{'} + (q_{dcl} + q_{ba} + q_{mc})^2$$
$$= 0,022\times 10^{-3} + 2\times 0,3[(0,941 + 4\times 0,0103 + 2\times 0,002)\times 10^{-3}]\times 0,203\times 10^{-3} + [(0,0103 + 0,002 + 0,103)\times 10^{-3}]^2$$
$$= 0,022\times 10^{-3}$$

Line N – 4:

$$h = q_d^{''} + 2\times k(f_d + 4\times q_{dcl} + 2\times q_{mc})\times q_d^{'} + (q_{dcl} + q_{ba} + q_{mc})^2$$
$$= 0,024\times 10^{-3} + 2\times 0,3[(1,021 + 4\times 0,0103 + 2\times 0,002)\times 10^{-3}]\times 0,22\times 10^{-3} + [(0,0103 + 0,002 + 0,103)\times 10^{-3}]^2$$
$$= 0,024\times 10^{-3}$$

⇨ **Probability of stopping power supply of area 2 (case 1):**

$$0,022\times 10^{-3} + 0,024\times 10^{-3} = 0,046\times 10^{-3}$$

Similar calculations apply for other dual conductors line network.

No.	Case	Line	Fault probability
1	Area 2 case 1	N – 3, N – 4	$8.44*10^{-5}$
2	Area 3 case 1	N – 5, N – 6	$6.2*10^{-5}$
3	Area 1 case 2	N – 1	$2.4*10^{-5}$

Table 2.64 Probability of power supply disturbance of dual conductors lines

2.4.3 Summary and provide optimization

Area	Indicators	Unit	Case 1 value	Case 2 value
1	**Investment K**	$	1 518 239	2 381 335
	Power loss ΔA	MWh	4471.73	5747.42
	$\Delta U\%$ **max**	%	3.73	8.95
	Non-ferrous metal used	Ton	179.747	273.6
	Cost annually Z	$	541 171.885	816 544.255
	Failure probability	%	$2.554*10^{-3}$	$1.074*10^{-3}$

Table 2.65 Summary of economy indicators of Area 1

Area	Indicators	Unit	Case 1 value	Case 2 value
2	**Investment K**	$	2 808 187	1 941 165
	Power loss ΔA	MWh	3451.86	3455.27
	$\Delta U\%$ **max**	%	2.61	3.38
	Non-ferrous metal used	Ton	171.57	188.834
	Cost annually Z	$	771 967.365	544 884.775
	Failure probability	%	$8.44*10^{-5}$	$3.625*10^{-3}$

Table 2.66 Summary of economy indicators of Area 2

Area	Indicators	Unit	Case 1 value	Case 2 value
3	**Investment K**	$	2 920 216	2 194 616
	Power loss ΔA	MWh	4502.432	4464.912
	$\Delta U\%$ **max**	%	3.11	3.8
	Non-ferrous metal used	Ton	177.09	219.214
	Cost annually Z	$	862 100.2	652 330.92
	Failure probability	%	$6.2*10^{-5}$	$3.845*10^{-3}$

Table 2.67 Summary of economy indicators of Area 2

After considering all indicators of technical and economic, i have come to the final conclusion. The most optimal case of every area is :

- Area 1 case 1 : Star circuit
- Area 2 case 2 : Ring circuit
- Area 3 case 2 : Ring circuit

Indicators	Unit	Value
Investment K	$	5654020
Power loss ΔA	MWh	12391.912
$\Delta U\%$ **max**	%	10.91
Non-ferrous metal used	Ton	587.795
Cost annually Z	$	1738387.58
Failure probability	%	10.024

Table 2.68 Summary of economy indicators of optimal options

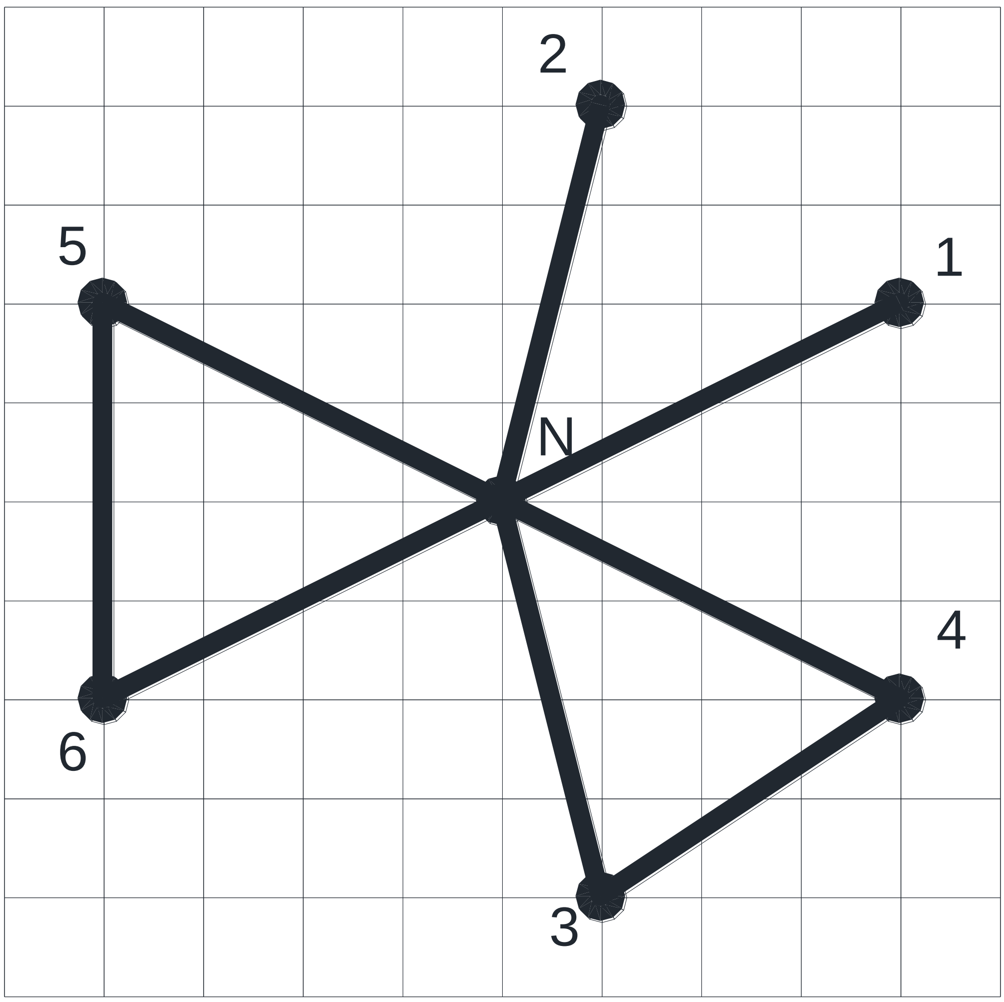


Figure 2.22 Optimal choice

CHAPTER 3. DETERMINATION OF RATED POWER TRANSFORMERS IN DISTRIBUTION STATION. STATION WIRING, AND NETWORK WIRING DIAGRAMS

3.1 Requirements

- he wiring outline should work as indicated by the accompanying necessities: Ensuring dependability and effortlessness, however the activity cycle should be adaptable, conservative or more all, guarantee wellbeing for individuals and hardware.
- In the design scope of this project, the power plant side only needs to start from the plant's high-voltage busbar.
- Select the limit and number of transformers dependent on the power supply necessities of each kind of load (note: a load with a pre-remunerated reactive limit should be utilized).
- In the scope of this project, no short-circuit calculation is required, but the diagram must show the proper placement of the circuit breaker.

3.2 Selecting the number and rated power of transformers

Transformer type:

- Use 3-phase 2-coil isolation transformers.
- Transformer has voltage change under load or ordinary voltage change as indicated by prerequisites.
- Number of transformers: Depends on the power supply requirement of the load.
- We choose 2 transformers for the load requiring uninterrupted power supply.
- We choose 1 transformer for the load requiring intermittent power supply.

3.3 Rated power of transformers

- For a station with 1 transformer, choose the capacity of the transformer according to the condition

$$S_{dmB} \geq S_{pt\max}$$

- For a station with 2 transformers, we should choose based on the following condition

$$S_{dmB} \geq \frac{S_{SC}}{1,4}$$

With:

S_{SC}: It is the capacity to be provided when a transformer failure occurs, in case the load is not cut off.

1.4: It is the passable factor for a transformer to overload 40% when a transformer disappointment happens with an overloaded season of 6 hours in 1 day and night and keeps going close to 5 days and evenings.

3.4 Selecting transformers

Load	P	Q-Q$_b$	S	Transformer quantity	Continuous required	Rated power
1	31.5	12.35	33.83	1	No	40
2	27.5	10.04	29.27	1	No	30
3	22.5	10.69	24.91	2	Yes	20
4	27.5	13.32	30.55	2	Yes	25
5	35	13.69	37.58	2	Yes	30
6	22.5	9.05	24.25	2	Yes	20

Table 3.1 Transformers selection

3.5 Calculation formulas and transformer parameters

– **Resistance:** $R_B = \frac{\Delta P_N \times U_{dm}^2}{S_{dm}^2} \times 10^3 (\Omega)$

- **Impedance:** $Z_B = \frac{U_N\%\times U_{dm}^2}{S_{dm}}\times 10(\Omega)$
- **Reactance:** $X_B = \sqrt{Z_B^2 - R_B^2}(\Omega)$
- **Resistance power loss in iron of a machine::**

$$\Delta Q_{Fe} = \frac{i_0\%\times S_{dm}}{100}(kVAr)$$

- **Active power loss in steel core::**

$$\Delta P_{Fe} = \Delta P_0$$

Where:

$\Delta P_N(k\mathrm{W})$; $U_{dm}(kV)$; $S_{dm}(KVA)$

R_B in station with 2 transformers = R_B of 1 transformer/2

X_B in station with 2 transformers = X_B of 1 transformer /2

ΔP_{Fe} in station with 2 transformers = ΔP_{Fe} of 1 transformer $\times 2$

ΔQ_{Fe} in station with 2 transformers = ΔQ_{Fe} of 1 transformer $\times 2$

Station	Transformer	Rated Power (MW)	Rated Voltage (kV)	ΔP_N (kW)	ΔP_{Fe} (kW)	%U	%i	R	X	ΔQ_{Fe} (kVar)
1	1	40	110	175	42	10.5	0.7	1.32	31.78	280
2	1	30	110	132	17	13	0.15	1.775	52.4	45
3	2	20	110	163	120	10.5	3	2.45	31.67	1200
4	2	25	110	120	58	10.5	0.8	1.16	25.38	400
5	2	30	110	132	34	13	0.15	0.885	26.2	90
6	2	20	110	163	120	10.5	3	2.45	31.67	1200

Table 3.2 Transformers' parameters

CHAPTER 4. DETERMINATION OF ECONOMIC COMPENSATION AND TOTAL POWER LOSS

4.1 Calculation contents

- Economic remuneration as well as expanding line Cosφ it is additionally a technique to help decrease power misfortune and limit misfortune.
- In the extent of this undertaking, we need to focus on the financial remuneration to build the Cosφ of the line and decrease the power misfortune by putting static pay in the electrical network as opposed to utilizing a coordinated compensator on the grounds that in the plan of the capacitor network. compensators are all the more regularly utilized in light of the fact that capacitors devour almost no P (active power) power. Furthermore, the utilization of pay capacitors additionally has advantages, for example, financial capacitors that are modest, don't have similar working expenses as the remuneration machine because of less misfortunes than compensators, actually, the capacitor is not difficult to fix and upkeep.

4.2 Calculations requirements

- Calculate using reactive power of the load before preliminary compensation.
- The iron loss of the transformer and the reactive capacity due to line capacitance is not considered.
- Power loss P (active power) is not considered.
- Consider only the resistance of the line and of the transformer.
- Set the offset capacity Q at each load as an unknown number and then write the equation for the computational loss cost Z of the electrical network due to the economical compensation equipment.
- Calculate the partial derivative $\frac{\delta_Z}{\delta Q_{bui}}$ and let it be zero.

- Proceed to solve the system of linear first-order equations the unknown number Q_b.
- If solving the power $Q_{b,i} = 0$, the ith load does not need to be compensated, we subtract one partial derivative equation I and for the remaining equations $Q_{b,i} = 0$ and solve the system of equations n - 1 hidden number Q_b
- Attention: If $Q_{b,i}$ have smaller than zero result, we have to solve it again and we should only compensate Cosφ to 0.95 to be economically effective.

4.3 Economic compensation

Cost calculation: $Z=Z_1+Z_2+Z_3$

– **Annual cost due to investment in equipment is compensated:**

$$Z_1 = (a_{vh} + a_{tc}) \times K_0 \times Q_{bu}$$

Where:

K_0: cost of 1 unit capacity compensation equipment, with

$$K_0 = 5\$ / kVAr = 5 \times 10^3 \$ / MVAr$$

a_{vh}: the operating coefficient of the compensation device, with $a_{vh} = 0,1$

a_{tc}: return coefficient of additional investment, with $a_{tc} = 0,125$

– **Costs due to power loss:**

$$Z_2 = c \times T \times \Delta P^* \times Q_b$$

Which:

c: Cost 1 MWh of power loss, with $c = 0,05\$ / kWh = 50\$ / MWh$

ΔP^*: Loss of capacity of compensation equipment, with static capacitors equal to: $\Delta P^* = 0,005$

T: capacitor operating time, if the operation is 1 year, then T=8760 (h)

– **Cost of power loss due to capacity components of the transmission line and transformer after installation of compensation equipment:**

$$Z_3 = c \times \Delta P \times \tau$$

Where:

c: Cost 1 MWh of power loss, with $c = 0,05\$ / kWh = 50\$ / MWh$

ΔP : Line and transformer losses, with $\Delta P = \frac{(Q - Q_{bu})^2}{U^2} \times R$

τ : Time maximum power loss, with $\tau = 3410,9(h)$

4.3.1 Area 1

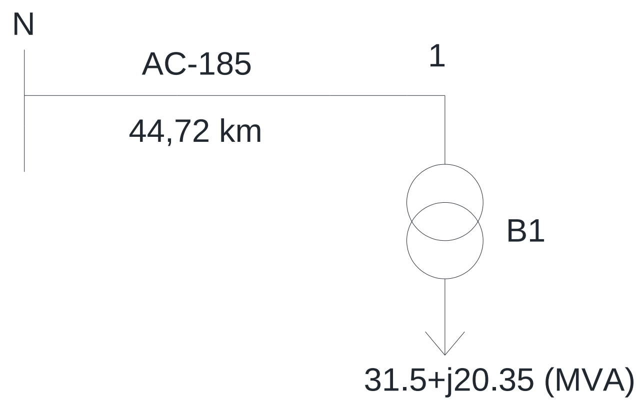


Figure 4.1

The transformer winding resistance is directed toward 110kV:

$$R_{B1} = \frac{\Delta P_N \times U_{dm}^2}{S_{dm}^2} \times 10^3 = \frac{175 \times 110^2}{40000^2} \times 10^3 = 1.32(\Omega)$$

Line resistance:

$$R_{N-1} = 0.17 \times 44.72 = 7.6024(\Omega)$$

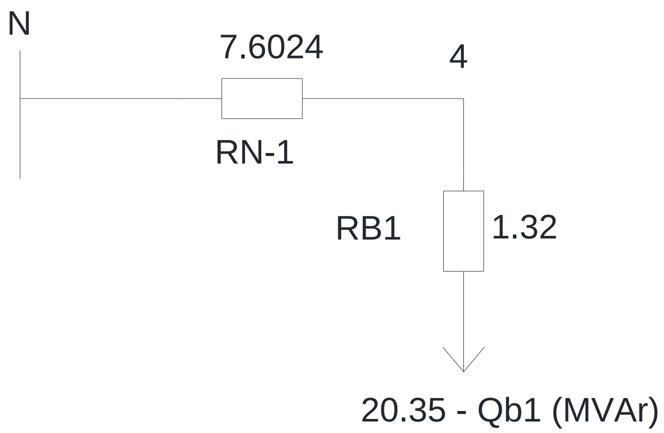


Figure 4.2

Cost calculation: Z=Z$_1$+Z$_2$+Z$_3$

$$Z_1 = (a_{vh} + a_{tc}) \times K_0 \times Q_{bu} = (0,1+0,125) \times 5000 \times Q_{bu1} = 1125 \times Q_{bu1}$$

$$Z_2 = c \times T \times \Delta P^* \times Q_b = 65 \times 0,005 \times 8760 \times Q_{bu1} = 2847 \times Q_{bu1}$$

$$Z_3 = c \times \Delta P \times \tau = \frac{c \times \tau}{U^2} \times (Q_1 - Q_{bu1})^2 \times (R_{N-1} + R_{B1})$$
$$= \frac{65 \times 3410,9}{110^2} \times (20.35 - Q_{bu1})^2 \times (7.062 + 1.32)$$
$$= 163.48 \times (20.35 - Q_{bu1})^2$$

$$Z = Z_1 + Z_2 + Z_3 = 1125 \times Q_{bu1} + 2847 \times Q_{bu1} + 163.48 \times (20.35 - Q_{bu1})^2$$
$$= 163.48 Q_{bu1}{}^2 + 2681.6 Q_{bu1} + 67700$$

Calculate its Partial derivative

$$\frac{d_Z}{dQ_{bu1}} = 326.96 Q_{bu1} - 2681.6 = 0$$

$$Q_{bu1} = 8.2 (MVAr)$$

Power factor at load after compensation

$$\tan\varphi_1^{'} = \frac{Q_1 - Q_{bu1}}{P_1} = \frac{20.35 - 8.2}{19} = 0,37 \rightarrow Cos\varphi_1^{'} = 0,933$$

- ⇨ **Thus Q$_{bu1}$= 8.2 (MVAr)**

Similar calculations used for Load 2. Thus

$$Q2 = 6.65 (MVAr)$$

$$Cos\varphi_1^{'} = 0,935$$

Load	P_{pt} (MW)	$\cos\varphi$	Q_{pt} (MVAr)	Q_b (MVAr)	$Q_{pt} - Q_b$ (MVAr)	S (MVA)	S' (MVA)	$\cos\varphi^{'}$
1	31.5	0.84	20.35	8.2	12.15	37.5	33.76	0.933
2	27.5	0.85	17.04	6.65	10.39	32.35	29.4	0.935

Table 4.1 Economic compensation for Load 1 and 2

4.3.2 Area 3 and Area 2

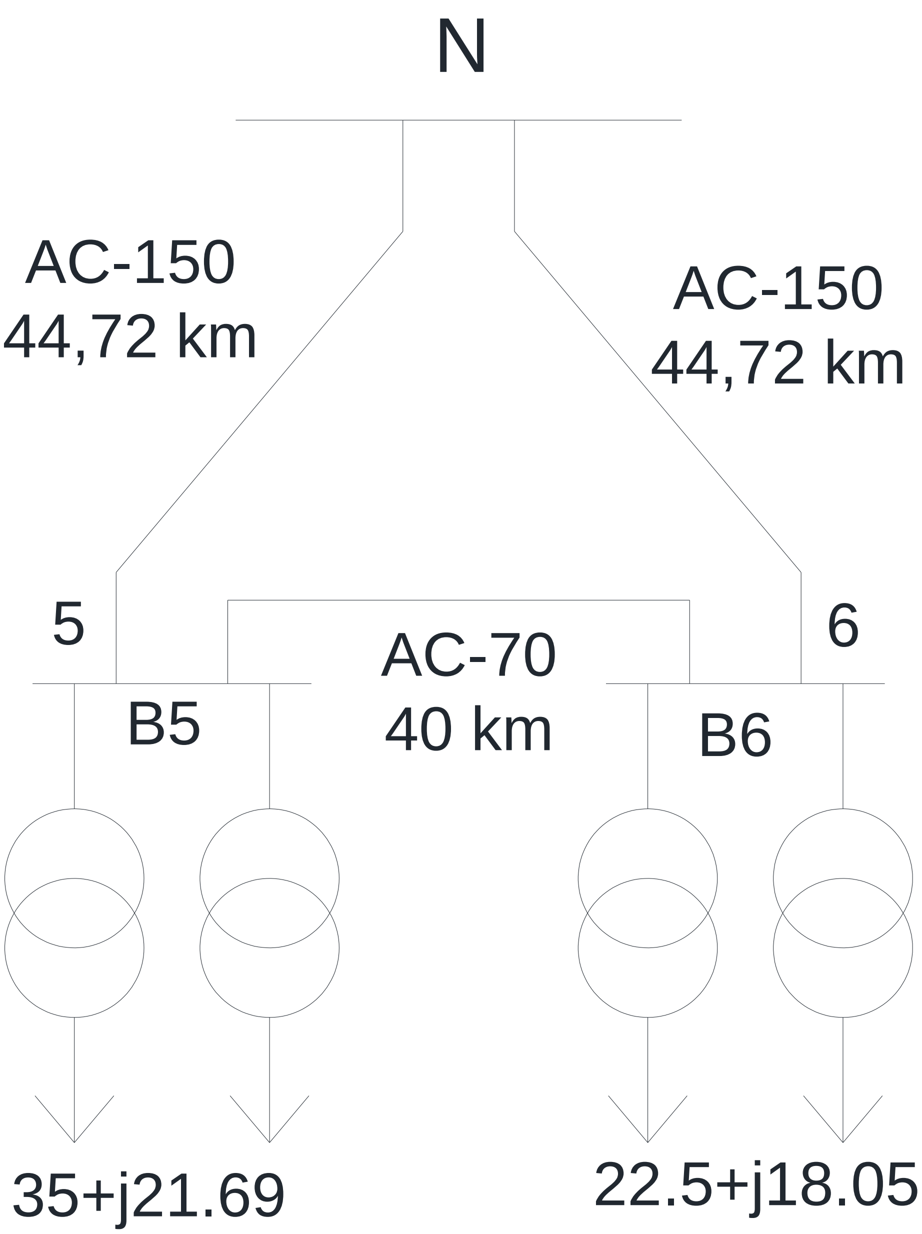


Figure 4.3

The transformer winding resistance is directed toward 110kV:

$$R_{B5} = \frac{\Delta P_N \times U_{dm}^2}{2 \times S_{dm}^2} \times 10^3 = \frac{132 \times 110^2}{2 \times 30000^2} \times 10^3 = 0.885(\Omega)$$

$$R_{B6} = \frac{\Delta P_N \times U_{dm}^2}{2 \times S_{dm}^2} \times 10^3 = \frac{163 \times 110^2}{2 \times 20000^2} \times 10^3 = 2.45(\Omega)$$

Line resistance:

$$R_{N-6} = 0.21 \times 44.72 = 9.4(\Omega)$$

$$R_{5-6} = 0.46 \times 40 = 18.4(\Omega)$$

$$R_{N-5} = 0.17 \times 44.72 = 7.6(\Omega)$$

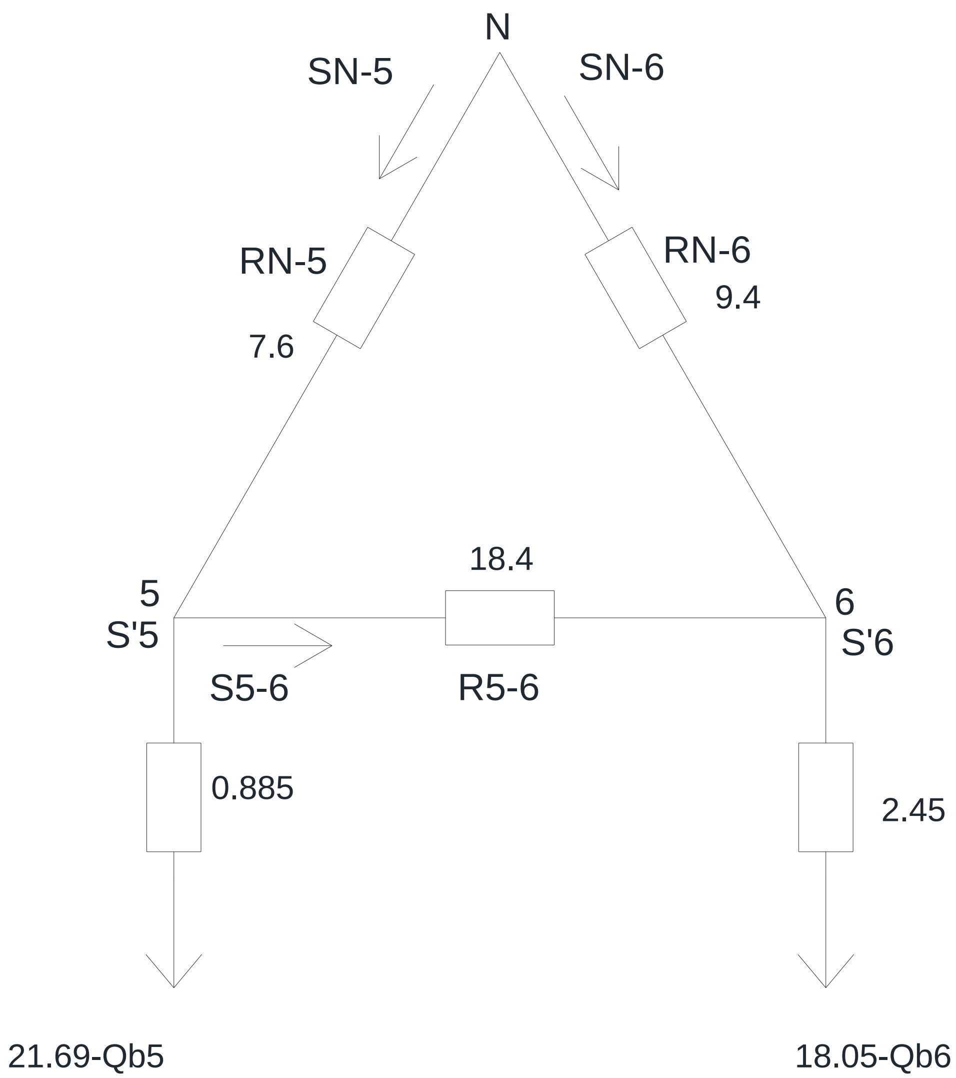


Figure 4.4

Set $x = 21.69 - Q_{bu5}$; $y = 18.05 - Q_{bu6}$

Distribution of reactive power in resistance diagram

$$Q_{N5} = \frac{x \times 27.8 + y \times 9.4}{35.4} = 0.785x + 0.265y$$

$$Q_{N6} = \frac{x \times 7.6 + y \times 26}{35.4} = 0.215x + 0.734y$$

$$Q_{56} = Q_{N5} - x = -0.215x + 0.265y$$

$$Z_1 + Z_2 = 1125 \times (Q_{bu5} + Q_{bu6}) + 2847 \times (Q_{bu5} + Q_{bu6})$$
$$= 3972 \times (Q_{bu5} + Q_{bu6})$$
$$= -3972 \times (-Q_{bu5} - Q_{bu6})$$
$$= -3972 \times [-39.74 + (21.69 - Q_{bu5}) + (18.05 - Q_{bu6})$$
$$= -3972 \times [-39.74 + x + y]$$
$$= 157847.28 - 3972x - 3972y$$

$$Z_3 = c \times \Delta P \times \tau = \frac{c \times \tau}{U^2} \times (Q_5 - Q_{bu5})^2 \times (R_{N-5} + R_{B5})$$
$$= \frac{65 \times 3410,9}{110^2} \times [x^2 \times 0.885 + 2.45 \times y^2$$
$$+ (0.785x + 0.265y)^2 \times 7.6$$
$$+ (0.215x + 0.734y)^2 \times 9.4$$
$$+ (-0.215x + 0.265y)^2 \times 18.4]$$
$$= 18.323 \times (6.849x^2 + 4.032xy + 9.334y^2)$$

$$Z = Z_1 + Z_2 + Z_3 = 157847.28 - 3972x - 3972y + 18.323 \times (6.849x^2 + 4.032xy + 9.334y^2)$$

Calculate its Partial derivative

$$\frac{dz}{dx} = -3972 + 250.988x + 73.88y = 0$$

$$\frac{dz}{dy} = -3972 + 73.88x + 342.05y = 0$$

From two equations above, thus

$$x = 13.24$$
$$y = 8.75$$

These equations equivalent to

$$21.69 - Q_{bu5} = x = 13.24$$
$$18.05 - Q_{bu6} = y = 8.75$$

Thus

$$Q_{bu5} = 8.45(MVAr)$$
$$Q_{bu6} = 9.3(MVAr)$$

Power factors of these two loads are

$$Cos\varphi_5^{'} = 0.935$$
$$Cos\varphi_6^{'} = 0.932$$

Similar calculations apply for area 2

Load	P_{pt} (MW)	$\cos\varphi$	Q_{pt} (MVAr)	Q_b (MVAr)	$Q_{pt} – Q_b$ (MVAr)	S (MVA)	S' (MVA)	$\cos\varphi^{'}$
3	22.5	0.72	21.69	12.42	9.27	31.25	24.33	0.925
4	27.5	0.9	13.32	2.49	10.85	30.55	29.56	0.93
5	35	0.85	21.69	8.45	13.24	41.17	37.42	0.935
6	22.5	0.78	18.05	9.3	8.75	28.84	24.14	0.932

Table 4.2 Economic compensation for Load 3, 4, 5 and 6

4.4 Summarize

Load	P_{pt} (MW)	$\cos\varphi$	Q_{pt} (MVAr)	Q_b (MVAr)	$Q_{pt} – Q_b$ (MVAr)	S (MVA)	S' (MVA)	$\cos\varphi^{'}$
1	31.5	0.84	20.35	8.2	12.15	37.5	33.76	0.933
2	27.5	0.85	17.04	6.65	10.39	32.35	29.4	0.935
3	22.5	0.72	21.69	12.42	9.27	31.25	24.33	0.925
4	27.5	0.9	13.32	2.49	10.85	30.55	29.56	0.93
5	35	0.85	21.69	8.45	13.24	41.17	37.42	0.935
6	22.5	0.78	18.05	9.3	8.75	28.84	24.14	0.932
Total	166.5		112.14	47.51	64.65	201.66	178.61	

Table 4.3 Summary of economic compensation

CHAPTER 5. ACCURACY BALANCE CALCULATION AND DISTRIBUTION OF FORMULAR COMPENSATION

5.1 Calculation purpose

- In the extent of this section, we need to figure the reactive power balance in the electrical network, however in the computation interaction, we need to note: If the power supply needs more reactive ability to supply the load, we need to repay persuasively. Notwithstanding, this requires a sensible dissemination of remuneration gadgets (capacitors).
- According to the issue, the source has the power factor Cosφ = 0.9 on the grounds that the power supply is adequate active power P. Subsequently, the reactive limit produced by the source will be equivalent to: $Q_F = P_F \times \tan \varphi_F$

5.2 Calculate power at the end of line to the bar

5.2.1 Sending power of N – 1, N – 2

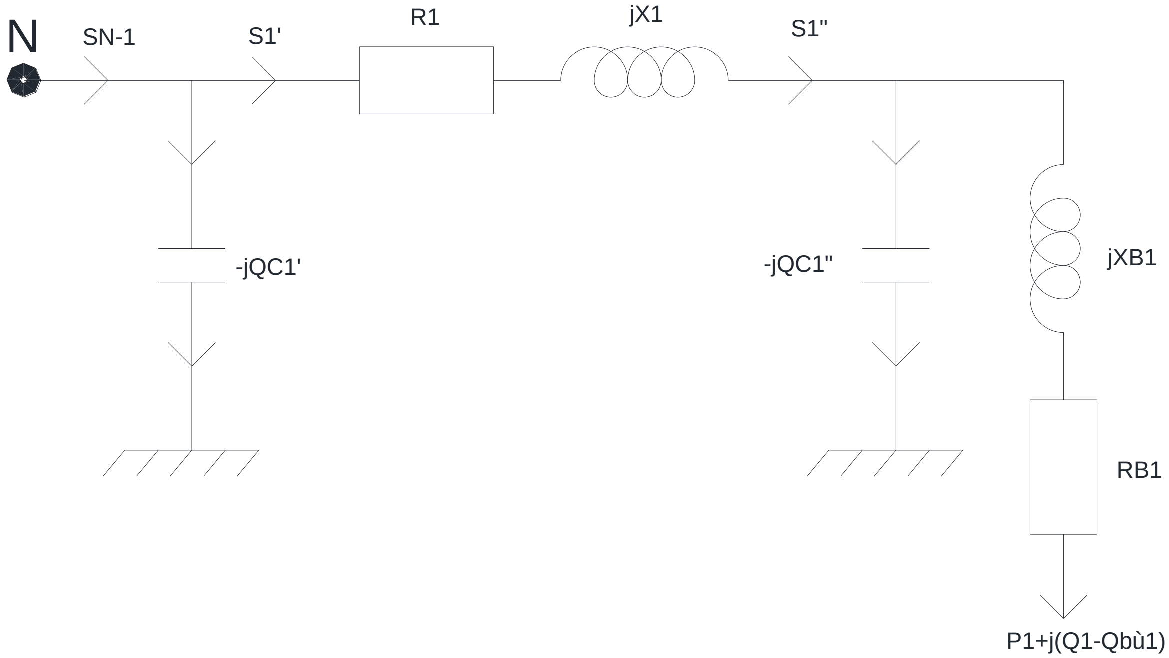


Figure 5.1

- **Power loss in transformer B1:**

$$\Delta P_{B1} = \frac{P_1^2 + (Q_1 - Q_{bu1})^2}{U_{dm}^2} \times R_{B1} = \frac{31.5^2 + (12.15)^2}{110^2} \times 1.32 = 0.124(MW)$$

$$\Delta Q_{B1} = \frac{P_1^2 + (Q_1 - Q_{bu1})^2}{U_{dm}^2} \times X_{B1} = \frac{31.5^2 + 12.15^2}{110^2} \times 31.78 = 2.99(MVAr)$$

- **Reactive power due to capacitance of line end N – 1:**

$$\Delta Q_{C1} = \frac{Y_1}{2} \times U_{dm}^2 = \frac{126.1 \times 10^{-6}}{2} \times 110^2 = 0.7623(MVAr)$$

- **Power at the end of line impedance of line N – 1:**

$$\begin{aligned} S_{T1} &= (P_1 + j(Q_1 - Q_{b1})) + (\Delta P_{B1} + j\Delta Q_{B1}) + (\Delta P_{Fe1} + j\Delta Q_{Fe1}) - j\Delta Q_{C1} \\ &= (31.5 + j12.15) + (0.124 + j2.99) + (42 + j280) \times 10^{-3} - j0.7623 \\ &= 31.666 + j14.66(MVA) \end{aligned}$$

- **Power loss on line impedance N – 1:**

$$\Delta S_1 = \frac{(P_1^{"})^2 + (Q_1^{"})^2}{U_{dm}^2} \times (R_1 + jX_1) = \frac{31.666^2 + 14.66^2}{110^2} \times (7.6 + 18.1) = 0.765 + j1.82(MVA)$$

- **Sending power of line N – 1:**

$$\begin{aligned} S_{N-1} &= S_1^{"} + \Delta S_1 - j\Delta Q_{C1} = (31.666 + j14.66) + (0.765 + j1.82) - j0.7623 \\ &= 32.431 + j15.72(MVA) \end{aligned}$$

Similar calculations apply for line N-2, thus

$$S_{N-2} = 28.316 + j14.112(MVA)$$

5.2.2 Sending power of N – 5 – 6, N – 3 – 4

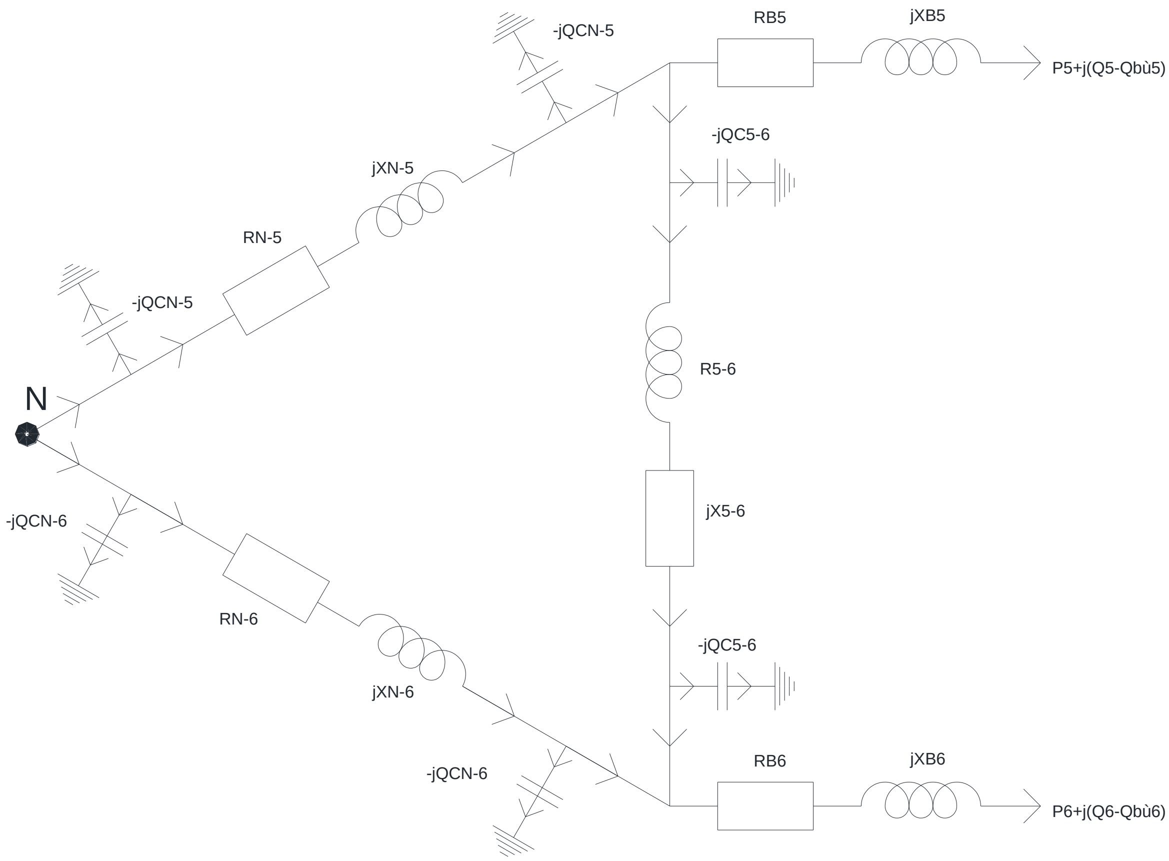


Figure 5.2

- **Calculate power at node 5**

- **Power loss in transformer B5:**

$$\Delta S_{B5} = \frac{P_5^2 + (Q_5 - Q_{bu5})^2}{U_{dm}^2} \times (R_{B5} + jX_{B5}) = \frac{35^2 + 13.24^2}{110^2} \times (0.885 + j26.2) = 0.102 + j3.03(M\text{VA})$$

- **Power in station B5:**

$$S_{T5} = (P_5 + j(Q_5 - Q_{b5})) + (\Delta P_{B5} + j\Delta Q_{B5}) + (\Delta P_{Fe5} + j\Delta Q_{Fe5})$$
$$= (35 + j13.24) + (0.102 + j3.03) + (34 + j90) \times 10^{-3}$$
$$= 35.136 + j16.36(MVA)$$

- **Reactive power is generated by 1/2 of the capacitance of the line N - 5**

$$\Delta Q_{C5} = \frac{Y_5}{2} \times U_{dm}^2 = \frac{126.1 \times 10^{-6}}{2} \times 110^2 = 0.763(MVAr)$$

- **Reactive power is generated by 1/2 of the capacitance of the line 5 – 6**

$$\Delta Q_{C5-6} = \frac{Y_{5-6}}{2} \times U_{dm}^{2} = \frac{104 \times 10^{-6}}{2} \times 110^{2} = 0.63(MVAr)$$

- **Power at node 5 :**

$$S_5^{'} = P_{T5} + j(Q_{T5} - \Delta Q_{CN-5} - \Delta Q_{C5-6}) = 35.136 + j(16.36 - 0.763 - 0.63) = 35.136 + j14.97(MVA)$$

Similar calculations for node 6, node 3 and node 4, thus

$$S_6^{'} = 22.738 + j10.09$$
$$S_3^{'} = 22.74 + j10.763$$
$$S_4^{'} = 27.642 + j11.763$$

Approximate power distribution according to the total impedance

$$Z_{N-5} = R_{N-5} + jX_{N-5} = 7.6 + j18.1(\Omega)$$
$$Z_{5-6} = R_{5-6} + jX_{5-6} = 18.4 + j17.64(\Omega)$$
$$Z_{N-6} = R_{N-6} + jX_{N-6} = 9.4 + j18.33(\Omega)$$

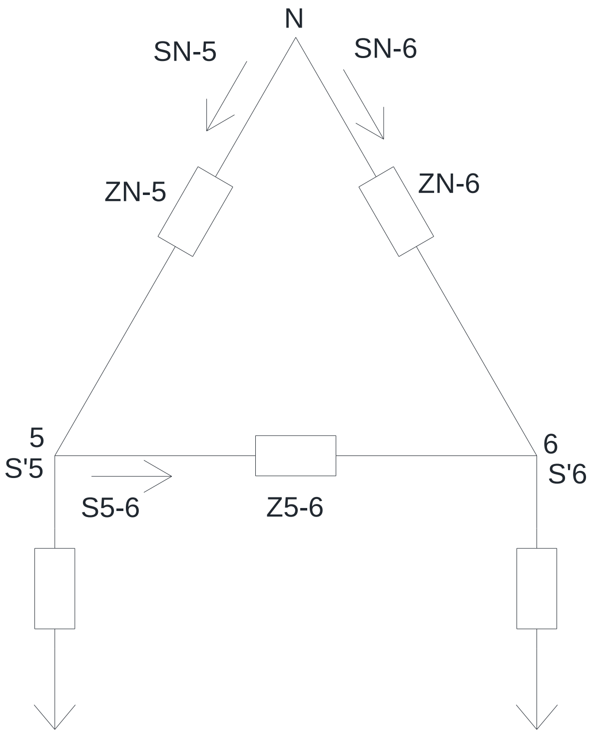


Figure 5.3

Power delivered on line N – 5

$$S_{N-5}^{*}=\frac{S_{5}^{*'}(Z_{5-6}+Z_{N-6})+S_{6}^{*'}(Z_{N-6})}{Z_{5-6}+Z_{N-6}+Z_{N-5}}$$
$$=\frac{(35.136-j14.97)\times(27.8+j35.97)+(22.738-j10.09)\times(9.4+j18.33)}{35.4+j54.07}$$
$$=31.38-j14.65(MVA)$$
$$\Rightarrow S_{N-5}=31.38+j14.65(MVA)$$

$$S_{N-6}^{*}=\frac{S_{6}^{*'}(Z_{5-6}+Z_{N-5})+S_{5}^{*'}(Z_{N-5})}{Z_{5-6}+Z_{N-6}+Z_{N-5}}$$
$$=\frac{(22.738-j10.09)\times\left(26+j35.74\right)+(35.136-j14.967)\times(7.6+j18.1)}{35.4+j54.07}$$
$$=26.51-j10.19(MVA)$$
$$\Rightarrow S_{N-6}=26.51+j10.19(MVA)$$

Re-check

$$S_{N-5}+S_{N-6}\approx S_{5}^{'}+S_{6}^{'}$$
$$\rightarrow S_{5}^{'}+S_{6}^{'}=35.136+j14.967+22.738+j10.09=57.874+j25.054(MVA)$$
$$\rightarrow S_{N-5}+S_{N-6}=31.38+j14.65+26.51+j10.19=57.89+j24.84(MVA)$$

Similar calculations apply for area 2, so

$$S_{N-3}=24.03+j11.23(MVA)$$
$$S_{N-4}=25.36+j11.42(MVA)$$

- **Power delivered on line 5 – 6**

$$S_{5-6}=S_{N-5}-S_{5}^{'}=(31.38+j14.65)-(35.136+j14.97)=-3.756-j0.32(MVA)$$

- **Power loss on 5 – 6**

$$\Delta P_{5-6}=\frac{P_{5-6}^{2}+Q_{5-6}^{2}}{U_{dm}^{2}}\times R_{5-6}=\frac{(-3.756)^{2}+(-0.32)^{2}}{110^{2}}\times 18.3=0.021(M\mathrm{W})$$
$$\Delta Q_{5-6}=\frac{P_{5-6}^{2}+Q_{5-6}^{2}}{U_{dm}^{2}}\times X_{5-6}=\frac{(-3.756)^{2}+(-0.32)^{2}}{110^{2}}\times 17.64=0.021(MVAr)$$

- **Power loss on N – 5**

$$\Delta P_{N-5}=\frac{P_{N-5}^{2}+Q_{N-5}^{2}}{U_{dm}^{2}}\times R_{N-5}=\frac{31.38^{2}+14.65^{2}}{110^{2}}\times 7.6=0.753(M\mathrm{W})$$
$$\Delta Q_{N-5}=\frac{P_{N-5}^{2}+Q_{N-5}^{2}}{U_{dm}^{2}}\times X_{N-5}=\frac{31.38^{2}+14.65^{2}}{110^{2}}\times 18.1=1.794(MVAr)$$

- **Power loss on N – 6**

$$\Delta P_{N-6} = \frac{P_{N-6}^2 + Q_{N-6}^2}{U_{dm}^2} \times R_{N-6} = \frac{26.51^2 + 10.19^2}{110^2} \times 9.4 = 0.63(MW)$$

$$\Delta Q_{N-6} = \frac{P_{N-6}^2 + Q_{N-6}^2}{U_{dm}^2} \times X_{5-6} = \frac{26.51^2 + 10.19^2}{110^2} \times 18.33 = 1.22(MVAr)$$

- **Sending power of line N – 5 – 6**

$$S_{N-5-6} = S_{5-6} + (\Delta P_{5-6} + j\Delta Q_{5-6}) - j\Delta Q_{5C-6} + S_{T5} - j\Delta Q_{CN-5} + (\Delta P_{N-5} + j\Delta Q_{N-5}) - j\Delta Q_{CN-5}$$
$$= (3.756 + j0.32) + (0.021 + j0.021) - j0.63 + (35.136 + j14.97) - j0.763 + (0.753 + j1.794) - j0.763$$
$$= 39.67 + j14.95$$

- **Sending power of line N – 6**

$$S_{N-6} = S_{N-6} + (\Delta P_{N-6} + j\Delta Q_{N-6}) - j\Delta Q_{CN-6}$$
$$= (26.51 + j10.19) + (0.63 + j1.22) - j0.75$$
$$= 24.13 + j10.57(MVA)$$

Similar calculations apply for area 2

$$S_{N-3-4} = 24.536 + j10.266(MVA)$$
$$S_{N-4} = 25.96 + j12.19(MVA)$$

Line	P (MW)	Q (MVAr)
N – 1	32.431	15.72
N – 2	28.316	14.112
N – 3	24.536	10.266
N – 4	25.96	12.19
N – 5	39.67	14.95
N – 6	24.13	10.57
$\sum S_i$	175.043	77.808

Table 5.1 Sending power for every load

- **Total apparent power is generated on high voltage bus bar**

$$S_{yc\Sigma} = P_{yc\Sigma} + jQ_{yc\Sigma} = 168.027 + j77.322(MVA)$$

- **Active power is generated**

$$P_F = P_{yc\Sigma} = 168.027(MW)$$

- **Generating source is sufficient to provide active power for the load and capable of adjusting reactive power according to power factor** $\text{Cos}\varphi$=0,9
- **Reactive power is generated**

$$\text{Cos}\,\varphi_F = 0,9 \Rightarrow \text{Tan}\,\varphi_F = 0,484$$
$$Q_F = P_F \times \text{Tan}\,\varphi_F = 168.027 \times 0,484 = 81.325(MVAr)$$

- Because $Q_F = 81.325(MVAr) > Q_{yc\Sigma} = 77.322MVAr)$ so we do not need to force-compensate reactive capacity for the electrical network
- **Then the source only needs to provide reactive power**

$$Q_F = Q_{yc\Sigma} = 77.322(MVAr)$$

⇨ **Thus** $\text{Tan}\,\varphi_F = \dfrac{Q_{yc\Sigma}}{P_F} = \dfrac{77.322}{168.027} = 0,46 \Rightarrow \text{Cos}\,\varphi_F = 0,908$

CHAPTER 6. POWER DISTRIBUTION CALCULATION IN ELECTRIC NETWORK

6.1 Purpose

- In the extent of this section, we need to precisely characterize the power appropriation boundaries at greatest load, at least load and issue in the electrical network.
- The estimation consequences of this part will incorporate the voltage and stage removal point at the load hubs, the active power misfortune and reactive power of the lines and transformers.

6.2 Calculation of working status of extremely accessories network

6.2.1 Replacement diagrams of the electric network

- Line N – 1

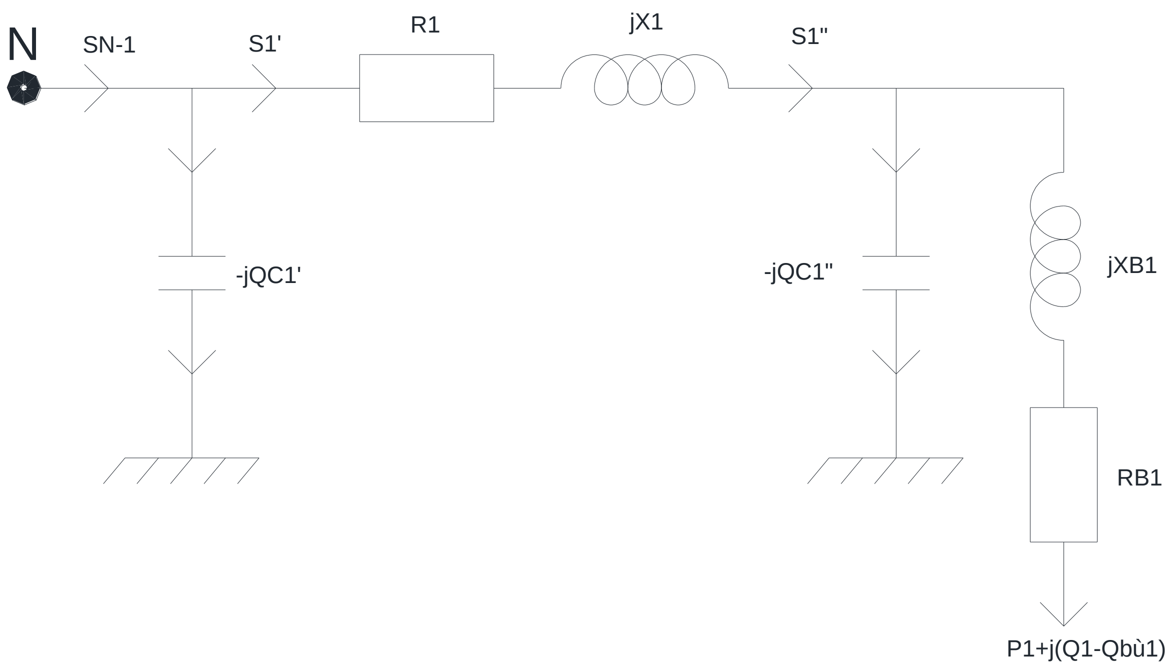


Figure 6.1

- Line N – 2

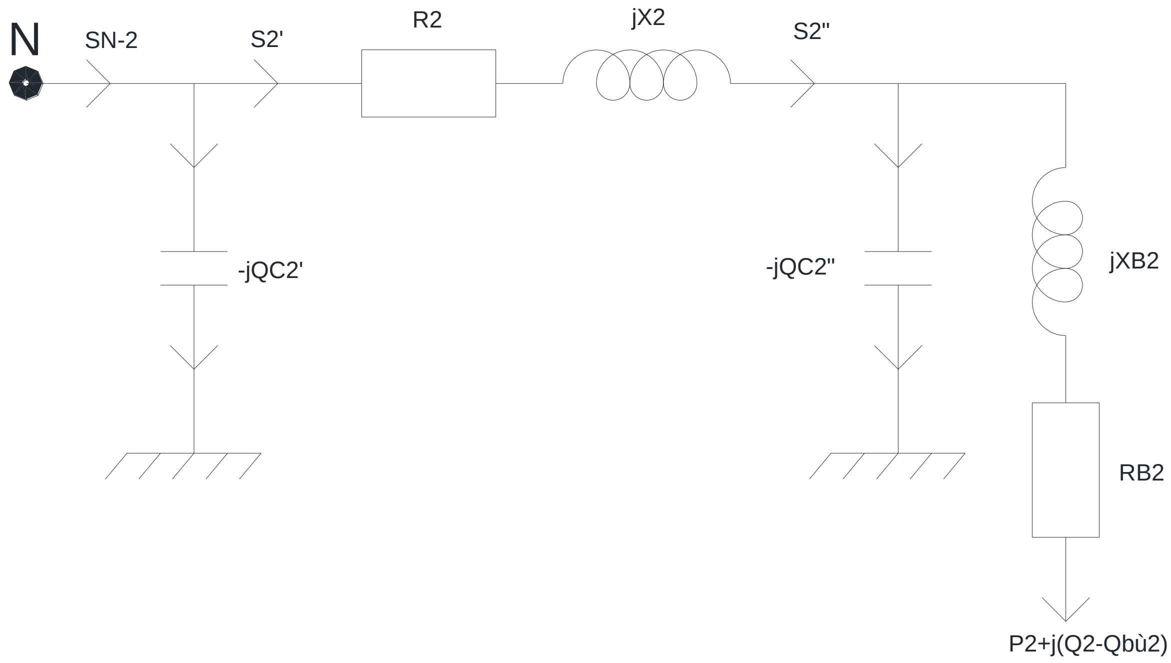


Figure 6.2

- Line N – 3 – 4

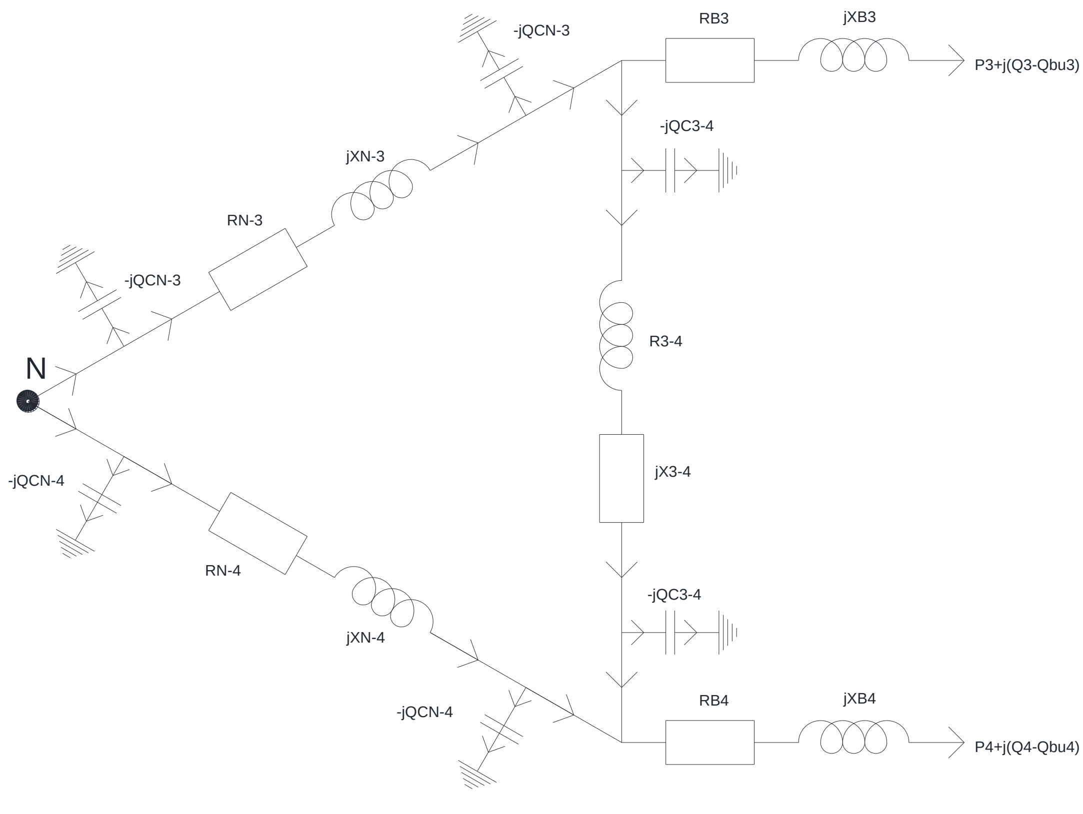


Figure 6.3

- Line N – 5 – 6

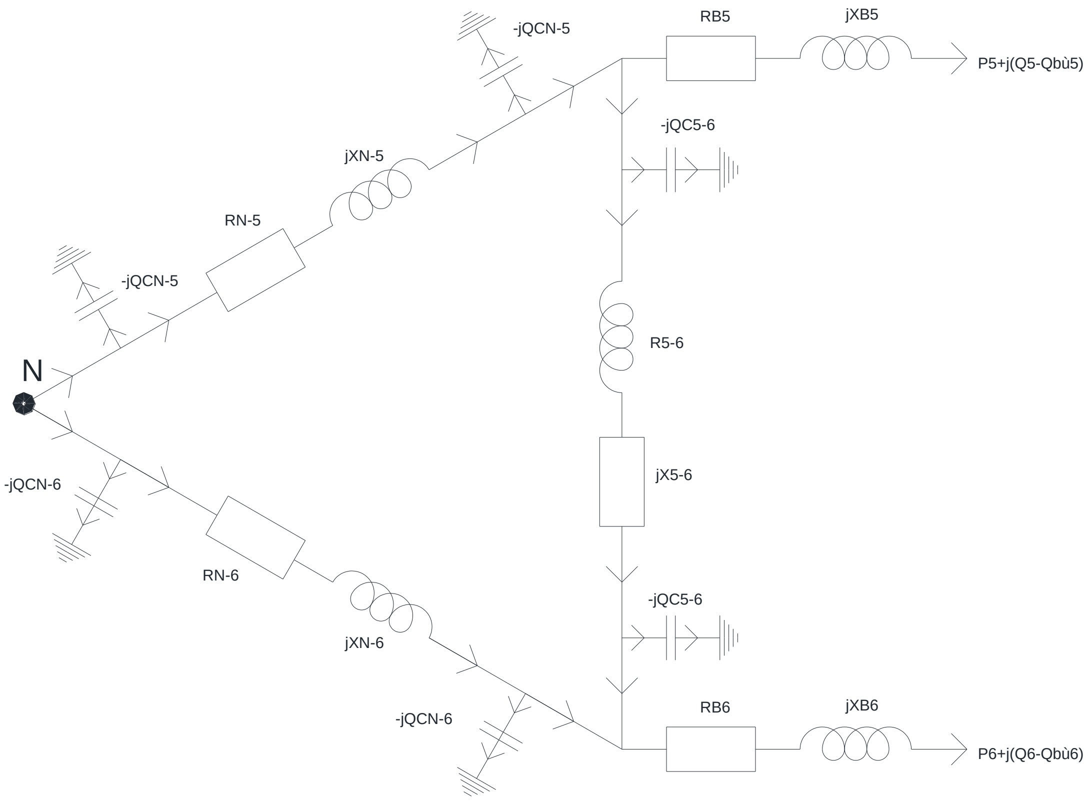


Figure 6.4

6.2.2 Loads, lines and voltage transformers summary

Load	P (MVA)	Q_{pt} (MVAr)	$Cos\varphi$ (before)	Q_b (MVAr)	$Q_{pt} - Q_{bu}$	$Cos\varphi$ (after)
1	31.5	20.35	0.84	8.2	12.15	0.933
2	27.5	17.04	0.85	6.65	10.39	0.935
3	22.5	21.69	0.72	12.42	9.27	0.925
4	27.5	13.32	0.9	2.49	10.85	0.93
5	35	21.69	0.85	8.45	13.24	0.935
6	22.5	18.05	0.78	9.3	8.75	0.932
Total	**166.5**	**112.14**		**47.51**	**64.65**	

Table 6.1 Summary loads parameters

Area	Line	$R=r_0*l$ (Ω)	$X=x_0*l$ (Ω)	$Y(1/\Omega).10^{-6}$
1	**N – 1**	7.6	18.1	126.1
	N – 2	8.66	16.9	114.2
2	**N – 3**	8.66	16.9	114.2
	3 – 4	16.58	15.9	93.73
	N – 4	9.4	18.33	123.87
3	**N – 5**	7.6	18.1	126.1
	5 – 6	18.4	17.64	104
	N - 6	9.4	18.33	123.87

Table 6.2 Summary line parameters

Load	Quantity	S_{dm}	R_B (Ω)	X_B (Ω)	ΔP_{Fe} (MW)	ΔQ_{Fe} (MVAr)
1	1	40	1.32	31.78	42	280
2	1	30	1.775	52.4	17	45
3	2	20	2.45	31.67	120	1200
4	2	25	1.16	25.38	58	400
5	2	30	0.885	26.2	34	90
6	2	20	2.45	31.67	120	1200

Table 6.3 Summary transformers parameters

6.3 Calculation of voltage and total power loss at maximum load.

When load at maximum : $U_N = 1{,}1 \times U_{dm} = 1{,}1 \times 110 = 121(kV)$

6.3.1 The reverse process calculating from the end to the start of lines, use rated voltage

- **Power loss in transformer B1:**

$$\Delta P_{B1} = \frac{P_1^2 + (Q_1 - Q_{bu1})^2}{U_{dm}^2} \times R_{B1} = \frac{31.5^2 + (12.15)^2}{110^2} \times 1.32 = 0.124(M\mathrm{W})$$

$$\Delta Q_{B1} = \frac{P_1^2 + (Q_1 - Q_{bu1})^2}{U_{dm}^2} \times X_{B1} = \frac{31.5^2 + 12.15^2}{110^2} \times 31.78 = 2.99(MVAr)$$

- **Reactive power due to capacitance of line end N – 1:**

$$\Delta Q_{C1} = \frac{Y_1}{2} \times U_{dm}^2 = \frac{126.1 \times 10^{-6}}{2} \times 110^2 = 0.7623(MVAr)$$

- **Power at the end of line impedance of line N – 1:**

$$S_{T1} = (P_1 + j(Q_1 - Q_{b1})) + (\Delta P_{B1} + j\Delta Q_{B1}) + (\Delta P_{Fe1} + j\Delta Q_{Fe1}) - j\Delta Q_{C1}$$
$$= (31.5 + j12.15) + (0.124 + j2.99) + (42 + j280) \times 10^{-3} - j0.7623$$
$$= 31.666 + j14.66(MVA)$$

- **Power loss on line impedance N – 1:**

$$\Delta S_1 = \frac{(P_1^{''})^2 + (Q_1^{''})^2}{U_{dm}^2} \times (R_1 + jX_1) = \frac{31.666^2 + 14.66^2}{110^2} \times (7.6 + 18.1) = 0.765 + j1.82(MVA)$$

- **Sending power of line N – 1:**

$$S_{N-1} = S_1^{''} + \Delta S_1 - j\Delta Q_{C1} = (31.666 + j14.66) + (0.765 + j1.82) - j0.7623$$
$$= 32.431 + j15.72(MVA)$$

Similar calculations apply for line N-2, thus

$$S_{N-2} = 28.32 + j14.112(MVA)$$

- **Calculate power at node 5**

- **Power loss in transformer B5:**

$$\Delta S_{B5} = \frac{P_5^2 + (Q_5 - Q_{bu5})^2}{U_{dm}^2} \times (R_{B5} + jX_{B5}) = \frac{35^2 + 13.24^2}{110^2} \times (0.885 + j26.2)$$
$$= 0.102 + j3.03(MVA)$$

- **Power in station B5:**

$$S_{T5} = (P_5 + j(Q_5 - Q_{b5})) + (\Delta P_{B5} + j\Delta Q_{B5}) + (\Delta P_{Fe5} + j\Delta Q_{Fe5})$$
$$= (35 + j13.24) + (0.102 + j3.03) + (34 + j90) \times 10^{-3}$$
$$= 35.136 + j16.36(MVA)$$

- **Reactive power is generated by 1/2 of the capacitance of the line N - 5**

$$\Delta Q_{C5} = \frac{Y_5}{2} \times U_{dm}^2 = \frac{126.1 \times 10^{-6}}{2} \times 110^2 = 0.763(MVAr)$$

- **Reactive power is generated by 1/2 of the capacitance of the line 5 – 6**

$$\Delta Q_{C5-6} = \frac{Y_{5-6}}{2} \times U_{dm}^2 = \frac{104 \times 10^{-6}}{2} \times 110^2 = 0.63(MVAr)$$

- **Power at node 5 :**

$$S_5^{'} = P_{T5} + j(Q_{T5} - \Delta Q_{CN-5} - \Delta Q_{C5-6}) = 35.136 + j(16.36 - 0.763 - 0.63) = 35.136 + j14.967(MVA)$$

Similar calculations for node 6, node 3 and node 4, thus

$$S_6^{'} = 22.738 + j10.09$$
$$S_3^{'} = 22.74 + j10.763$$
$$S_4^{'} = 27.642 + j11.763$$

Approximate power distribution according to the total impedance

$$Z_{N-5} = R_{N-5} + jX_{N-5} = 7.6 + j18.1(\Omega)$$
$$Z_{5-6} = R_{5-6} + jX_{5-6} = 18.4 + j17.64(\Omega)$$
$$Z_{N-6} = R_{N-6} + jX_{N-6} = 9.4 + j18.33(\Omega)$$

Power delivered on line N – 5

$$S_{N-5}^{*} = \frac{S_5^{*'}(Z_{5-6} + Z_{N-6}) + S_6^{*'}(Z_{N-6})}{Z_{5-6} + Z_{N-6} + Z_{N-5}}$$
$$= \frac{(35.136 - j14.967) \times (27.8 + j35.97) + (22.738 - j10.09) \times (9.4 + j18.33)}{35.4 + j54.07}$$
$$= 31.38 - j14.65(MVA)$$
$$\Rightarrow S_{N-5} = 31.38 + j14.65(MVA)$$

$$S_{N-6}^{*} = \frac{S_6^{*'}(Z_{5-6}+Z_{N-5}) + S_5^{*'}(Z_{N-5})}{Z_{5-6}+Z_{N-6}+Z_{N-5}}$$
$$= \frac{(22.738 - j10.09)\times\left(26+j35.74\right) + (35.136 - j14.967)\times(7.6+j18.1)}{35.4+j54.07}$$
$$= 26.51 - j10.19(MVA)$$
$$\Rightarrow S_{N-6} = 26.51 + j10.19(MVA)$$

Similar calculations apply for area 2, so

$$S_{N-3} = 24.03 + j11.23(MVA)$$
$$S_{N-4} = 25.36 + j11.42(MVA)$$

- **Power delivered on line 5 – 6**

$$S_{5-6} = S_{N-5} - S_5^{'} = (31.38 + j14.65) - (35.136 + j14.97) = -3.756 - j0.32(MVA)$$

- **Power loss on 5 – 6**

$$\Delta P_{5-6} = \frac{P_{5-6}^2 + Q_{5-6}^2}{U_{dm}^2}\times R_{5-6} = \frac{(-3.756)^2 + (-0.32)^2}{110^2}\times 18.3 = 0.021(M\mathrm{W})$$
$$\Delta Q_{5-6} = \frac{P_{5-6}^2 + Q_{5-6}^2}{U_{dm}^2}\times X_{5-6} = \frac{(-3.756)^2 + (-0.32)^2}{110^2}\times 17.64 = 0.021(MVAr)$$

- **Power loss on N – 5**

$$\Delta P_{N-5} = \frac{P_{N-5}^2 + Q_{N-5}^2}{U_{dm}^2}\times R_{N-5} = \frac{31.38^2 + 14.65^2}{110^2}\times 7.6 = 0.753(M\mathrm{W})$$
$$\Delta Q_{N-5} = \frac{P_{N-5}^2 + Q_{N-5}^2}{U_{dm}^2}\times X_{N-5} = \frac{31.38^2 + 14.65^2}{110^2}\times 18.1 = 1.794(MVAr)$$

- **Power loss on N – 6**

$$\Delta P_{N-6} = \frac{P_{N-6}^2 + Q_{N-6}^2}{U_{dm}^2}\times R_{N-6} = \frac{26.51^2 + 10.19^2}{110^2}\times 9.4 = 0.63(M\mathrm{W})$$
$$\Delta Q_{N-6} = \frac{P_{N-6}^2 + Q_{N-6}^2}{U_{dm}^2}\times X_{5-6} = \frac{26.51^2 + 10.19^2}{110^2}\times 18.33 = 1.22(MVAr)$$

- **Sending power of line N – 5 – 6**

$$S_{N-5-6} = S_{5-6} + (\Delta P_{5-6} + j\Delta Q_{5-6}) - j\Delta Q_{5C-6} + S_{T5}$$
$$- j\Delta Q_{CN-5} + (\Delta P_{N-5} + j\Delta Q_{N-5}) - j\Delta Q_{CN-5}$$
$$= (3.756 + j0.32) + (0.021 + j0.021) - j0.63$$
$$+ (35.136 + j14.97) - j0.763 + (0.753 + j1.794) - j0.763$$
$$= 39.67 + j14.95$$

❖ **Sending power of line N – 6**

$$S_{N-6} = S''_{N-6} + (\Delta P_{N-6} + j\Delta Q_{N-6}) - j\Delta Q_{CN-6}$$
$$= (26.51 + j10.19) + (0.63 + j1.22) - j0.75$$
$$= 24.13 + j10.57(MVA)$$

Similar calculations apply for area 2

$$S_{N-3-4} = 24.536 + j10.266(MVA)$$
$$S_{N-4} = 25.96 + j12.19(MVA)$$

6.3.2 The process calculating from the start to the end of lines to find voltage at nodes

❖ **Line N – 1**

❖ **Calculate voltage at node 1**

– **Sending power on line N – 1 (from previous calculations)**

$$S_1' = 32.431 + j15.72(MVA)$$

– **Voltage drop on N – 1:**

$$\Delta U_1 = \frac{P_1' \times R_1 + Q_1' \times X_1}{U_N} = \frac{32.431 \times 7.6 + 15.72 \times 18.1}{121} = 4.388(kV)$$

– **Voltage at the end of line N – 1:**

$$U_1 = U_N - \Delta U_1 = 121 - 4.388 = 116.612(kV)$$

– **Power before station B1:**

$$S_{B1} = (P_1 + j(Q_1 - Q_{b1})) + (\Delta P_{B1} + j\Delta Q_{B1})$$
$$= (31.5 + j12.15) + (0.124 + j2.99)$$
$$= 31.624 + j15.14(MVA)$$

– **Voltage drop on station B1:**

$$\Delta U_{B1} = \frac{P_{B1} \times R_{B1} + Q_{B1} \times X_{B1}}{U_1} = \frac{31.624 \times 1.32 + 15.14 \times 31.78}{116.612} = 4.484(kV)$$

– **Load 1’s voltage convert to primary side:**

$$U_1' = U_1 - \Delta U_{B1} = 116.612 - 4.484 = 112.128(kV)$$

- **Secondary side voltage of station B1:**

$$U_{haB1} = \frac{U_1^{'}}{k} = \frac{U_1^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{112.128}{\frac{110}{22\times 1,1}} = 24.67(kV)$$

- **Voltage difference:**

$$\% \ \Delta U \ = \frac{U_{haB1} - U_{dmha}}{U_{dmha}} \times 100 = \frac{24.67-22}{22} \times 100 = 12.13\%$$

❖ **Line N – 2:**

❖ **Calculate voltage at node 2:**

- **Sending power on line N – 2 (from previous calculations)**

$$S_2^{'} = 28.316 + j14.112(MVA)$$

- **Voltage drop on N – 2:**

$$\Delta U_2 = \frac{P_2^{'} \times R_2 + Q_2^{'} \times X_2}{U_N} = \frac{28.316 \times 1.775 + 14.112 \times 52.4}{121} = 6.52(kV)$$

- **Voltage at the end of line N – 2:**

$$U_2 = U_N - \Delta U_2 = 121 - 6.52 = 114.48(kV)$$

- **Power before station B2:**

$$S_{B2} = (P_2 + j(Q_2 - Q_{b2})) + (\Delta P_{B2} + j\Delta Q_{B2})$$
$$= (27.5 + j10.39) + (0.102 + j3.03)$$
$$= 27.602 + j13.69(MVA)$$

- **Voltage drop on station B2:**

$$\Delta U_{B2} = \frac{P_{B2} \times R_{B2} + Q_{B2} \times X_{B2}}{U_2} = \frac{27.602 \times 1.775 + 13.69 \times 52.4}{114.48} = 6.69kV)$$

- **Load 2's voltage convert to primary side:**

$$U_2^{'} = U_2 - \Delta U_{B2} = 114.48 - 6.69 = 107.79(kV)$$

- **Secondary side voltage of station B2:**

$$U_{haB2} = \frac{U_2^{'}}{k} = \frac{U_2^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{117.79}{\frac{110}{22\times 1,1}} = 23.7138(kV)$$

– **Voltage difference:**

$$\% \ \Delta U = \frac{U_{haB2} - U_{dmha}}{U_{dmha}} \times 100 = \frac{23.7138 - 22}{22} \times 100 = 7.79\%$$

❖ **Line N – 5:**

❖ **Calculate voltage at node 5:**

– **Sending power on line N – 5 (from previous calculations) sai số**

$$S_5^{'} = S_{N-5} + j\Delta Q_{CN-5} = 39.66 + j14.95 + j0.763 = 39.66 + j15.712(MVA)$$

– **Voltage drop on line N – 5:**

$$\Delta U_5 = \frac{P_5^{'} \times R_5 + Q_5^{'} \times X_5}{U_N} = \frac{39.66 \times 7.6 + 15.72 \times 18.1}{121} = 4.84(kV)$$

– **Voltage at the end of line N – 5:**

$$U_5 = U_N - \Delta U_5 = 121 - 4.84 = 116.16(kV)$$

– **Power before station B5:**

$$S_{B5} = (P_5 + j(Q_5 - Q_{b5})) + (\Delta P_{B5} + j\Delta Q_{B5})$$
$$= (35 + j13.24) + (0.102 + j3.03)$$
$$= 35.102 + j16.27(MVA)$$

– **Voltage drop on station B5:**

$$\Delta U_{B5} = \frac{P_{B5} \times R_{B5} + Q_{B5} \times X_{B5}}{U_5} = \frac{35.102 \times 0.885 + 16.27 \times 26.2}{116.16} = 3.93(kV)$$

– **Load 5's voltage convert to primary side:**

$$U_5^{'} = U_5 - \Delta U_{B5} = 116.16 - 3.93 = 112.23(kV)$$

– **Secondary side voltage of station B5:**

$$U_{haB5} = \frac{U_5^{'}}{k} = \frac{U_5^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{112.23}{\frac{110}{22 \times 1,1}} = 24.7(kV)$$

– **Voltage difference:**

$$\% \ \Delta U = \frac{U_{haB5} - U_{dmha}}{U_{dmha}} \times 100 = \frac{24.7 - 22}{22} \times 100 = 12.2\%$$

- **Line 5 – 6:**
- **Sending power on line 5 – 6**

$$S'_{5-6} = -3.756 - j0.32$$

- **Voltage drop on 5 – 6:**

$$\Delta U_{5-6} = \frac{P'_{5-6} \times R_{5-6} + Q'_{5-6} \times X_{5-6}}{U_N} = \frac{-3.756 \times 18.4 - 0.32 \times 17.64}{121} = -0.72(kV)$$

- **Voltage at the end of line 5-6 (also known as voltage on the left of node 6):**

$$U_{6t} = U_5 - \Delta U_{5-6} = 116.16 - (-0.72) = 116.87(kV)$$

- **Line N – 6:**
- **Calculate voltage at node 6:**
- **Sending power on line N – 6 (from previous calculations)**

$$S'_6 = S_{N-6} + j\Delta Q_{CN-6} = 27.136 + j10.57 + j0.75 = 27.136 + j11.32(MVA)$$

- **Voltage drop on line N – 6:**

$$\Delta U_6 = \frac{P'_6 \times R_6 + Q'_6 \times X_6}{U_N} = \frac{27.136 \times 9.4 + 11.32 \times 18.33}{121} = 3.82(kV)$$

- **Voltage at the end of line N – 6 (also known as voltage on the right of node 6):**

$$U_{6p} = U_N - \Delta U_6 = 121 - 3.82 = 117.18(kV)$$

- **Voltage at node 6:**

$$U_6 = \frac{U_{6t} + U_{6p}}{2} = \frac{116.87 + 117.18}{2} = 117.02(kV)$$

- **Power before station B6:**

$$\begin{aligned} S_{B6} &= (P_6 + j(Q_6 - Q_{b6})) + (\Delta P_{B6} + j\Delta Q_{B6}) \\ &= (22.5 + j8.75) + (0.118 + j1.52) \\ &= 22.618 + j10.27(MVA) \end{aligned}$$

- **Voltage drop on station B6:**

$$\Delta U_{B6} = \frac{P_{B6} \times R_{B6} + Q_{B6} \times X_{B6}}{U_6} = \frac{22.618 \times 2.45 + 10.27 \times 31.67}{117.19} = 3.25(kV)$$

- **Load 6's voltage convert to primary side:**

$$U_6^{'} = U_6 - \Delta U_{B6} = 117.02 - 3.25 = 113.77(kV)$$

- **Secondary side voltage of B6:**

$$U_{haB6} = \frac{U_6^{'}}{k} = \frac{U_6^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{115.94}{\frac{110}{22\times 1,1}} = 25.03(kV)$$

- **Voltage difference:**

$$\%\ \Delta U = \frac{U_{haB6} - U_{dmha}}{U_{dmha}} \times 100 = \frac{25.03 - 22}{22} \times 100 = 13.77\%$$

❖ Similar calculation apply for area 2, thus

$U_{N-3} = 117.71(kV)$

$U_{c3} = 114.33(kV)$

$U_{h3} = 25.15(kV)$

$\%\ \Delta U$ at node 3 = 14.33%

$U_{N-4} = 117.02(kV)$

$U_{c4} = 114.18(kV)$

$U_{h4} = 25.12(kV)$

$\%\ \Delta U$ at node 4 = 14.18%

Line	Active power loss ΔP_L (MW)	Reactive power loss ΔQ_L (MVAr)	The reactive power is generated by the line capacitance ΔQ_C on both heads (MVAr)
N – 1	0.765	1.82	1.525
N – 2	0.677	1.32	1.38
N – 3	0.503	0.982	1.38
3 – 4	1.29	0.468	1.134
N – 4	0.6	1.17	1.499
N – 5	0.753	1.794	1.525
5 – 6	3.756	0.32	1.2584
N – 6	0.626	1.22	1.499
Σ	8.97	9.094	11.2

Table 6.4 Lines losses at maximum load

Station	ΔP_{Fe} (MW)	ΔQ_{Fe} (MVAr)	$\Delta P_{CU} = \Delta P_B$ (MW)	$\Delta Q_{CU} = \Delta Q_B$ (MVAr)
1	0.042	0.28	0.124	2.99
2	0.017	0.045	0.127	3.74
3	0.12	1.2	0.12	1.55
4	0.058	0.4	0.084	1.83
5	0.034	0.09	0.102	3.03
6	0.12	1.2	0.118	1.52
Σ	0.349	3.215	0.675	14.66

Table 6.5 Transformers losses at maximum load

Line	Primary voltage(kV)	Secondary converted to primary voltage(kV)	Secondary voltage(kV)	% ΔU
1	116.612	112.128	24.67	12.13
2	114.48	107.79	23.7138	7.79
3	117.71	114.33	25.15	14.33
4	117.21	114.18	25.12	14.18
5	116.16	112.22	24.68	12.22
6	117.02	113.77	25.03	13.77

Table 6.6 Voltage at loads at maximum load

Line	P (MW)	Q (MVAr)
N – 1	32.431	15.72
N – 2	28.316	14.112
N – 3	24.03	11.23
N – 4	25.36	11.42
N – 5	31.38	14.65
N – 6	26.51	10.19
$\sum S_i$	168.027	77.322

Table 6.7 Sending power at maximum load

6.4 Calculation of voltage and total power loss at minimum Load

6.4.1 Data

Load	P_{ptmax} (MW)	P_{ptmin} (%P_{max}) (MW)		Cos φ	Q_{ptmin} (MVAr)
1	31.5	40%	12.6	0.84	8.14
2	27.5	40%	11	0.85	6.81
3	22.5	40%	9	0.72	8.67
4	27.5	40%	11	0.9	5.32
5	35	40%	14	0.85	8.67
6	22.5	40%	9	0.78	7.22

Table 6.8 Loads at minimum

When the load at minimum : $U_N = 1,05 \times U_{dm} = 1,05 \times 110 = 115,5(kV)$

6.4.2 Calculation of voltage and total power loss at minimum load

- **Sending power on line N – 1:**

- **Power loss in transformer B1:**

$$\Delta P_{B1} = \frac{P_1^2 + Q_1^2}{U_{dm}^2} \times R_{B1} = \frac{12.6^2 + 8.14^2}{110^2} \times 1.32 = 0.024(MW)$$

$$\Delta Q_{B1} = \frac{P_1^2 + Q_1^2}{U_{dm}^2} \times X_{B1} = \frac{12.6^2 + 8.14^2}{110^2} \times 31.78 = 0.59(MVAr)$$

- **Reactive power due to capacitance of line end N – 1:**

$$\Delta Q_{C1} = \frac{Y_1}{2} \times U_{dm}^2 = \frac{126.1 \times 10^{-6}}{2} \times 110^2 = 0.763(MVAr)$$

- **Power at the end of line N – 1:**

$$S_1^{"} = (P_1 + jQ_1) + (\Delta P_{B1} + j\Delta Q_{B1}) + (\Delta P_{Fe1} + j\Delta Q_{Fe1}) - j\Delta Q_{C1}$$
$$= (12.6 + j8.14) + (0.024 + j0.59) + (42 + j280)\times 10^{-3} - 0.763$$
$$= 12.66 + j8.25(MVA)$$

- **Power loss on line impedance of N – 1:**

$$\Delta S_1 = \frac{(P_1^{"})^2 + (Q_1^{"})^2}{U_{dm}^2}\times (R_1 + jX_1) = \frac{12.66^2 + 8.25^2}{110^2}\times (7.6 + j18.1) = 0.143 + j0.341(MVA)$$

- **Power before line impedance N – 1:**

$$S_{N-1} = S_1^{"} + \Delta S_1 - j\Delta Q_{C1} = 12.66 + j8.25 + 0.143 + j0.34 - j0.763 = 12.8 + j7.82(MVA)$$

Similar calculation for N-2

$$S_2^{"} = 11.04 + j6.89(MVA)$$

$$\Delta S_2 = 0.121 + j0.23(MVA)$$

$$S_{N-2} = 11.16 + j6.44(MVA)$$

- **Sending power of line N – 5 – 6 – N:**

- **Calculate power at node 5**

- **Power loss on transformer B5:**

$$\Delta P_{B5} = \frac{P_5^2 + Q_5^2}{U_{dm}^2}\times R_{B5} = \frac{14^2 + 8.67^2}{110^2}\times 0.885 = 0.02(MW)$$

$$\Delta Q_{B5} = \frac{P_5^2 + Q_5^2}{U_{dm}^2}\times X_{B5} = \frac{14^2 + 8.67^2}{110^2}\times 26.2 = 0.587(MVAr)$$

- **Reactive power due to capacitance of line end N – 5 :**

$$\Delta Q_{C5} = \frac{Y_5}{2}\times U_{dm}^2 = \frac{126.1\times 10^{-6}}{2}\times 110^2 = 0.763(MVAr)$$

- **Reactive power due to capacitance of line end 5 – 6 :**

$$\Delta Q_{C5-6} = \frac{Y_{5-6}}{2}\times U_{dm}^2 = \frac{104\times 10^{-6}}{2}\times 110^2 = 0.63(MVAr)$$

- **Computing power of node 5 (high voltage):**

$$S_5^{'} = (P_5 + jQ_5) + (\Delta P_{B5} + j\Delta Q_{B5}) + (\Delta P_{Fe5} + j\Delta Q_{Fe5}) - \Delta Q_{CN-5} - \Delta Q_{C5-6}$$
$$= 14 + j8.67 + 0.02 + j0.587 + (34 + j90)\times 10^{-3} - j0.763 - j0.63$$
$$= 14.05 + j7.96(MVA)$$

- **Calculate power at node 6**

- **Power loss in transformer B6:**

$$\Delta P_{B6} = \frac{P_6^2 + Q_6^{\,2}}{U_{dm}^2}\times R_{B6} = \frac{9^2 + 7.22^2}{110^2}\times 9.4 = 0.027(MW)$$

$$\Delta Q_{B6} = \frac{P_6^2 + Q_6^{\,2}}{U_{dm}^2}\times X_{B6} = \frac{9^2 + 7.22^2}{110^2}\times 18.33 = 0.35(MVAr)$$

- **Reactive power due to capacitance of line end N – 6:**

$$\Delta Q_{C6} = \frac{Y_6}{2}\times U_{dm}^2 = \frac{123.87\times 10^{-6}}{2}\times 110^2 = 0.75(MVAr)$$

- **Reactive power due to capacitance of line end 5 – 6:**

$$\Delta Q_{C5-6} = \frac{Y_{5-6}}{2}\times U_{dm}^2 = \frac{104\times 10^{-6}}{2}\times 110^2 = 0.63(MVAr)$$

- **Computing power of node 6 (high voltage):**

$$S_6^{'} = (P_6 + jQ_6) + (\Delta P_{B6} + j\Delta Q_{B6}) + (\Delta P_{Fe6} + j\Delta Q_{Fe6}) - \Delta Q_{CN-6} - \Delta Q_{C5-6}$$
$$= 9 + j7.22 + 0.027 + j0.35 + (120 + j1200)\times 10^{-3} - j0.75 - 0.63$$
$$= 9.14 + j7.4(MVA)$$

- **Power distribution according to impedance**

$$Z_{N-5} = R_{N-5} + jX_{N-5} = 7.6 + j18.1(\Omega)$$
$$Z_{5-6} = R_{5-6} + jX_{5-6} = 18.4 + j17.64(\Omega)$$
$$Z_{N-6} = R_{N-6} + jX_{N-6} = 9.4 + j18.33(\Omega)$$

- **Power on line N – 5**

$$S_{N-5}^{*} = \frac{S_5^{*'}(Z_{5-6} + Z_{N-6}) + S_6^{*'}(Z_{N-6})}{Z_{5-6} + Z_{N-6} + Z_{N-5}}$$
$$= \frac{(14.05 - j7.96)\times(27.8 + j35.97) + (9.14 - j7.4)\times(9.4 + j18.33)}{35.4 + j54.07}$$
$$= 12.56 - j8.4(MVA)$$
$$\Rightarrow S_{N-5} = 12.56 + j8.4(MVA)$$

❖ Power on line N – 6

$$S_{N-6}^{*}=\frac{S_6^{*'}(Z_{5-6}+Z_{N-5})+S_5^{*'}(Z_{N-5})}{Z_{5-6}+Z_{N-6}+Z_{N-5}}$$

$$=\frac{(9.14-j7.4)\times\left(26+j35.74\right)+(14.05-j7.96)\times(7.6+j18.1)}{35.4+j54.07}$$

$$=10.62-j6.96(MVA)$$

$$\Rightarrow S_{N-6}=10.62+j6.96(MVA)$$

- **Check the results**

$$S_{N-5}+S_{N-6}=S_5^{'}+S_6^{'}$$

$$\rightarrow S_{N-5}+S_{N-6}=12.56+j8.4+10.62+j6.96=23.18+j15.36(MVA)$$

$$\rightarrow S_5^{'}+S_6^{'}=14.05+j7.96+9.14+j7.4=23.19+j15.36(MVA)$$

❖ Power on line 5 – 6

$$S_{5-6}=S_{N-5}-S_5^{'}=(12.56+j8.j)-(14.05+j7.96)=-1.49-j0.438(MVA)$$

❖ Power loss on line 5 – 6

$$\Delta P_{5-6}=\frac{P_{5-6}^2+Q_{5-6}^2}{U_{dm}^2}\times R_{5-6}=\frac{(-1.49)^2+(-0.438)^2}{110^2}\times 18.4=3.68\times 10^{-3}(M\mathrm{W})$$

$$\Delta Q_{5-6}=\frac{P_{5-6}^2+Q_{5-6}^2}{U_{dm}^2}\times X_{5-6}=\frac{(-1.49)^2+(-0.438)^2}{110^2}\times 17.64=3.53\times 10^{-3}(MVAr)$$

❖ Power loss on line N – 5

$$\Delta P_{N-5}=\frac{P_{N-5}^2+Q_{N-5}^2}{U_{dm}^2}\times R_{N-5}=\frac{12.56^2+8.4^2}{110^2}\times 7.6=0.143(M\mathrm{W})$$

$$\Delta Q_{N-5}=\frac{P_{N-5}^2+Q_{N-5}^2}{U_{dm}^2}\times X_{N-5}=\frac{12.56^2+8.4^2}{110^2}\times 18.1=0.341(MVAr)$$

❖ Power loss on line N – 6

$$\Delta P_{N-6}=\frac{P_{N-6}^2+Q_{N-6}^2}{U_{dm}^2}\times R_{N-6}=\frac{10.62^2+6.96^2}{110^2}\times 9.4=0.125(M\mathrm{W})$$

$$\Delta Q_{N-6}=\frac{P_{N-6}^2+Q_{N-6}^2}{U_{dm}^2}\times X_{5-6}=\frac{10.62^2+6.96^2}{110^2}\times 18.33=0.244(MVAr)$$

❖ Sending power of line N – 5 – 6

$$S_{N-5-6}=S_{5-6}+(\Delta P_{5-6}+j\Delta Q_{5-6})-j\Delta Q_{5C-6}+S_{T5}-j\Delta Q_{CN-5}+(\Delta P_{N-5}+j\Delta Q_{N-5})-j\Delta Q_{CN-5}$$

$$=1.49+j0.438+(3.68+j3.53)\times 10^{-3}-j0.63+14.05+j7.96-j0.763+0.143+j0.341-j0.763$$

$$=15.69+j6.59(MVA)$$

❖ **Sending power of line N – 6**

$$S_{N-6} = S_{N-6} + (\Delta P_{N-6} + j\Delta Q_{N-6}) - j\Delta Q_{CN-6}$$
$$= (10.62 + j6.96) + (0.125 + j0.244) - j0.75$$
$$= 10.41 + j6.88(MVA)$$

Similar calculations for area 2.

$$S^{"}_{N-3} = 9.876 + j7.724(MVA)$$
$$S^{"}_{N-4} = 10.34 + j6.01(MVA)$$

$$\Delta S_{N-3} = 0.1125 + j0.2195(MVA)$$
$$\Delta S_{N-4} = 0.11 + j0.216(MVA)$$

$$S_{N-3} = 10 + j8.6(MVA)$$
$$S_{N-4} = 12.7 + j7.54(MVA)$$

6.4.3 The process calculating from the start to the end of lines to find voltage at nodes

❖ **Line N – 1:**

❖ **Calculate voltage at node 1:**

– **Power before line impedance of N – 1 (from previous calculations)**

$$S_1^{'} = 12.8 + j7.82(MVA)$$

– **Voltage drop on line N – 1:**

$$\Delta U_1 = \frac{P_1^{'} \times R_1 + Q_1^{'} \times X_1}{U_N} = \frac{12.8 \times 7.6 + 7.82 \times 18.1}{115.5} = 2.069(kV)$$

– **Voltage at the end of line N – 1:**

$$U_1 = U_N - \Delta U_1 = 115.5 - 2.069 = 113.43(kV)$$

– **Power before transformer impedance B1:**

$$S_{B1} = (P_1 + jQ_1) + (\Delta P_{B1} + j\Delta Q_{B1})$$
$$= (12.6 + j8.14) + (0.024 + j0.59)$$
$$= 12.62 + j8.73(MVA)$$

– **Voltage drop on transformer B1:**

$$\Delta U_{B1} = \frac{P_{B1} \times R_{B1} + Q_{B1} \times X_{B1}}{U_1} = \frac{12.62 \times 1.32 + 8.73 \times 31.78}{113.43} = 2.59(kV)$$

- **Load 1 voltage is converted to high voltage side:**

$$U_1^{'} = U_1 - \Delta U_{B1} = 113.43 - 2.59 = 110.84(kV)$$

- **Voltage at secondary side of transformerT1:**

$$U_{haB1} = \frac{U_1^{'}}{k} = \frac{U_1^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{110.84}{\frac{110}{22\times 1{,}1}} = 24.38(kV)$$

- **Voltage difference :**

$$\%\ \Delta U\ = \frac{U_{haB1} - U_{dmha}}{U_{dmha}} \times 100 = \frac{24.38 - 22}{22} \times 100 = 10.84\%$$

Similar to N – 2

$U_2 = 113.72(kV)$

$U^{'}{}_2 = 110.07(kV)$

$U_{haB2} = 24.21(kV)$

% ΔU U2 = 10.07%

- ❖ **Line N – 5:**
- ❖ **Voltage at node 5:**

- **Power before impedance of line N – 5 (from previous calculations)**

$$S_5^{'} = S_{N-5} + j\Delta Q_{CN-5} = 15.69 + j6.59 + j0.763 = 15.69 + j7.35(MVA)$$

- **Voltage drop on N – 5:**

$$\Delta U_5 = \frac{P_5^{'} \times R_5 + Q_5^{'} \times X_5}{U_N} = \frac{15.69 \times 7.6 + 7.35 \times 18.1}{115.5} = 2.18(kV)$$

- **Voltage at the end of line N – 5:**

$$U_5 = U_N - \Delta U_5 = 115.5 - 2.185 = 113.315(kV)$$

- **Power before transformer impedance B5:**

$$S_{B5} = (P_5 + jQ_5) + (\Delta P_{B5} + j\Delta Q_{B5})$$
$$= (14 + j8.67) + (0.02 + j0.587)$$
$$= 14.02 + j9.264(MVA)$$

- **Voltage drop on transformer B5:**

$$\Delta U_{B5} = \frac{P_{B5} \times R_{B5} + Q_{B5} \times X_{B5}}{U_5} = \frac{14.02 \times 0.885 + 9.264 \times 26.2}{113.315} = 2.25(kV)$$

– **Load 5 voltage is converted to high voltage side:**

$$U_5^{'} = U_5 - \Delta U_{B5} = 113.315 - 2.25 = 111.06(kV)$$

– **Voltage at secondary side of transformerT5:**

$$U_{haB5} = \frac{U_5^{'}}{k} = \frac{U_5^{'}}{\dfrac{U_{dmcao}}{U_{ktha}}} = \frac{111.06}{\dfrac{110}{22\times 1{,}1}} = 24.43(kV)$$

– **Voltage difference :**

$$\%\ \Delta U = \frac{U_{haB5} - U_{dmha}}{U_{dmha}} \times 100 = \frac{24.43 - 22}{22} \times 100 = 11{,}.063\%$$

❖ **Line 5 – 6:**

– **Power before line impedance of 5 – 6 (from previous calculations)**

$$S_{5-6}^{'} = -1.49 - j0.438(MVA)$$

– **Voltage drop on line 5 – 6:**

$$\Delta U_{5-6} = \frac{P_{5-6}^{'} \times R_{5-6} + Q_{5-6}^{'} \times X_{5-6}}{U_N} = \frac{-1.49 \times 18.4 - 0.438 \times 17.64}{113.315} = -0.31(kV)$$

– **Voltage at the end of line 5 – 6 on the left:**

$$U_{6t} = U_5 - \Delta U_{5-6} = 113.315 - (-0.31) = 113.625(kV)$$

❖ **Line N – 6:**

❖ **Voltage calculation at node 6:**

– **Power before line impedance of N – 6 (from previous calculations)**

$$S_6^{'} = S_{N-6} + j\Delta Q_{CN-6} = 10.74 + j6.88 + j0.75 = 10.74 + j7.63(MVA)$$

– **Voltage drop on line N – 6:**

$$\Delta U_6 = \frac{P_6^{'} \times R_6 + Q_6^{'} \times X_6}{U_N} = \frac{10.745 \times 9.4 + 7.63 \times 18.33}{115.5} = 2.086(kV)$$

– **Voltage at the end of line N – 6 bên phải:**

$$U_{6p} = U_N - \Delta U_6 = 115.5 - 2.086 = 113.41(kV)$$

– **Voltage at node 6:**

$$U_6 = \frac{U_{6t} + U_{6p}}{2} = \frac{113.62 + 113.41}{2} = 113.5(kV)$$

- **Power before transformer impedance B6:**

$$S_{B6} = (P_6 + jQ_6) + (\Delta P_{B6} + j\Delta Q_{B6})$$
$$= (9 + j7.22) + (0.027 + j0.348)$$
$$= 9.026 + j7.57(MVA)$$

- **Voltage drop on transformer B6:**

$$\Delta U_{B6} = \frac{P_{B6} \times R_{B6} + Q_{B6} \times X_{B6}}{U_6} = \frac{9.026 \times 2.45 + 7.57 \times 31.67}{113.5} = 2.3(kV)$$

- **Load 6 voltage is converted to high voltage side:**

$$U_6^{'} = U_6 - \Delta U_{B6} = 113.5 - 2.3 = 111.2(kV)$$

- **Voltage at secondary side of transformerT6:**

$$U_{haB6} = \frac{U_6^{'}}{k} = \frac{U_6^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{111.2}{\frac{110}{22 \times 1,1}} = 24.46(kV)$$

- **Voltage difference :**

$$\% \ \Delta U = \frac{U_{haB6} - U_{dmha}}{U_{dmha}} \times 100 = \frac{24.46 - 22}{22} \times 100 = 11.21\%$$

Similar calculations apply for area 2.

$U_3 = 113.39(kV)$

$U^{'}_3 = 110.66(kV)$

$U_{haB3} = 24.345(kV)$

$\% \ \Delta U$ 3 = 10.66%

$U_4 = 113.86(kV)$

$U^{'}_4 = 112.11(kV)$

$U_{haB4} = 24.66(kV)$

$\% \ \Delta U$ 4 = 12.11%

Line	Active power loss ΔP_L (MW)	Reactive power loss ΔQ_L (MVAr)	The reactive power is generated by the line capacitance ΔQ_C on both heads (MVAr)
N – 1	0.143	0.341	1.525
N – 2	0.121	0.236	1.38
N – 3	0.112	0.22	1.38
3 – 4	0.003	0.003	1.6
N – 4	0.111	0.216	1.6
N – 5	0.143	0.341	1.525
5 – 6	0.0036	0.0035	1.26
N – 6	0.125	0.244	1.5
$\sum$	0.7616	1.6045	11.77

Table 6.9 Power losses at minimum load

Station	ΔP_{Fe} (MW)	ΔQ_{Fe} (MVAr)	$\Delta P_{CU} = \Delta P_B$ (MW)	$\Delta Q_{CU} = \Delta Q_B$ (MVAr)
1	0.042	0.28	0.0245	0.5909
2	0.017	0.045	0.0245	0.7252
3	0.12	1.2	0.0316	0.4089
4	0.058	0.4	0.0143	0.3133
5	0.034	0.09	0.0198	0.5874
6	0.12	1.2	0.0269	0.3484
$\sum$	0.391	3.215	0.1416	2.9741

Table 6.10 Transformer losses at minimum load

Load	Primary voltage(kV)	Secondary converted to primary voltage(kV)	Secondary voltage(kV)	% ΔU
1	113.43	110.83	24.38	10.83
2	113.72	110.07	24.21	10.07
3	113.39	110.66	24.345	10.66
4	113.86	112.11	24.66	12.11
5	113.31	111.063	24.434	11.06
6	113.41	111.21	24.466	11.21

Table 6.11 Voltage at loads at minimum load

Line	P (MW)	Q (MVAr)
N – 1	12.81	7.82
N – 2	11.16	6.44
N – 3	10	8.6
N – 4	10.45	4.19
N – 5	15.7	6.59
N – 6	10.74	6.88
$\sum S_i$	70.86	40.52

Table 6.12 Sending power at minimum load

6.5 Calculate status at fault operations

- Requirements:
  - When faults happen, voltage is U_N=1,1×110=121 (kV)
  - Maximum loads which were compensation.
  - Calculate the fault of a line of double-line, a broken line of a ring or a transformer failure
  - When calculating one-wire breakage of double-line, note that it is necessary to use resistances, inductance, and capacitance of the line at the time of the failure calculated in Chapter 2.

6.5.1 A transformer broken down fault station

When a transformer in Station 5 breakdown, we have data

Load	Transformer	R_B (Ω)	X_B (Ω)	ΔP_{Fe} (KW)	ΔQ_{Fe} (KVAr)
5	1	1.77	52.4	17	45
6	2	2.45	31.67	120	1200

Table 6.13 Transformer parameters when a transformer brokedown

Line	R (Ω)	X (Ω)	Y(1/Ω).10^{-6}
N – 5	7.6	18.1	126.1
5 – 6	18.4	17.64	104
N – 6	9.4	18.33	123.87

Table 6.14 Line parameters when a transformer brokedown

- **Computing power at node 5**

- **Power loss in B5:**

$$\Delta P_{B5} = \frac{P_5^2 + (Q_5 - Q_{bu5})^2}{U_{dm}^2} \times R_{B5} = \frac{35^2 + 13.24^2}{110^2} \times 1.77 = 0.205(MW)$$

$$\Delta Q_{B5} = \frac{P_5^2 + (Q_5 - Q_{bu5})^2}{U_{dm}^2} \times X_{B5} = \frac{35^2 + 13.24^2}{110^2} \times 52.4 = 6.065(MVAr)$$

❖ **Reactive power due to capacitance of line end N – 5 :**

$$\Delta Q_{C5} = \frac{Y_5}{2} \times U_{dm}^2 = \frac{126.1 \times 10^{-6}}{2} \times 110^2 = 0.763(MVAr)$$

❖ **Reactive power due to capacitance of line end 5 – 6:**

$$\Delta Q_{C5-6} = \frac{Y_{5-6}}{2} \times U_{dm}^2 = \frac{104 \times 10^{-6}}{2} \times 110^2 = 0.63(MVAr)$$

❖ **Computing power at node 5 (high voltage):**

$$\begin{aligned} S_5^{'} &= (P_5 + j(Q_5 - Q_{b5})) + (\Delta P_{B5} + j\Delta Q_{B5}) + (\Delta P_{Fe5} + j\Delta Q_{Fe5}) - \Delta Q_{CN-5} - \Delta Q_{C5-6}) \\ &= 35 + j13.24 + 0.205 + j6.064 + (17 + j45) \times 10^{-3} - j0.763 - j0.63 \\ &= 35.22 + 17.95(MVA) \end{aligned}$$

➢ **Calculate power at node 6**

❖ **Power loss in transformer B6:**

$$\Delta P_{B6} = \frac{P_6^2 + (Q_6 - Q_{bu6})^2}{U_{dm}^2} \times R_{B6} = \frac{22.5^2 + 8.75^2}{110^2} \times 2.45 = 0.118(MW)$$

$$\Delta Q_{B6} = \frac{P_6^2 + (Q_6 - Q_{bu6})^2}{U_{dm}^2} \times X_{B6} = \frac{22.5^2 + 8.75^2}{110^2} \times 31.67 = 1.525(MVAr)$$

❖ **Reactive power due to capacitance of line end N – 6:**

$$\Delta Q_{C6} = \frac{Y_6}{2} \times U_{dm}^2 = \frac{123.87 \times 10^{-6}}{2} \times 110^2 = 0.75(MVAr)$$

❖ **Reactive power due to capacitance of line end 5 – 6 :**

$$\Delta Q_{C5-6} = \frac{Y_{5-6}}{2} \times U_{dm}^2 = \frac{104 \times 10^{-6}}{2} \times 110^2 = 0.63(MVAr)$$

❖ **Computing power 6 (high voltage):**

$$\begin{aligned} S_6^{'} &= (P_6 + j(Q_6 - Q_{b6})) + (\Delta P_{B6} + j\Delta Q_{B6}) + (\Delta P_{Fe6} + j\Delta Q_{Fe6}) - \Delta Q_{CN-6} - \Delta Q_{C5-6} \\ &= 22.5 + j8.75 + 0.118 + j1.525 + (120 + j1200) \times 10^{-3} - j0.63 - j0.75 \\ &= 22.738 + 10.09(MVA) \end{aligned}$$

- **Power distribution according to impedance**

$$Z_{N-5} = R_{N-5} + jX_{N-5} = 7.6 + j18.1(\Omega)$$
$$Z_{5-6} = R_{5-6} + jX_{5-6} = 18.4 + j17.64(\Omega)$$
$$Z_{N-6} = R_{N-6} + jX_{N-6} = 9.4 + j18.33(\Omega)$$

- **Sending power on line N – 5**

$$S^*_{N-5} = \frac{S^{*'}_5(Z_{5-6} + Z_{N-6}) + S^{*'}_6(Z_{N-6})}{Z_{5-6} + Z_{N-6} + Z_{N-5}}$$
$$= \frac{(35.22 - j17.95) \times (27.8 + j35.97) + (22.738 - j10.09) \times (9.4 + j18.33)}{35.4 + j54.07}$$
$$= 31.25 - j16.96(MVA)$$
$$\Rightarrow S_{N-5} = 31.25 + j16.96(MVA)$$

- **Sending power on line N – 6**

$$S^*_{N-6} = \frac{S^{*'}_6(Z_{5-6} + Z_{N-5}) + S^{*'}_6(Z_{N-5})}{Z_{5-6} + Z_{N-6} + Z_{N-5}}$$
$$= \frac{(22.738 - j10.09) \times \left(26 + j35.74\right) + (35.22 - j17.95) \times (7.6 + j18.1)}{35.4 + j54.07}$$
$$= 26.7 - j11.08(MVA)$$
$$\Rightarrow S_{N-6} = 26.7 + j11.08(MVA)$$

- **Check the results**

$$S_{N-5} + S_{N-6} = S^{'}_5 + S^{'}_6$$
$$\rightarrow S_{N-5} + S_{N-6} = 31.25 + j16.96 + 26.7 + j11.08 = 57.95 + j28.04(MVA)$$
$$\rightarrow S^{'}_5 + S^{'}_6 = 35.22 + j17.95 + 22.738 + j10.09 = 57.95 + j28.04(MVA)$$

- **Sending power on line 5 – 6**

$$S_{5-6} = S_{N-5} - S^{'}_5 = (31.25 + j16.96) - (35.22 + j17.95) = -3.972 - j0.99(MVA)$$

- **Power loss on line 5 – 6**

$$\Delta P_{5-6} = \frac{P^2_{5-6} + Q^2_{5-6}}{U^2_{dm}} \times R_{5-6} = \frac{(-3.97)^2 + (-0.99)^2}{110^2} \times 18.4 = 0.0255(MW)$$
$$\Delta Q_{5-6} = \frac{P^2_{5-6} + Q^2_{5-6}}{U^2_{dm}} \times X_{5-6} = \frac{(-3.97)^2 + (-0.99)^2}{110^2} \times 17.64 = 0.0244(MVAr)$$

- **Power loss on line N – 5**

$$\Delta P_{N-5} = \frac{P_{N-5}^2 + Q_{N-5}^2}{U_{dm}^2} \times R_{N-5} = \frac{31.25^2 + 16.96^2}{110^2} \times 7.6 = 0.794(MW)$$

$$\Delta Q_{N-5} = \frac{P_{N-5}^2 + Q_{N-5}^2}{U_{dm}^2} \times X_{N-5} = \frac{31.25^2 + 16.96^2}{110^2} \times 18.1 = 1.89(MVAr)$$

- **Power loss on line N – 6**

$$\Delta P_{N-6} = \frac{P_{N-6}^2 + Q_{N-6}^2}{U_{dm}^2} \times R_{N-6} = \frac{26.7^2 + 11.08^2}{110^2} \times 9.4 = 0.65(MW)$$

$$\Delta Q_{N-6} = \frac{P_{N-6}^2 + Q_{N-6}^2}{U_{dm}^2} \times X_{5-6} = \frac{26.7^2 + 11.08^2}{110^2} \times 18.33 = 1.266(MVAr)$$

- **Sending power of line N – 5 – 6**

$$S_{N-5-6} = S_{5-6} + (\Delta P_{5-6} + j\Delta Q_{5-6}) - j\Delta Q_{5C-6} + S_{T5} - j\Delta Q_{CN-5} + (\Delta P_{N-5} + j\Delta Q_{N-5}) - j\Delta Q_{CN-5}$$
$$= 3.97 + j0.99 + 0.0255 + j0.0244 - j0.63 + 35.22 + j17.95 - j0.763 + 0.795 + j1.89 - 0.j763$$
$$= 40 + j18.71(MVA)$$

- **Sending power of line N – 6**

$$S_{N-6} = S_{N-6} + (\Delta P_{N-6} + j\Delta Q_{N-6}) - j\Delta Q_{CN-6}$$
$$= 26.7 + j11.08 + +0.65 + j1.266 - j0.75$$
$$= 27.34 + j10.61(MVA)$$

- **Line N – 5:**
- **Calculate voltage at node 5:**

– **Power before line impedance of N – 5 (from previous calculations)**

$$S_5^{'} = S_{N-5} + j\Delta Q_{CN-5} = 40.01 + j18.7 + j0.763 = 40.01 + j19.47(MVA)$$

– **Voltage drop on line N – 5:**

$$\Delta U_5 = \frac{P_5^{'} \times R_5 + Q_5^{'} \times X_5}{U_N} = \frac{40.01 \times 7.6 + 19.47 \times 18.1}{110} = 5.97(kV)$$

– **Voltage at the end of line N – 5:**

$$U_5 = U_N - \Delta U_5 = 110 - 5.97 = 104.03(kV)$$

– **Power before transformer impedance B5:**

$$S_{B5} = (P_5 + jQ_5) + (\Delta P_{B5} + j\Delta Q_{B5})$$
$$= (35 + j13.24) + (0.205 + j6.064)$$
$$= 35.205 + j19.304(MVA)$$

- **Voltage drop on transformer B5:**

$$\Delta U_{B5} = \frac{P_{B5} \times R_{B5} + Q_{B5} \times X_{B5}}{U_5} = \frac{35.205 \times 1.77 + 19.304 \times 52.4}{114.03} = 10.32(kV)$$

- **Load 5 voltage is converted to primary side:**

$$U_5^{'} = U_5 - \Delta U_{B5} = 104.03 - 10.32 = 93.7(kV)$$

- **Voltage at secondary side of transformer T5:**

$$U_{haB5} = \frac{U_5^{'}}{k} = \frac{U_5^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{20.61}{\frac{110}{22 \times 1,1}} = 24.43(kV)$$

- **Voltage difference :**

$$\%\ \Delta U = \frac{U_{haB5} - U_{dmha}}{U_{dmha}} \times 100 = \frac{20.61 - 22}{22} \times 100 = -6.3\%$$

❖ **Line 5 – 6:**

- **Power before line impedance of 5 – 6 (from previous calculations)**

$$S_{5-6}^{'} = -3.97 - j0.99(MVA)$$

- **Voltage drop on line 5 – 6:**

$$\Delta U_{5-6} = \frac{P_{5-6}^{'} \times R_{5-6} + Q_{5-6}^{'} \times X_{5-6}}{U_N} = \frac{-3.97 \times 18.4 - 0.99 \times 17.64}{113.315} = 0.824(kV)$$

- **Voltage at the end of line 5 – 6 on the left:**

$$U_{6t} = U_5 - \Delta U_{5-6} = 104.03 - 0.824 = 103.2(kV)$$

❖ **Line N – 6:**

❖ **Calculate voltage at node 6:**

- **Power before line impedance of N – 6 (from previous calculations)**

$$S_6^{'} = S_{N-6} + j\Delta Q_{CN-6} = 21.35 + j10.61 + j0.75 = 27.35 + j11.36(MVA)$$

- **Voltage drop on line N – 6:**

$$\Delta U_6 = \frac{P_6^{'} \times R_6 + Q_6^{'} \times X_6}{U_N} = \frac{27.35 \times 9.4 + 11.36 \times 18.33}{110} = 4.23(kV)$$

- **Voltage at the end of line N – 6 on the right side:**

$$U_{6p} = U_N - \Delta U_6 = 110 - 4.23 = 105.77(kV)$$

- **Voltage at node 6:**

$$U_6 = \frac{U_{6t} + U_{6p}}{2} = \frac{1105.77 + 103.2}{2} = 104.485(kV)$$

- **Power before transformer impedance B6:**

$$S_{B6} = (P_6 + jQ_6) + (\Delta P_{B6} + j\Delta Q_{B6})$$
$$= (22.5 + j8.75) + (0.118 + j1.525)$$
$$= 22.618 + j10.275(MVA)$$

- **Voltage drop on transformer B6:**

$$\Delta U_{B6} = \frac{P_{B6} \times R_{B6} + Q_{B6} \times X_{B6}}{U_6} = \frac{22.618 \times 2.45 + 10.275 \times 31.67}{104.485} = 3.644(kV)$$

- **Load 6 voltage converted to primary side:**

$$U_6^{'} = U_6 - \Delta U_{B6} = 104.485 - 3.644 = 100.84(kV)$$

- **Voltage at secondary side of transformerT6:**

$$U_{haB6} = \frac{U_6^{'}}{k} = \frac{U_6^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{100.84}{\frac{110}{22 \times 1,1}} = 22.185(kV)$$

- **Voltage difference :**

$$\% \ \Delta U = \frac{U_{haB6} - U_{dmha}}{U_{dmha}} \times 100 = \frac{22.185 - 22}{22} \times 100 = 0.843\%$$

Similar calculations use for other ring circuit.

Type of incident	**Line**	**Active Power loss ΔP_L (MW)**	**Reactive power loss ΔQ_L (MVAr)**	**The reactive capacity is generated by the line capacitance on both side ΔQ_C (MVAr)**
Transformer breakdown B3 (Ring N – 3 – 4 – N)	N – 3	0.547	1.068	1.38
	3 – 4	0.0068	0.0065	1.134
	N – 4	0.6	1.185	1.5
Transformer breakdown B4 (Ring N –3 – 4 – N)	N – 3	0.547	1.068	1.38
	3– 4	0.0086	0.0082	1.134
	N – 4	0.607	1.185	1.5
Transformer breakdown B5 (Ring N – 5 – 6 – N)	N – 5	0.794	1.891	1.525
	5 – 6	0.0255	0.0244	1.26
	N – 6	0.65	1.266	1.5
Transformer breakdown B6 (Ring N – 5 – 6 – N)	N – 5	0.764	1.82	1.525
	5 – 6	0.021	0.02	1.26
	N – 6	0.637	1.243	1.5

Table 6.15 Power losses at fault operation

Type of incident	**Station**	ΔP_{Fe} **(kW)**	ΔQ_{Fe} **(kVAr)**	$\Delta P_{CU} = \Delta P_B$ **(MW)**	$\Delta Q_{CU} = \Delta Q_B$ **(MVAr)**
Transformer breakdown B3 (Ring N – 3 – 4 – N)	3	60	600	0.239	3.099
	4	58	400	0.0837	1.833
Transformer breakdown B4 (Ring N –3 – 4 – N)	3	120	1200	0.12	1.55
	4	29	200	0.1675	3.66
Transformer breakdown B5 (Ring N – 5 – 6 – N)	5	17`	45	0.204	6.064
	6	120	1200	0.118	1.525
Transformer breakdown B6 (Ring N – 5 – 6 – N)	5	34	90	0.102	3.032
	6	60	600	0.236	3.05

Table 6.16 Transformer losses at fault operation

Type of incident	Load	Primary voltage(kV)	Secondary converted to primary voltage(kV)	Secondary voltage(kV)	% ΔU
Transformer breakdown B3 (Ring N – 3 – 4 – N)	N – 3	106.55	98.15	21.59	-1.85
	N – 4	105.62	102.57	22.56	2.57
Transformer breakdown B4 (Ring N –3 – 4 – N)	N – 3	106.55	102.81	22.62	2.82
	N – 4	105.34	98.125	21.587	-1.874
Transformer breakdown B5 (Ring N – 5 – 6 – N)	N – 5	104.03	93.7	20.615	-6.29
	N – 6	105.78	100.84	22.185	0.843
Transformer breakdown B6 (Ring N – 5 – 6 – N)	N – 5	104.7	100.32	22.07	0.324
	N – 6	105.635	96.64	21.26	-3.35

Table 6.17 Voltage at fault operation

Type of incident	Line	P (MW)	Q (MVAr)
Transformer breakdown B3 (Ring N – 3 – 4 – N)	N – 3	25.58	10.89
	N – 4	26	12.2
Transformer breakdown B4 (Ring N –3 – 4 – N)	N – 3	25.586	10.897
	N – 4	26	13.83
Transformer breakdown B5 (Ring N – 5 – 6 – N)	N – 5	40.01	18.714
	N – 6	27.35	10.61
Transformer breakdown B6 (Ring N – 5 – 6 – N)	N – 5	39.65	14.84
	N – 6	27.15	11.52

Table 6.18 Sending power at fault operation

6.5.2 Breakage of transmission wire

When line N – 6 break, we have data

Load	Transformer	R_B (Ω)	X_B (Ω)	ΔP_{Fe} (KW)	ΔQ_{Fe} (KVAr)
5	2	0.885	26.2	120	1200
6	2	2.45	31.67	120	1200

Table 6.19 Transformer parameters when a line broke

Line	R (Ω)	X (Ω)	Y(1/Ω).10^{-6}
N – 5	7.6	18.1	126.1
5 – 6	18.4	17.64	104

Table 6.20 Line parameters when a line broke

- **Calculate power at node 6**

- **Power loss in transformer B6:**

$$\Delta P_{B6} = \frac{P_6^2 + (Q_6 - Q_{bu6})^2}{U_{dm}^2} \times R_{B6} = \frac{28^2 + (17,35 - 5,69)^2}{110^2} \times 1,16 = 0,08(MW)$$

$$\Delta Q_{B6} = \frac{P_6^2 + (Q_6 - Q_{bu6})^2}{U_{dm}^2} \times X_{B6} = \frac{28^2 + (17,35 - 5,69)^2}{110^2} \times 25,38 = 1,92(MVAr)$$

- **Reactive power due to capacitance of line end 5 – 6:**

$$\Delta Q_{C5-6} = \frac{Y_{5-6}}{2} \times U_{dm}^2 = \frac{104,2 \times 10^{-6}}{2} \times 110^2 = 0,63(MVAr)$$

- **Power at the end of impedance of line 5 – 6:**

$$\begin{aligned} S_6^{"} &= (P_6 + j(Q_6 - Q_{b6})) + (\Delta P_{B6} + j\Delta Q_{B6}) + (\Delta P_{Fe6} + j\Delta Q_{Fe6}) - j\Delta Q_{C5-6} \\ &= 28,138 + j13,98 - j0,63 \\ &= 28,138 + j13,35(MVA) \end{aligned}$$

- **Power loss on line impedance 5 – 6:**

$$\Delta S_{5-6} = \frac{(P_6^{''})^2 + (Q_6^{''})^2}{U_{dm}^2} \times (R_{5-6} + jX_{5-6}) = \frac{28,138^2 + 13,35^2}{110^2} \times (18,4 + j17,6)$$
$$= 1,47 + j1,41(MVA)$$

❖ **Sending power of line 5 – 6:**

$$S_{5-6} = S_6^{''} + \Delta S_{5-6} - j\Delta Q_{C5-6} = 29,608 + j14,76 - j0,63 = 29,608 + j14,13(MVA)$$

➢ **Calculate power at node 5**

❖ **Power loss in transformer B5:**

$$\Delta P_{B5} = \frac{P_5^2 + (Q_5 - Q_{bu5})^2}{U_{dm}^2} \times R_{B5} = \frac{22^2 + (14,21 - 4,68)^2}{110^2} \times 2,46 = 0,11(MW)$$

$$\Delta Q_{B5} = \frac{P_5^2 + (Q_5 - Q_{bu5})^2}{U_{dm}^2} \times X_{B5} = \frac{22^2 + (14,21 - 4,68)^2}{110^2} \times 31,66 = 1,5(MVAr)$$

❖ **Power go in transformer B5:**

$$S_{T5} = (P_5 + j(Q_5 - Q_{b5})) + (\Delta P_{B5} + j\Delta Q_{B5}) + (\Delta P_{Fe5} + j\Delta Q_{Fe5})$$
$$= (22 + j(14,21 - 4,68)) + (0,11 + j1,5) + (120 + j1200) \times 10^{-3}$$
$$= 22,23 + j12,23(MVA)$$

❖ **Reactive power due to capacitance of line end N – 5:**

$$\Delta Q_{C5} = \frac{Y_5}{2} \times U_{dm}^2 = \frac{123,87 \times 10^{-6}}{2} \times 110^2 = 0,74(MVAr)$$

❖ **Power at the of line impedance N – 5:**

$$S_5^{''} = S_{5-6} + S_{T5} - j\Delta Q_{C5} = 29,608 + j14,13 + 22,23 + j12,23 - j0,74 = 51,838 + j25,62(MVA)$$

❖ **Power loss on line impedance N – 5:**

$$\Delta S_{N-5} = \frac{(P_5^{''})^2 + (Q_5^{''})^2}{U_{dm}^2} \times (R_{N-5} + jX_{N-5}) = \frac{51,838^2 + 25,62^2}{110^2} \times (9,39 + j18,33) = 2,59 + j5,06(MVA)$$

❖ **Power before line impedance of N – 5:**

$$S_5^{'} = S_5^{''} + \Delta S_{N-5} = 51,838 + j25,62 + 2,59 + j5,06 = 54,428 + j30,68(MVA)$$

❖ **Sending power of line N – 5:**

$$S_{N-5} = S_5^{'} - j\Delta Q_{C5} = 54,428 + j30,68 - j0,74 = 54,428 + j29,94(MVA)$$

- **Calculate voltage at node 5:**

– **Power before line impedance of N – 5 (from previous calculations)**

$$S_5^{'} = 54,428 + j30,68(MVA)$$

– **Voltage drop on line N – 5:**

$$\Delta U_5 = \frac{P_5^{'} \times R_5 + Q_5^{'} \times X_5}{U_N} = \frac{54,428 \times 9,39 + 30,68 \times 18,33}{121} = 8,871(kV)$$

– **Voltage at the end of line N – 5:**

$$U_5 = U_N - \Delta U_5 = 121 - 8,871 = 112,129(kV)$$

– **Power before transformer impedance B5:**

$$\begin{aligned} S_{B5} &= (P_5 + j(Q_5 - Q_{b5})) + (\Delta P_{B5} + j\Delta Q_{B5}) \\ &= (22 + j(14,21 - 4,68)) + (0,11 + j1,5) \\ &= 22,11 + j11,03(MVA) \end{aligned}$$

– **Voltage drop on transformer B5:**

$$\Delta U_{B5} = \frac{P_{B5} \times R_{B5} + Q_{B5} \times X_{B5}}{U_5} = \frac{22,11 \times 2,46 + 11,03 \times 31,66}{112,129} = 3,599(kV)$$

– **Load 5 voltage is converted to primary side:**

$$U_5^{'} = U_5 - \Delta U_{B5} = 112,129 - 3,599 = 108,53(kV)$$

– **Voltage at secondary side of transformerT5:**

$$U_{haB5} = \frac{U_5^{'}}{k} = \frac{U_5^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{108,53}{\frac{110}{22 \times 1,1}} = 23,876(kV)$$

– **Voltage difference :**

$$\% \ \Delta U = \frac{U_{haB5} - U_{dmha}}{U_{dmha}} \times 100 = \frac{23,876 - 22}{22} \times 100 = 8,52\%$$

- **Calculate voltage at node 6:**

– **Power before line impedance of 5 – 6 (from previous calculations)**

$$S_6^{'} = 29,608 + j14,76(MVA)$$

– **Voltage drop on line N – 6:**

$$\Delta U_{5-6} = \frac{P_6^{'} \times R_{5-6} + Q_6^{'} \times X_{5-6}}{U_5} = \frac{29,608 \times 18,4 + 14,76 \times 17,6}{112,129} = 7,175(kV)$$

- **Voltage at the end of line 5 – 6:**

$$U_6 = U_5 - \Delta U_{5-6} = 112,129 - 7,175 = 104,954(kV)$$

- **Power before transformer impedance B6:**

$$S_{B6} = (P_6 + j(Q_6 - Q_{b6})) + (\Delta P_{B6} + j\Delta Q_{B6})$$
$$= (28 + j(17,35 - 5,69)) + (0,08 + j1,92)$$
$$= 28,08 + j13,58(MVA)$$

- **Voltage drop on transformer B6:**

$$\Delta U_{B6} = \frac{P_{B6} \times R_{B6} + Q_{B6} \times X_{B6}}{U_6} = \frac{28,08 \times 1,16 + 13,58 \times 25,38}{104,954} = 3,594(kV)$$

- **Load 6 voltage is converted to primary side:**

$$U_6^{'} = U_6 - \Delta U_{B6} = 104,954 - 3,594 = 101,36(kV)$$

- **Voltage at secondary side of transformerT6:**

$$U_{haB6} = \frac{U_6^{'}}{k} = \frac{U_6^{'}}{\frac{U_{dmcao}}{U_{ktha}}} = \frac{101,36}{\frac{110}{22 \times 1,1}} = 22,299(kV)$$

- **Voltage difference :**

$$\% \ \Delta U = \frac{U_{haB6} - U_{dmha}}{U_{dmha}} \times 100 = \frac{22,299 - 22}{22} \times 100 = 1,35\%$$

Similar calculations apply for the other ring.

Type of incident	Line	Active power loss ΔP_L (MW)	Reactive power loss ΔQ_L (MVAr)	The reactive capacity is generated by the line capacitance on both side ΔQ_C (MVAr)
Line N – 4 break (Ring N – 3 –4 – N)	N – 3	2.3	4.23	1.38
	3 – 4	0.732	1.427	1.134
Line N – 3 break (Ring N – 3 – 4 – N)	N – 4	2.525	4.923	1.5
	4 – 3	0.867	0.831	1.134
Line N – 6 break (Ring N – 5 – 6 – N)	N – 5	2.597	6.18	1.525
	5 – 6	0.94	0.9	1.26
Line N – 5 break (Ring N – 5 – 6 – N)	N – 6	3.2	6.25	1.5
	6 – 5	0.916	2.18	1.26

Table 6.21 Power losses on line when a line broke

Type of incident	Station	ΔP_{Fe} (kW)	ΔQ_{Fe} (kVAr)	$\Delta P_{CU} = \Delta P_B$ (MW)	$\Delta Q_{CU} = \Delta Q_B$ (MVAr)
Line N – 4 break (Ring N – 3 –4 – N)	3	120	1200	0.12	1.55
	4	58	400	0.0837	3.66
Line N – 3 break (Ring N – 3 – 4 – N)	3	120	1200	0.12	1.55
	4	58	400	0.0837	3.66
Line N – 6 break (Ring N – 5 – 6 – N)	5	34	90	0.1025	3.03
	6	120	1200	0.118	1.525
Line N – 5 break (Ring N – 5 – 6 – N)	5	34	90	0.1025	3.03
	6	120	1200	0.118	1.525

Table 6.22 Power losses in transformer when a line broke

Type of incident	Line	Primary voltage (kV)	Secondary converted to primary voltage(kV)	Secondary voltage(kV)	% ΔU
Line N – 4 break (Ring N – 3 –4 – N)	N – 3	113.23	109.717	24.137	9.71
	3 – 4	107.2	100.03	22	0.031
Line N – 3 break (Ring N – 3 – 4 – N)	N – 4	112.4	105.56	23.22	5.56
	4 – 3	107.35	103.65	22.8	3.645
Line N – 6 break (Ring N – 5 – 6 – N)	N – 5	112.44	108.373	23.842	8.373
	5 – 6	106.93	103.37	22.74	3.37
Line N – 5 break (Ring N – 5 – 6 – N)	N – 6	111.435	108.017	23.74	8.01
	6 – 5	103.088	98.65	21.7	-1.35

Table 6.23 Voltage at nodes when a line broke

Type of incident	Line	P (MW)	Q (MVAr)
Line N – 4 break (Ring N – 3 –4 – N)	N – 3	53.39	28.25
Line N – 3 break (Ring N – 3 – 4 – N)	N - 4	53.744	29.2
Line N – 6 break (Ring N – 5 – 6 – N)	N – 5	61.41	31.43
Line N – 5 break (Ring N – 5 – 6 – N)	N – 6	61.99	31.35

Table 6.24 Sending power when a line broke

6.5.3 Summarize

Type of incident	Line	Active power loss ΔP_L (MW)	Reactive power loss ΔQ_L (MVAr)	The reactive capacity is generated by the line capacitance on both side ΔQ_C (MVAr)
Transformer breakdown B3 (Ring N – 3 – 4 – N)	N – 3	0.547	1.068	1.38
	3 – 4	0.0068	0.0065	1.134
	N – 4	0.6	1.185	1.5
Transformer breakdown B4 (Ring N –3 – 4 – N)	N – 3	0.547	1.068	1.38
	3– 4	0.0086	0.0082	1.134
	N – 4	0.607	1.185	1.5
Line N – 4 break (Ring N – 3 –4 – N)	N – 3	2.3	4.23	1.38
	3 – 4	0.732	1.427	1.134
Line N – 3 break (Ring N – 3 – 4 – N)	N – 4	2.525	4.923	1.5
	4 – 3	0.867	0.831	1.134
Transformer breakdown B5 (Ring N – 5 – 6 – N)	N – 5	0.794	1.891	1.525
	5 – 6	0.0255	0.0244	1.26
	N – 6	0.65	1.266	1.5
Transformer breakdown B6 (Ring N – 5 – 6 – N)	N – 5	0.764	1.82	1.525
	5 – 6	0.021	0.02	1.26
	N – 6	0.637	1.243	1.5
Line N – 6 break (Ring N – 5 – 6 – N)	N – 5	2.597	6.18	1.525
	5 – 6	0.94	0.9	1.26
Line N – 6 break (Ring N – 5 – 6 – N)	N – 6	3.2	6.25	1.5
	6 – 5	0.916	2.18	1.26

Table 6.25 Power losses on line in incidents

Type of incident	**Station**	ΔP_{Fe} **(kW)**	ΔQ_{Fe} **(kVAr)**	$\Delta P_{CU} = \Delta P_B$ **(MW)**	$\Delta Q_{CU} = \Delta Q_B$ **(MVAr)**
Transformer breakdown B3 (Ring N – 3 – 4 – N)	3	60	600	0.239	3.099
	4	58	400	0.0837	1.833
Transformer breakdown B4 (Ring N –3 – 4 – N)	3	120	1200	0.12	1.55
	4	29	200	0.1675	3.66
Line N – 4 break (Ring N – 3 –4 – N)	3	120	1200	0.12	1.55
	4	58	400	0.0837	3.66
Line N – 3 break (Ring N – 3 – 4 – N)	3	120	1200	0.12	1.55
	4	58	400	0.0837	3.66
Transformer breakdown B5 (Ring N – 5 – 6 – N)	5	17	45	0.204	6.064
	6	120	1200	0.118	1.525
Transformer breakdown B6 (Ring N – 5 – 6 – N)	5	34	90	0.102	3.032
	6	60	600	0.236	3.05
Line N – 6 break (Ring N – 5 – 6 – N)	5	34	90	0.1025	3.03
	6	120	1200	0.118	1.525
Line N – 6 break (Ring N – 5 – 6 – N)	5	34	90	0.1025	3.03
	6	120	1200	0.118	1.525

Table 6.26 Power losses in transformer in incidents

Type of incident	Load	Primary voltage(kV)	Secondary converted to primary voltage(kV)	Secondary voltage(kV)	Voltage difference(%)
Transformer breakdown B3 (Ring N – 3 – 4 – N)	3	106.55	98.15	21.59	-1.85
	4	105.62	102.57	22.56	2.57
Transformer breakdown B4 (Ring N –3 – 4 – N)	3	106.55	102.81	22.62	2.82
	4	105.34	98.125	21.587	-1.874
Line N – 4 break (Ring N – 3 –4 – N)	3	113.23	109.717	24.137	9.71
	4	107.2	100.03	22	0.031
Line N – 3 break (Ring N – 3 – 4 – N)	4	112.4	105.56	23.22	5.56
	3	107.35	103.65	22.8	3.645
Transformer breakdown B5 (Ring N – 5 – 6 – N)	5	104.03	93.7	20.615	-6.29
	6	105.78	100.84	22.185	0.843
Transformer breakdown B6 (Ring N – 5 – 6 – N)	5	104.7	100.32	22.07	0.324
	6	105.635	96.64	21.26	-3.35
Line N – 6 break (Ring N – 5 – 6 – N)	5	112.44	108.373	23.842	8.373
	6	106.93	103.37	22.74	3.37
Line N – 6 break (Ring N – 5 – 6 – N)	6	111.435	108.017	23.74	8.01
	5	103.088	98.65	21.7	-1.35

Table 6.27 Voltage at nodes in incidents

Type of incident	Line	P (MW)	Q (MVAr)
Transformer breakdown B3 (Ring N – 3 – 4 – N)	N – 3	25.58	10.89
	N – 4	26	12.2
Transformer breakdown B4 (Ring N –3 – 4 – N)	N – 3	25.586	10.897
	N – 4	26	13.83
Line N – 4 break (Ring N – 3 –4 – N)	N – 3	53.39	28.25
Line N – 3 break (Ring N – 3 – 4 – N)	N - 4	53.744	29.2
Transformer breakdown B5 (Ring N – 5 – 6 – N)	N – 5	40.01	18.714
	N – 6	27.35	10.61
Transformer breakdown B6 (Ring N – 5 – 6 – N)	N – 5	39.65	14.84
	N – 6	27.15	11.52
Line N – 6 break (Ring N – 5 – 6 – N)	N – 5	61.41	31.43
Line N – 6 break (Ring N – 5 – 6 – N)	N – 6	61.99	31.35

Table 6.28 Sending power in incidents

CHAPTER 7. VOLTAGE ADJUSTMENT, TAP-CHANGER SELECTING

7.1 Content

- To guarantee the nature of the voltage while changing the voltage at the hour of activity, introduce remuneration hardware, sanely disseminate limit in the electrical network, ... Numerous proportions of voltage guideline have been applied.
- In this chapter, I compute and select the tap changer of the transformer to ensure the voltage difference of the bus bar stay in the allowance.

7.2 Tap changer selecting

- To know the most appropriate and is board, we need to pick the voltage divider for the transformer, the transformer to be placed into activity to guarantee the busbar voltage of the superload. load, least and attempt inside the permitted range. Currently, transformers applied to 115kV (110kV) with a limit of 16MVA or more are regularly intended for under-load voltage controllers.
- In this computation, we consider a 115/23kV transformer, which has a voltage controller under load. With an evaluated recurrence of 50Hz, the machine will have a voltage change of ± 16% with ± 8 stages (counting 9=8 additions and 8 decreases each with a 1.78% distinction).

Transformer ratio: $k = \frac{U_{pa.cao}}{U_{kt.ha}}$

Tap changing %	**Tap changer**	**$U_{pa.cao}$**
+14.24	8	131.38
+12.46	7	129.33
+10.68	6	127.28
+8.9	5	125.24
+7.12	4	123.19
+5.34	3	121.14
+3.56	2	119.09
+1.78	1	117.05
+0	0	115
-1.78	-1	112.95
-3.56	-2	110.91
-5.34	-3	108.86
-7.12	-4	106.81
-8.9	-5	104.77
-10.68	-6	102.72
-12.46	-7	100.67
-14.24	-8	98.62

Table 7.1 Tap changer parameters

Transformer ratio: $k = \frac{U_{pa.cao}}{U_{kt.ha}} = \frac{U_1^{'}}{U_{ha.yc}} = \frac{U_1 - \Delta U_B}{U_{ha.yc}}$

- **$U_{pa.cao}$:** voltage corresponding to the tap
- **U_1:** voltage at Primary voltage when have load
- **U_1'**: voltage in Secondary voltage convert to primary side.
- **ΔU_B:** voltage drop in transformer.
- **$U_{kt.ha}$**: no-load-voltage on secondary side usually higher than rated:

$$U_{kt.ha} = 1.1 \times U_{dm.ha} = 1.1 \times 22 = 24.2(kV)$$

As per the prerequisite, we have an appraised voltage of 22 kV on the optional side and a reasonable Voltage distinction of ± 5% from the evaluated voltage, so the necessary low voltage is:

$$U_{ha.yc} = (0.95 \to 0.5) \times 22 = 20.9 \to 23.1(kV)$$

7.2.1 Select tap-changer at maximum load

Secondary voltage converted to primary side:

$$U^{'}_{1max} = 112.13(kV)$$

Computing voltage at tap:

$$U_{patt} = U^{'}_{1max} \times \frac{U_{kt.ha}}{U_{ha.yc}} = 112.13 \times \frac{24.2}{23.1} = 117.467(kV)$$

- ⇨ **Select tap "+2" with voltage is 119.09 kV**

Checking voltage at Secondary voltage after select tap:

$$U_{ha1} = U^{'}_{1max} \times \frac{U_{kt.ha}}{U_{patc}} = 112.13 \times \frac{24,2}{119,09} = 22.785(kV)$$

- ⇨ **Satisfied the conditions of $\mathbf{U_{ha.yc}}$**

Voltage difference after select tap:

$$\%U_{ha1} = \frac{U_{ha1} - U_{dm.ha}}{U_{dm.ha}} \times 100 = \frac{22.785 - 22}{22} \times 100 = 3.57\%$$

Calculate all other nodes with similar means**.**

Node	Secondary voltage converted to Primary voltage(kV)	Voltage at tap (kV)	Tap select	Voltage at Secondary voltage(kV)	Voltage difference(%)
1	112.128	117.467	+2	22.785	3.571
2	107.79	112.922	-1	23.094	4.975
3	114.33	119.774	+3	22.839	3.816
4	114.18	119.617	+3	22.809	3.680
5	112.22	117.563	+2	22.803	3.654
6	113.77	119.187	+3	22.727	3.308

Table 7.2 Tap-changers selection at maximum load

7.2.2 Select tap-changer at minimum load

Secondary voltage converted to primary side:

$$U'_{1\min} = 110.83(kV)$$

Coputing voltage at tap:

$$U_{patt} = U'_{1\min} \times \frac{U_{kt.ha}}{U_{ha.yc}} = 110.83 \times \frac{24.2}{23.1} = 116.108(kV)$$

⇨ **Select tap "+1" with voltage 117,05 kV**

Checking voltage at Secondary voltage after select tap:

$$U_{ha1} = U'_{1\min} \times \frac{U_{kt.ha}}{U_{patc}} = 110.83 \times \frac{24.2}{117.05} = 22.914(kV)$$

⇨ **Satisfied the conditions of $U_{ha.yc}$**

⇨

Voltage difference after select tap:

$$\%U_{ha1} = \frac{U_{ha1} - U_{dm.ha}}{U_{dm.ha}} \times 100 = \frac{22.914 - 22}{22} \times 100 = 4.155\%$$

Calculate all other nodes with similar means**.**

Node	Secondary voltage converted to Primary voltage(kV)	Voltage at tap (kV)	Tap select	Voltage at Secondary voltage(kV)	Voltage difference(%)
1	110.83	116.108	+1	22.914	4.155
2	110.07	115.311	+1	22.757	3.440
3	110.66	115.930	+1	22.879	3.995
4	112.11	117.449	+2	22.782	3.553
5	111.063	116.352	+1	22.962	4.374
6	111.21	116.506	+1	22.993	4.512

Table 7.3 Tap-changers selection at minimum load

7.2.3 Select tap-changer at fault operation

Only considered the situation where a line in the circuit break. To demostrate, I use ring N – 5 – 6 – N. Calculate only the situations of each station where the line connect directly to the System break, meaning compute station 5 at fault only when N-5 break.

Secondary voltage converted to primary side:

$$U'_{5f1} = 98.65(kV)$$

Computing voltage at tap:

$$U_{patt} = U'_{5f1} \times \frac{U_{kt.ha}}{U_{ha.yc}} = 98.65 \times \frac{24.2}{23.1} = 103.34(kV)$$

⇨ **Select tap "-5" with voltage 104.77 kV**

Checking voltage at Secondary voltage after select tap:

$$U_{ha5} = U'_{5f1} \times \frac{U_{kt.ha}}{U_{patc}} = 98.65 \times \frac{24.2}{104.77} = 22.786(kV)$$

⇨ **Satisfied the conditions of $U_{ha.yc}$**

Voltage difference after select tap:

$$\%U_{ha5} = \frac{U_{ha5} - U_{dm.ha}}{U_{dm.ha}} \times 100 = \frac{22.786 - 22}{22} \times 100 = 3.57\%$$

Calculate all other nodes with similar means**.**

Node	Secondary voltage converted to Primary voltage(kV)	Voltage at tap (kV)	Tap select	Voltage at Secondary voltage(kV)	Voltage difference(%)
3	103.65	108.58	-3	23.04	4.73
4	100.03	107.8	-4	22.66	3.01
5	98.65	103.34	-5	22.78	3.57
6	103.37	108.29	-3	22.98	4.45

Table 7.4 Tap-changers selection at fault operation

7.3 Summarize

Station	Status	Secondary voltage before selection (kV)	Tap	Secondary voltage after selection (kV)	ΔU %
1	Maximum load	24.67	+2×1.78%	22.785	3.571
	Minimum load	24.38	+1×1.78%	22.914	4.155
2	Maximum load	23.7138	-1×1.78%	23.094	4.975
	Minimum load	24.21	+1×1.78%	22.757	3.440
3	Maximum load	25.15	+3×1.78%	22.839	3.816
	Minimum load	24.345	+1×1.78%	22.879	3.995
	Fault	22.8	-3×1.78%	23.04	4.73
4	Maximum load	25.12	+3×1.78%	22.809	3.680
	Minimum load	24.66	+2×1.78%	22.782	3.553
	Fault	22	-4×1.78%	22.66	3.01
5	Maximum load	24.68	+2×1.78%	22.803	3.654
	Minimum load	24.434	+1×1.78%	22.962	4.374
	Fault	21.7	-5×1.78%	22.78	3.57
6	Maximum load	25.03	+3×1.78%	22.727	3.308
	Minimum load	24.466	+1×1.78%	22.993	4.512
	Fault	22.74	-3×1.78%	22.98	4.45

Table 7.5 Tap-changers selections

CHAPTER 8. ECONOMIC AND TECHNICAL INDICATORS OF THE DESIGNED ELECTRIC NETWORK

8.1 Contents

- In the last part of this venture, we will figure the expense forecast of the entire undertaking just as the financial and specialized pointers.
- Once an itemized outline of the undertaking is finished, development costs, for example, the development of the transformer station, PC establishment, and development of the transmission line can be set up.
- In this rundown dependent on the power misfortune estimation and insights of financial and specialized markers, we will ascertain the expense of power load.

8.2 Total power loss calculation at maximum load

❖ Active power loss on lines**:**

$$\sum \Delta P_L = 8.97(MW)$$

❖ Power losses in transformers:

- Copper loss (short circuit loss): $\sum \Delta P_{cu} = 0.675(MW)$
- Core loss (open circuit loss): $\sum \Delta P_{Fe} = 0.349(MW)$

❖ Compensation instruments loss**:**

❖ Since the compensation device is a static capacitor, thus $\Delta P^* = 0.05$

$$\sum \Delta P_{bu} = \Delta P \times \sum Q_{bu} = 0.005 \times 47.51 = 0.23755(MW)$$

❖ Total capacity has losses:

$$\begin{aligned}\Delta P_\Sigma &= \sum \Delta P_L + \sum \Delta P_{cu} + \sum \Delta P_{Fe} + \sum \Delta P_{bu} \\ &= 8.97 + 0.675 + 0.349 + 0.23755 \\ &= 10.23155(MW)\end{aligned}$$

❖ Percentage of power loss of total load:

$$\Delta P_\Sigma\% = \frac{\Delta P_\Sigma}{P_\Sigma} \times 100\% = \frac{10.23155}{166.5} \times 100 = 6.145\%$$

8.3 Total annual loss of income in the designed electric network

- ❖ Electrical loss in iron core of transformer (assume transformer all year long) with T = 8760 hours

$$\Delta A_{Fe} = (\sum \Delta P_{Fe} \times T) = 0.349 \times 8760 = 3057.24 (MWh)$$

- ❖ Electrical loss one lines and in transformer windings:

$$\Delta A_R = (\sum \Delta P_L + \sum \Delta P_{Cu}) \times \tau = (8.97 + 0.675) \times 3410.9 = 32898.13 (MWh)$$

- ❖ Electrical loss in compensation devices:

$$\Delta A_{bu} = \sum \Delta P_{bu} \times T_{\max} = 0.23755 \times 5000 = 1187.75 (MWh)$$

- ❖ Toltal electrical loss in network:

$$\Delta A_{\Sigma} = \Delta A_{Fe} + \Delta A_R + \Delta A_{bu} = 3057.24 + 32898.13 + 1187.75 = 37143.12 (MWh)$$

- ❖ Percentage of total electrical losses of total electrical energy supplied to the load:

$$A_{\Sigma} = P_{\Sigma} \times T_{\max} = 166.5 \times 5000 = 832500$$

$$\Delta A_{\Sigma}\% = \frac{\Delta A_{\Sigma}}{A_{\Sigma}} \times 100\% = \frac{37143.12}{832500} \times 100 = 4.46\%$$

8.4 Calculate cost of electrical parts

- ➢ $a_{vh(L)}$: Line operation coefficient (Depreciation, repair, service)
  - The line with reinforced concrete pillars: $a_{vh(L)}$=0,04
  - Line with steel pillars: $a_{vh(L)}$=0,07
- ➢ $a_{vh(T)}$: Operation coefficient of the transformer station, we take $a_{vh(T)}$=0.14
- ➢ K_L: investment in construction of lines
  - Lines of reinforced concrete pillars K_L=5 654 020 ($)
- ➢ K_T: Total investment for transformer station construction

- Station 1: S_{rated}=40 MVA, quantity: 1

  Use PL1 page 200 in the book "Thiết kế nhà máy điện và trạm biến áp" by Huỳnh Nhơn, the price of the transformer is 5 379 332.7*10^3 (dong).

  Toltal cost of station 1 is 5 379 332.7*10^3 (dong).
- Station 2 : S_{rated} = 30MVA, quantity: 1

  Use PL3 page 245 in the book "Thiết kế nhà máy điện và trạm biến áp" by Huỳnh Nhơn, the price of the transformer is 470*10^3(USD)

  Total cost of station 2 is 470*10^3(USD)
- Station 3 : S_{rated} = 20MVA, quantity: 2

  Use PL3 page 245 in the book "Thiết kế nhà máy điện và trạm biến áp" by Huỳnh Nhơn, the price of the transformer is 16.3*10^3(RUP)

  Total cost of station 3 is 32.6*10^3 (RUP)
- Station 4 : S_{rated} = 25MVA, quantity: 2

  Use PL4.2 page 130 of "Thiết kế mạng điện" by Hồ Văn Hiến, the price of a transformer is 64*10^3(RUP)

  Total cost of statin 4 is 128*10^3(RUP)
- Station 5 : S_{rated} = 40MVA, quantity: 2

  Use PL3 page 245 in the book "Thiết kế nhà máy điện và trạm biến áp" by Huỳnh Nhơn, the price of the transformer is 470*10^3(USD)

  Total cost of station 2 is 940*10^3(USD)
- Station 6: S_{rated} = 20MVA, quantity: 2

  Use PL3 page 245 in the book "Thiết kế nhà máy điện và trạm biến áp" by Huỳnh Nhơn, the price of the transformer is 16.3*10^3(RUP)

  Total cost of station 6 is 32.6*10^3 (RUP)

Station	Voltage (kV)	Power (MVA)	Transformer quantity	Price of 1 (*10^3RUB)	Price of 1 (*10^3VND)	Price of 1 (*10^3USD)	Total rice (*10^3USD)
1	110/22	40	1		5 379 332.7		233.054
2	110/22	30	1			470	470
3	110/22	20	2	16.3			0.43
4	110/22	25	2	64			1.688
5	110/22	30	2			470	940
6	110/22	20	2	16.3			0.43
						$\sum$	1645.602

Table 8.1 Stations investment

⇨ **Currency converter:**

1 USD = 75.8 RUB

1 USD = 23 081.87 VND

❖ **Annual operational costs of the electrical network:**

$$Y = a_{vh(L)} \times K_L + a_{vh(T)} \times K_T + c \times \Delta A_\Sigma$$
$$= 0.04 \times 5\ 654\ 020 + 0.14 \times 1645602 + 65 \times 37143.12$$
$$= 2870847.88\$$$

❖ **Electricity network cost for 1 MWh of electricity to load:**

$$\beta = \frac{Y}{A_\Sigma} = \frac{2870847.88}{832500} = 3.448(\$ / MWh)$$

❖ **Construction cost of electricity network for 1 MW of maximum load capacity:**

$$K_\Sigma = K_L + K_T = 5654020 + 1645602 = 7299622\$$$

⇨ $k = \frac{K_\Sigma}{P_\Sigma} = \frac{7299622}{166.5} = 43841.57(\$ / MW)$

From the above calculations we have a summary table of economic and technical indicators as follows:

Indicators	Unit	Value	Note
Maximum voltage difference	%	14.33	When load 3 at max
Maximum fault voltage difference	%	9.71	Line N – 4 break
Total length	Km	337.39	
Total capacity of stations	MVA	260	
The total reactive power generated by the line capacitance	MVAr	11.2	
The total compensation amount	MVAr	47.51	
Line investment	$	5 654 020	
Transformer investment	$	1 645 602	
Total maximum load	MW	168.027	
Annual load power	MWh	832500	
Total capacity loss	MW	10.23155	
Total capacity loss in percentage	%	6.145	
Total power loss	MWh	37143.12	
Total power loss in percentage	%	4.46	
Cost of building electrical network for 1MW of additional charge	$/MW	43841.57	
Non-ferrous metal used	Ton	587.795	
Cost of electricity load	$/kWh	3.448	
Annual operating costs	$	2870847.88	

Table 8.2 Economic and technical indicators of project

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