REPUBLIC OF MALAWI

FEASIBILITY STUDY OF NKULA B-LILONGWE B TRANSMISSION LINE CONSTRUCTION PROJECT

AUGUST 1989

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to a request from the Government of the Republic of Malawi, the Japanese Government decided to conduct a survey on Nkula B - Lilongwe B Transmission Line Construction Project and entrusted the survey to Japan International Cooperation Agency (JICA).

JICA sent to the Republic of Malawi a survey team headed by Mr. Masao Koike, the Electric Power Development Co., Ltd., from March 1989 to July 1989.

The team exchanged views with the officials concerned of the Government of the Republic of Malawi and conducted a field survey. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the development of the Project and to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the Republic of Malawi for their close cooperation extended to the team.

August, 1989

Kensuke Yanagiya
President
Japan International Cooperation Agency

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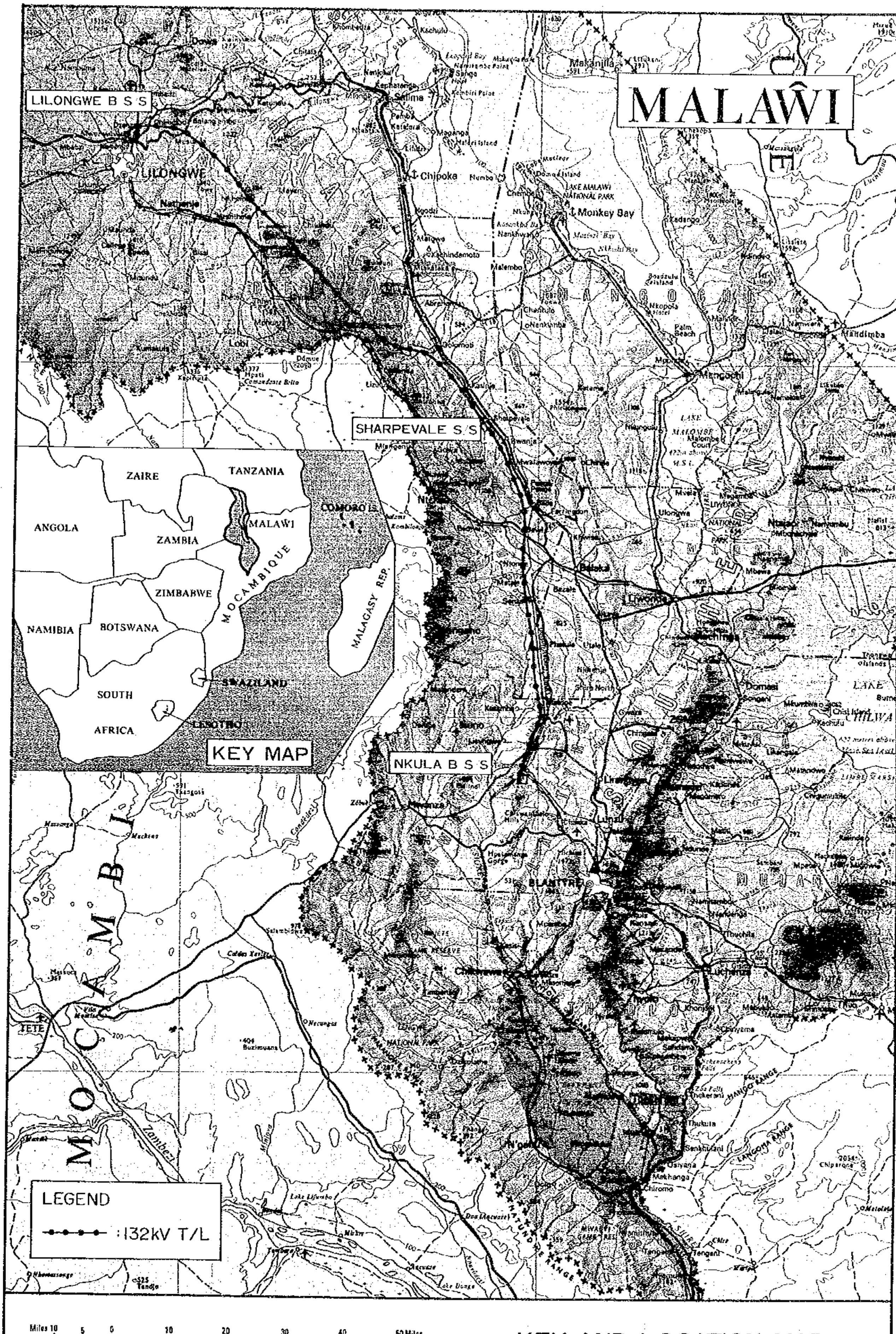
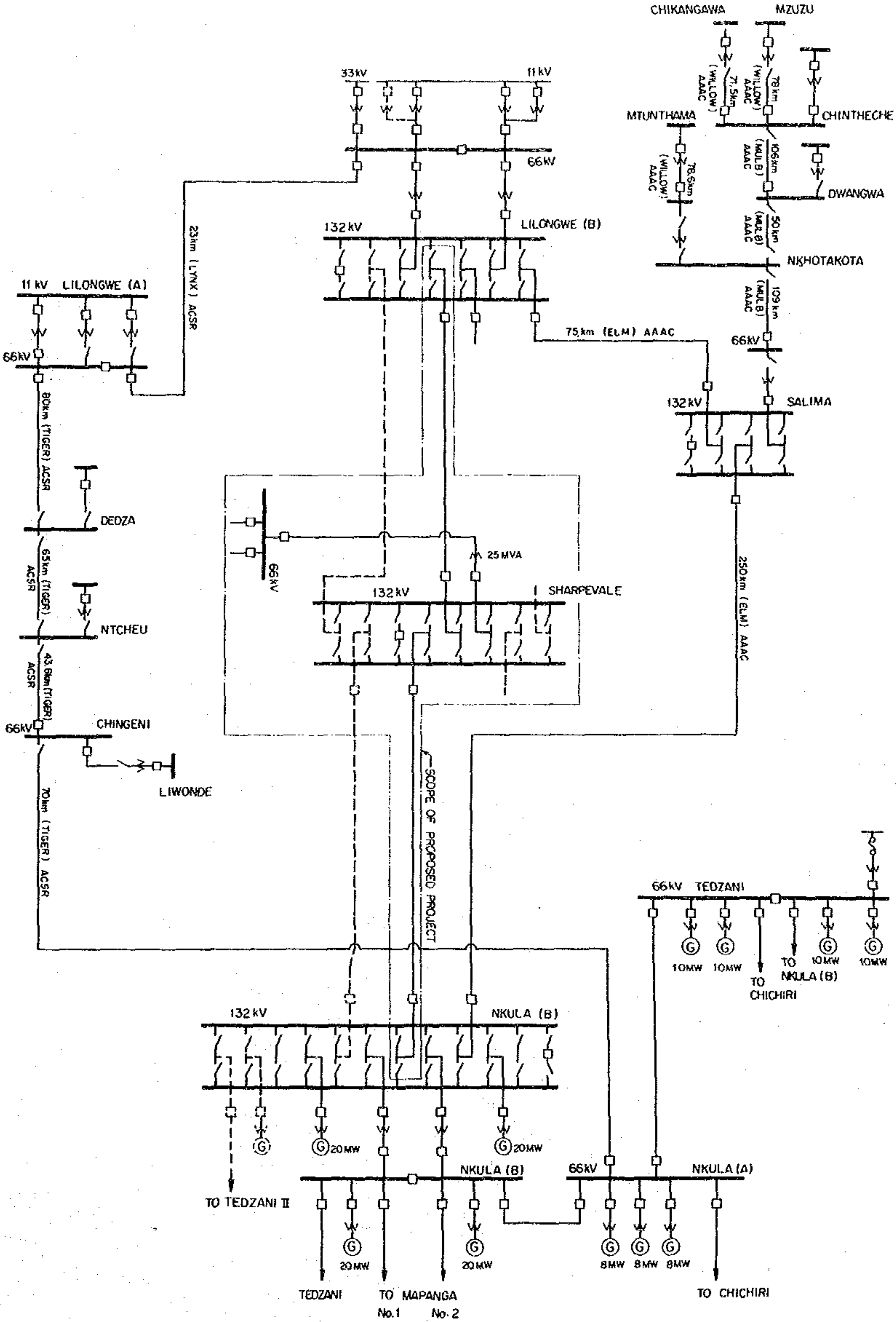


KEY AND LOCATION MAP

TRANSMISSION SYSTEM



CHAPTER 1 INTRODUCTION

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1-1 Historical Development

In the Republic of Malawi, generation capacity of 144.6 MW which shares 85% of its total generation equipment capacity (current total installed capacity is 169.8 MW including 25.4 MW of stand by thermal plant) is produced by hydraulic power. Hydro-electric power stations are concentrated in a basin of the Shire River flowing through the southern part of the country, and the power generated there is being supplied to the whole country of Malawi.

In particular, the central (capital city, Lilongwe) and northern areas receive electricity through single line of the 66 kV transmission line from the Nkula A Power Station (electric transmission capacity: 5 MW) and single line of the 132 kV wooden pole-supported transmission line from Nkula B Power Station (electric transmission capacity 20 MW). If one line of these power transmission lines is in fault, therefore, extreme load restriction and operation of uneconomical diesel power plants are compelled.

In order to attain safety supply of electricity to the central and northern region of the country and deal with a future increase in power demand in these areas, therefore, the Malawi Government is proceeding with electric power source development along the Shire River and enforcing a plan for reinforcement of power transmission and substation facilities there on a priority basis as the national energy policy.

As part of such steps, the Malawi Government asked the Japanese Government in July, 1988 to conduct a feasibility study (hereinafter referred to as F/S) in preparation for new establishment of a 250 km 132 kV overhead transmission line connecting the Nkula B Power Station along the Shire River and Lilongwe B Substation, in the capital city, as well as execution of a plan for new establishment and expansion of substations.

To consult on the scope of work (hereinafter referred to as S/W) for the F/S regarding the request about this case, the Japanese Government sent an S/W mission to the Republic of Malawi from December 2 to December 18, 1988 and carried out a summarizing investigation.

Furthermore to study the possibility of the installation of a 132 kV overhead transmission line between Nkula B Power Station and Lilongwe B Substation, the Japanese Government sent an F/S mission comprising six (6) engineers of Electric Power Development Co., Ltd. (EPDC) through Japan International Cooperation Agency (JICA) to the Republic of Malawi in March, 1989. After conducting site investigation and consultations with various local agencies and organizations concerned, the mission compiled an F/S report.

1-2 Purposes and Scope of Investigation

Purposes of the current F/S study were to implement (1) site survey, (2) collection of existing data concerning the matter, (3) consultations with the Repbulic of Malawi organizations concerned and completion and submission of an F/S report. The scope of work covers establishment of a 132 kV transmission line between the Nkula B Power Station and the Lilongwe B Substation and new construction and expansion of related substations.

1-3 Site Survey and Domestic Work

The F/S mission stayed in the Republic of Malawi for about one (1) month from March 4, 1989 and carried out consultations with the office of the President and Cabinet, the Ministry of Finance, the Economic Planning and Development Department, the Department of Statutory Bodies, the Electricity Supply Commission of Malawi (hereinafter referred to as ESCOM), etc., on-the-spot investigation and collection of related data.

After returning to Japan, the F/S mission studied the power supply-demand plan, system plan and 132 kV overhead transmission line facilities/substation construction plan on the basis of local investigation results under the guidance of the Chief Engineer and through cooperation of specialists in respective areas within an office of EPDC. It also carried out preliminary design of electric power facilities and analysis regarding the construction plan, construction cost estimation, economic evaluation, financial plan, etc. and subsequently formulated This Report.

1-4 Collected Data and Documents

The basic data used in preparing this Report was provided by the Office of President and Cabinet of Republic of Malawi, the Meteorological Agency, the ESCOM, etc. while the F/S mission was staying in the Republic of Malawi. The list of collected data and documents is shown in Annex 1.

1-5 Composition of F/S Mission

The F/S mission was composed of six (6) engineers of EPDC entrusted with the task. Their names are as follows:

1.	Mission leader	Masao Koike	General control
2.	Mission member (Virtual sub-mission leader)	Isao Saeki	Transmission line engineer
3.	Mission member	Hajime Mimizuka	Substation engineer
4.	Mission member	Katsutoshi Ono	System analysis engineer
5.	Mission member	Shusaku Watanabe	Civil engineer
6.	Mission member	Shigeru Nakano	Economic analysis engineer

CHAPTER 2 CONCLUSION AND RECOMMENDATION

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2-1 Conclusion

The conclusion obtained as a result of the current F/S study was as shown below:

(1) Efficiency of Transmission Line Establishment Plan

The plan for the establishment of a 132 kV transmission line between Nkula B Power Station and Lilongwe B substation signifies the construction of the facilities necessary and effective for electric power supply to Lilongwe (capital city), and the northern area.

(2) Early Start of Construction Work

The transmission lines supplying electricity to Lilongwe, the capital city, are double (2) circuits -- one single circuit of the 132 kV wooden pole-supported transmission line and another circuit of the 66 kV steel pole supported overhead transmission line. If some fault occurs in one (1) of the two (2) transmission line, extreme load restriction is compelled. In order to rectify such a state of affairs, it is necessary to promptly undertake construction of this 132 kV transmission line which will allow stabilized power supply.

(3) Necessity for Double Circuit Designed Overhead Transmission Line

Under This Project calling for connecting Nkula B Power Station and Lilongwe B substation, it is required to construct one (1) circuit transmission line on a priority basis.

In consideration of an anticipated power demand increase in Lilongwe, the capital, as well as around Lake Malawi, where resort development is planned, and also the need for stabilized power supply and improvement of its reliability in the northern and central region, it will become necessary to establish another single circuit in the near future. If the base construction cost of single circuit steel tower system and that of double circuit steel tower system equipped with only one (1) circuit are compared, the latter will be higher. In overall judgment of investment effects, however, the double circuit design system actually with only one (1) single circuit wiring has been adopted as described in 10-3-3.

(4) Power Demand Forecast

As a result of power demand forecast, total peak time power demand in the central power system including Lilongwe and the northern power system in respective years are estimated as follows:

Years	Peak Time Power Demand
1992	50.9 MW
1997	87.1 MW
2002	144.8 MW

The average of yearly growth rate will be about 11.3%. The time for start of the operation of the transmission line will be the 1992 on the premise that only single circuit will be constructed on the basis of the above shown demand forecast. The expansion of another circuit will become necessary at the end of 1999.

(5) The Termination of Transmission Line

The point of connection on the Nkula side will be the Nkula B Power Station while the corresponding point on the Lilongwe side will be the Lilongwe B Substation.

Also in Sharpevale, the median point of this 132 kV transmission line, a substation will be constructed in anticipation of future linkage with the northern power system and the need for meeting an increase in power demand due to resort development on coasts of lake Malawi.

(6) Scale of Transmission Line

The scale of the 132 kV transmission line was decided as below in consideration of an increase in power demand in the central and northern power systems and also the expansion plan for the Nkula B Power Station:

(a)	Section	:	From: Nkula B Power Station (existing) To: Lilongwe B Substation (existing) Via: Sharpevale Substation (to be newly established)
(b)	Total Length	:	250 km
(c)	Voltage	:	132 kV
(d)	Electric Circuit Method	:	3-phase, 3-wire formula
(e)	Frequency	:	50 Hz
(f)	Transmission Capacity	:	30 MW (at the Lilongwe B Substation)
(g)	No. of Circuits	:	Single circuit (Double circuit design system having only single actual circuit)
(h)	Conductor	:	605 MCM Aluminium conductor steel reinforced (ACSR) (Peacock)
(i)	Overhead Ground Wire	:	55 mm^2 aluminium clad steel wire (AC)
(j)	Insulation	:	254 mm-diameter, standard suspension insulators 11 units/set
(k)	Support	:	Double circuit, vertical formation, square-type and self-supporting steel tower

(7) Scale of Substation

At the midway point of this 132 kV overhead transmission line, a substation shall be newly installed at the point of Sharpevale city, from the consideration of the power supply in the future to the resort district of the Malawi Lake, and to the northern region. The scale of this substation is as follows:

(a) Substation Output Capacity : 25 MVA

(b) Transformer Capacity : 3-phase/132/66/33 kV, 25 MVA, 1 set

(c) Outline of Equipment

i) 132 kV Line Side

Bus-bar method	:	Double bus (pipe bus bar)
Transmission line outlet	:	6 sections (6 circuits)
Bus bar equipment	:	1 section
Main transformer primary side	:	1 section

ii) 66 kV Line Side

Bus-bar method	:	Single bus (pipe bus bar)
Transmission line outlet	:	2 sections (2 circuits)
Main transformer secondary side	:	1 section

iii) 33 kV Line Side

Indoors, cubicle type switchgear

Number of cubicles : 5 sets

(8) Construction Cost

The construction cost required for this transmission line project including the interest during the construction period is amount of US$35,445 x 10^3. (M.Kw 94,624 x 10^3). Its breakdown into foreign and domestic currencies is as follows.

Foreign currency	US$22,870 x 10^3 (M.Kw61,055 x 10^3)	(Including US$360 x 10^3 as the interest during the construction period)
Domestic currency	US$12,575 x 10^3 (M.Kw33,569 x 10^3)	(Including US$198 x 10^3 as the interest during the construction period)

The rate of the interest is set at 1%/year.

(9) Period of Construction

The construction period of this transmission line is presumed to require twenty-four (24) months in total. Hence, the period of construction shall be started in April, 1990, and completed in March, 1992.

(10) Economic Efficiency

Concerning the economic efficiency of this project, by inter-connecting the power systems of Capital Lilongwe and the northern district and southern power system to this 132 kV transmission line, the substituting power generating facility in Lilongwe can be saved, and the savable amount is evaluated at US$28,020 x 10^3/Year.

Furthermore, by the interconnection of this main line with Nkula B Power Station which will increase the capacity from 80 MW to 100 MW, the generated power of Nkula B Power Station will be effectively utilized.

(11) Others

Such effects that cannot be monetarily evaluated are the improved stability of power supply and the reduced fluctuation in voltage and frequency in Lilongwe District and the northern district, where power systems will be reinforced by this transmission line.

Furthermore, as stated in (6), by the new installation of a substation in Sharpevale, the extent of utilization of this 132 kV overhead transmission line will be raised, and it is also inferred that this line will significantly contribute to the development and growth of agriculture and various industries in districts of Salima and near Lake Malawi. The line will also facilitate rehabilitation of the existing 132 kV wood pole line.

2-2 Recommendation

From above conclusion, the followings are recommended concerning this 132 kV transmission line construction project.

(1) Time of Completion

Since, at the end of 1991, power will become insufficient in Capital, Lilongwe with the transmission capacity of the single circuits of 132 kV and 66 kV line and existing 132 kV line, constructed with wooden pole, is already passed 13 years from the commissioning which causing power supply difficulty at intervals in order to require the exchange of wood poles with line stoppage due to superannuate, this 132 kV transmission line construction project should be executed to be completed at latest by the end of March, in 1992.

(2) Switching Station for the Central and Northern Power Systems

In order to attain the effective operation of this 132 kV transmission line, a substation should be installed at Sharpevale for control of the 132 kV system.

(3) Accommodation of Finance for Construction Work

For the realization of the construction of this 132 kV transmission line, the Office of the President and Cabinet of Malawi is advised to promptly start the various preparations such as the establishment of the construction relating agencies and the accommodation of the required finance for the construction.

(4) Preparatory Work

As this 132 kV transmission line work is required to be completed in a rather short period, the wayleaves for line route, and acquisition of land for the substation should be obtained in advance.

(5) Recovery of Construction Cost

It is possible to cover the required finance of this 132 kV transmission line by the revenue obtainable from the electricity delivered through this line.

CHAPTER 3 BACKGROUND OF PROJECT

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3-1 Topography and Meteorology

The Republic of Malawi is located in the southern part on the eastern side of the African Continent between 9° and 17° S. Lat. It is an inland country stretching from north to south at the total distance of 800 km and measuring 145 km from east to west, with its territory bordering on the United Republic of Tanzania for the eastern side of its northern part, on the Republic of Zambia for the western side of its northern part and on the People's Republic of Mocambique for its southern part. It is one of the smallest countries in Africa, with its land area totaling no more than 119,140 km^2 (1.4 times more than the total area of Hokkaido). Its capital is Lilongwe, situated almost in the center of the country.

Ups and downs of its land are quite steep, and brown mountains are ranging, while Lake Malawi, which accounts for about 20% of its total area, stretches from north to south at the total distance of 580 km along its northeastern border. Because of these topographic features, Malawi is termed as one of the countries having the most beautiful natural scenery in Africa. Lake Malawi, which used to be called Lake Nyaza, is the terminal point of the Great Rift Valley of Africa, which starts in the Red Sea and runs through the eastern part of Africa southward, and represents a giant land dislocation created by violent changes in the earth's crust during the end of the Mesozoic era in the geological history. In Lake Malawi (a fresh-water lake with its surface situated at an altitude of 474 m), crocodiles and hippopotamuses are living. It is rimmed by high papyruses while above the lake there expands the Nyika Plateau with the altitude of 1,000-2,000 m. The mountainous and green scenery continuing from the Nyika Plateau to the Viphia Plateau in the Mzimba area located to the north of Lilongwe, the capital, is truly attractive.

The area reached when one comes down along the Shire River from Lake Malombe, situated just to the south of Lake Malawi, is a beautiful place where many blossoms are at their best in summer. The Shire River flows down southward, while creating cataracts and rushing streams here and there, and eventually joins the River Zambezi.

At the southern end of its land, namely near its border with Mozambique, there stand Mt. Mulanje, the highest peak in the country, and other mountains about 3,000 m high.

Malawi is blessed with many animals and plants, and five places - Nyika (3,134 km^2), Kasung (2,316 km^2), Lengwe (887 km^2), Liwonde (548 km^2) and Lake Malawi (94 km^2) -- have been designated as national park and four places -- Nkhotakota (1,802 km^2), Vwaza (1,000 km^2), Majete (784 km^2) and Mwabvi (340 km^2) -- have been designated as wild life reservation areas. These are powerful sight-seeing resources attracting a total of about 20,000 foreign tourists a year. These tourists account for approximately one third of all foreigners visiting the country.

Meteorologically, the country belongs to the Savanna Meteorological Zone. Temperature and rainfall vary greatly with the altitude which ranges from 36 m to 3,048 m from the sea level. Annual rainfall averages around 1,100 mm, but it changes from 800 mm to 2,500 mm depending on years. The rainy season lasts from November to April, while the dry season continues from May to October. From mid-April to mid-August, it is relatively cool with the average temperature standing at around 20°C, but between mid-August and mid-November, it is hot as expected, with the average temperature reaching about 27°C.

3-2 Politics and Economy

3-2-1 Overview

Malawi became independent as a member of the British Commonwealth in July 1964 and adopted the system of a republic in 1966. Its president has been Ngwazi Dr. H. Kamuzu Banda since its independence and he was given the title of life president in 1971.

Although Malawi adopts the policy of non-alignment politically, its foreign policy is realistic and based on moderate good neighbor policy line. Its relations with the U.K. and other Western Bloc Countries are good, while it is the only African country that maintains normal diplomatic relations with the Republic of South Africa.

The total population has been about 7.5 million since 1987, while the population density is 64 persons/km^2. The average population growth rate in the recent 10 years period from 1977 to 1987 was 3.1%, which was almost at the same level as the average figure of 3% for African countries south of the Sahara Desert.

The basic industry of Malawi is agriculture, and 85% of its total population are engaged in farming. The government has been pursuing the policy of putting priority on agricultural development, and by positively absorbing economic and technical assistance from Free Nations in the Western Bloc, it has been maintaining the food self-sufficiency rate at a high level. Because of the damage due to drought and other natural disasters and also entry of about 500,000 refugees from Mozambique (equivalent to about 7% of the total population of that country) due to political unrest there, however, the self-sufficiency rate of foods declined in 1987. Primary agricultural produce includes maize, which is the staple food, as well as tobacco, tea, sugar, cotton and beans, while fish caught in Lake Malawi provides valuable protein to the people in the country.

Its industry has been developing smoothly since its independence. However, competitive power of its products has declined since the scale of its domestic market is small and also since the cost of raw materials and equipment rose as the railway transportation routes from Ports Beira and Nacala through Mozambique were cut off. Its main industrial goods are textiles, fishing nets and processed foods, while cement and brick manufacture, iron processing and flour milling are seen with much expectations in regard to their future.

3-2-2 Gross Domestic Product (GDP)

Contributions to the gross domestic product (GDP) by each sector are shown in Table 3-1, and changes of GDP after 1973 are indicated in Table 3-2.

The dominant status of agriculture is also evident here, with 37% of GDP shouldered by agriculture.

In addition, GDP in 1987 was Kwacha 2,866 million (US$1,395 million) with per capita GDP of Kwacha 382 (US$186). GDP in 1977, when converted by the price in 1987, was Kwacha 2,282 million (US$1,111 million) with per capita GDP of Kwacha 412 (US$201). This means that the annual growth rate in average during the last decade was 2.3% in terms of GDP, and minus 0.8% in terms of per capita GDP. One of the reasons of the economic stagnation resides in decrease in agricultural products due to unfavorable meteorological conditions, but the greatest reason lies in the sudden increase in transport cost accompanying the fact that both routes of Beira and Nacala were blocked up, and the transport to the country had to depend on the transport by the road via Zambia and Zimbabwe to Durban in the union of South Africa.

3-2-3 Result of Export and Import and Remittance in Foreign Currency

Because of import surplus in trade balance since the independence of the country improvement on trade balance is one of the most important policy of the government. The result of export and import from 1970 to 1985 is shown in Table 3-3 and 3-4. As obvious from the table, two major market - leading commodities - tobacco and tea occupy more than 60% of the total exports, and the overwhelming share of agricultural product in export is noted. England, the former suzerain stands first among the destination of exports, and the Union of South Africa which governs the transport route stands first among the origins of import. Nearly half the total amount of export and import is occupied by the above two countries. Recently, Japan has rapidly made inroads into the Malawi market, standing fifth among the trading countries with respect to the total amount of export and import in 1985.

Most of the products exported to Japan is tobacco. Malawi stands third among the tobacco supplying countries to Japan, next to USA and Turkey. With regard to the import from Japan, cars occupy 45.9%, machinery 9.8%, iron and steel 8.5%, and textile products 7.0%.

Foreign currency income includes the foreign currency remittance from the Malawian workers working in the mines in the Union of South Africa (said to be 200,000 to 300,000 workers per year), amounting to about Kwacha 28.2 million in 1985 (equivalent to 6.7% of the total export amount) and greatly contributing to the foreign-currency income to the country.

Table 3-1 GDP by Sector of Origin, 1980-1996

(Percentage Share of Total)

	Outturn		Projection		
	1980	1986	1987	1991	1996
Agriculture	37.2	36.8	36.2	36.4	35.0
Manufacturing	11.6	12.1	12.1	11.9	12.0
Electricity and Water	1.9	2.1	2.1	2.1	2.0
Construction	5.7	4.2	4.2	4.2	4.8
Distribution	14.4	13.1	13.2	12.8	13.0
Financial and Professional Services	6.8	6.4	6.5	6.5	6.7
Ownership of Dwellings	4.2	4.4	4.4	4.4	4.4
Private, Social and Community Services	3.9	4.3	4.4	4.3	4.2
Government Services	10.3	13.3	13.8	13.8	13.9
Unallocable Finance Services	-2.7	-2.6	-2.6	-2.6	-2.7
GDP Total	100.0	100.0	100.0	100.0	100.0

Source : Statement of Development Policies 1987-1996 produced by Office of the President and Cabinet, Malawi

Table 3-2 Basic Economic Data

	GDP Defector		GDP (K Million)			GDP per Head	Exchange
			Current	1987	Popuration	in 1987 Price	Rate
Year	1980=100	1987=100	Price	Price	(Million)	(Kwacha)	(K/US$)
1973	50.7	20.0	364.0	1,820.0	4.79	380	0.8193
1974	59.9	23.7	461.5	1,947.3(7.0%)	5.10(6.5%)	382	0.8412
1975	65.1	25.7	529.7	2,061.1(5.8%)	5.24(2.7%)	393	0.8638
1976	70.8	28.0	612.0	2,185.7(6.0%)	5.37(2.5%)	407	0.9130
1977	80.8	31.9	728.0	2,282.1(4.4%)	5.54(3.2%)	412	0.9029
1978	82.0	32.4	800.7	2,471.3(8.3%)	5.68(2.5%)	435	0.8437
1979	85.7	33.9	864.5	2,550.1(3.2%)	5.86(3.2%)	435	0.8169
1980	100.0	39.5	1,005.1	2,544.6(-0.2%)	6.05(3.2%)	421	0.8121
1981	116.4	46.0	1,108.1	2,408.9(-5.3%)	6.23(3.0%)	387	0.8953
1982	127.1	50.2	1,245.1	2,480.3(3.0%)	6.41(2.9%)	387	1.0555
1983	141.7	56.0	1,436.9	2,565.9(3.5%)	6.62(3.3%)	388	1.1748
1984	161.2	63.7	1,708.5	2,682.1(4.5%)	6.84(3.3%)	392	1.4134
1985	183.3	72.4	2,023.1	2,794.3(4.2%)	7.06(3.2%)	396	1.7191
1986	202.9	80.1	2,301.1	2,872.8(2.8%)	7.28(3.1%)	395	1.8611
1987	253.2	100.0	2,865.7	2,865.7(-0.3%)	7.50(3.0%)	382	2.2087
1988				2,974.6(3.8%)	7.75(3.3%)	384	
1989				3,087.6(3.8%)	8.00(3.3%)	386	
1990				3,205.0(3.8%)	8.27(3.3%)	388	
1991				3,326.7(3.8%)	8.54(3.3%)	390	
1992				3,466.4(4.2%)	8.83(3.4%)	393	
1993				3,612.0(4.2%)	9.13(3.4%)	396	
1994				3,763.7(4.2%)	9.44(3.4%)	399	
1995				3,921.8(4.2%)	9.76(3.4%)	402	
1996				4,086.5(4.2%)	10.09(3.4%)	405	
Annual Growth Rate (%)							
1973-1987				3.3	3.25	0.04	
1987-1996				4.0	3.35	0.65	

Source : Actual data up to 1987 are quoted from International Financial Statistics 1988 issued by International Manetary Fund(IMF), future growth rate after 1988 are quoted from Statement of Development Policies 1987-1996 produced by Office of the President and Cabinet, Malawi and others are calculated by JICA mission, accordingly.

Note : Figures in bracket show the growth rate to the previous year.

Table 3-3 Direction of External Trade, 1970-1985
(Kwacha million)

	1970		1975		1980		1985		
	Export to	Import from	Export to	Import from	Export to	Import from	Export to	Import from	Total
United Kingdom	22.8	21.4	42.3	52.9	63.9	67.2	142.1	73.8	215.9
South Africa	3.2	10.2	5.6	52.8	7.5	131.5	26.8	187.3	214.1
U.S.A.	1.2	4.1	8.6	7.6	39.1	12.1	43.3	24.3	67.6
West Germany	1.3	3.1	4.6	8.7	17.1	18.1	34.6	27.4	62.0
Japan	0.2	4.4	1.0	16.5	4.4	25.0	13.8	38.2	52.0
Zimbabwe	4.3	16.6	7.4	25.7	12.3	12.7	9.8	29.4	39.2
Zambia	3.6	2.5	3.5	4.6	-	7.7	27.0	8.3	35.3
France	0.6	1.1	-	-	4.5	8.3	14.6	17.8	32.4
Netherlands	1.9	1.2	7.6	4.8	20.6	15.0	22.7	5.1	27.8
Australia	0.4	1.8	-	-	-	-	6.1	3.8	9.9
Ireland	1.6	-	-	-	-	-	1.7	-	1.7
Others	0.4	16.1	25.9	45.0	46.0	67.3	76.6	77.4	154.0
Total	41.5	82.5	106.5	218.6	215.4	365.0	419.1	492.8	911.9

Source : Statement of Development Policies 1987-1996 produced by Office of the President and Cabinet, Malawi

Table 3-4 Exports by Main Commodities, 1970-1985
(Kwacha million)

	1970	1975	1980	1985
Tobacco	16.6(40.0)	51.1(48.0)	108.8(50.5)	187.4(44.7)
Tea	10.9(26.3)	21.7(20.4)	29.8(13.8)	91.4(21.8)
Sugar	-	12.3(11.5)	34.7(16.1)	14.4(3.4)
Cotton	2.7(6.5)	1.9(1.8)	4.5(2.1)	12.9(3.1)
Pulses	1.0(2.4)	1.6(1.5)	1.8(0.8)	8.2(2.0)
Groundnuts	4.2(10.1)	6.5(6.1)	15.9(7.4)	5.9(1.4)
Rice	0.5(1.2)	1.6(1.5)	3.0(1.4)	0.3(0.1)
Others	5.6(13.5)	9.8(9.2)	16.9(7.8)	98.6(23.5)
Total Exports	41.5(100.0)	106.5(100.0)	215.4(100.0)	419.1(100.0)

Source : Statement of Development Policies 1987-1996 produced by Office of the President and Cabinet, Malawi
Note : Figures in bracket show the percentage shares of the total

3-2-4 Energy

In Malawi, 92% of its primary energy is provided by such non-commercial energy sources as fuelwood including charcoal and leftovers of agricultural produce, with the remaining 8% supplied by such commercial energy sources as hydro-electricity, petroleum and coal.

The annual consumption of fuelwood including charcoal totalled about 9,200,000 cubic meters (actual figure for 1985). Of these, 72% were applied to household use, 23% to drying tobacco and the remaining 5% to such business purposes as brick and tea production.

As a consequence, forests of 50,000 hectares are being lost every year. Being apprehensive of desolation of forests, the government is appealing for effective utilization of fuelwood and charcoal and at the same time calling for forestation and shift to alternative energy sources. Refer to Table 3-5.

Consumption of commercial energy increased sharply between 1970 and 1975. Business stagnated due to hikes of international crude oil prices in 1975-1980 and owing to higher commodity prices resulting from the severance of both Beira and Nacala routes after 1980, however, and the growth rate for the consumption of so-called imported energy slowed down. In recent years, the consumption rather turned downward. Refer to Table 3-6.

Hydro-electricity is one of the representative domestic energy sources in the country, and the electric power produced by four hydro power plants being along the River Shire located in southern part of the country –– Nkula Fall A and B, Tedzani Fall and Zomba –– (a total of 144.6 MW) account for as much as 99.8% (actual figure in 1988) of the total power generated. Malawi's total hydro-electric power potential is said to be 1,000 MW, and expansion of Nkula Fall B (20 MW) in the southern reaches of River Shire and the new establishment at Kapichira Fall (125 MW) are now in the stage of development preparation as next projects, while in the northern part of the country, mini-hydro power projects at Karonga (2,000 kW), Chilumba (200 kW), etc. are considered to be fairly promising.

In Malawi, where no oil resources are existent, total volume of oil and refined oil products are imported with the exception of quite small volume of ethanol, which is used after being mingled with diesel oil at the ratio of 20:80. Most of such oil products are utilized as automobile fuel. The effect of the change in the transportation routes is also serious, and because of the higher transportation cost including insurance premiums and also because of the devaluation of Kwacha, Malawi's currency, oil product prices increased as much as 33% between 1983 and 1985, despite decline of crude oil prices.

In 1981, a United States of America survey mission confirmed existence of oil reserve beneath the bottom of Lake Malawi, but the stage of commercial drilling has not yet been reached.

Malawi depends on imports for 90% (actual figure for 1986) of its coal requirement. Most of coal is consumed in industrial boilers, while coal imports, which rose to 70,000 tons in 1982, declined to 29,000 tons in 1985, owing to instability of coal imports as well as sharp price increases. Coal price, which was 70 Kwacha/ton when imports were made from Mozambique, jumped to 117 Kwacha/ton after import sources were shifted to Zambia and Zimbabwe. (actual figure for 1986) The estimated coal reserve within Malawi is said to surpass 800 million tons, but its development is only at its initial stage, as the Mining and Development Corporation (MIDCOR), established entirely with governmental contributions in 1985, is engaged in coal mining on a trial basis in the northern part of Kaziwiziwi area. Although there is some problem with regard to profitability because of high transport cost, the coal is expected to take the place of fuelwood and charcoal as the fuel for drying tobacco, if the mining operation progresses smoothly.

Table 3-5 Primary Energy Spply by Source, 1986
(Percentage Shere of Total)

	Final Energy Consumption
Fuelwood including Charcoal	90
Other Biomas	2
Hydro-electricity	3
Petroleum Products	4
Coal	1
Total	100

Source : Statement of Development Policies 1987-1996
produced by Office of the President and Cabinet, Malawi

Table 3-6 Commercil Energy Consumption, 1970-1985
(1,000 tonners, oil epuivalernt)

	1970	1975	1980	1985
Electricity	33.1	66.1	88.5	99.7
Petrolium Products	106.5	137.5	147.4	110.2
Coal	29.5	47.8	31.2	24.5
Total	169.1	251.4	267.1	234.4

Source : Statement of Development Policies 1987-1996 produced by Office of the President and Cabinet, Malawi

CHAPTER 4 PRESENT STATE OF ELECTRIC ENTERPRISE

CHAPTER 4 PRESENT STATE OF ELECTRIC ENTERPRISE

4-1 History of Electric Enterprise Development

The Electricity Supply Commission of Malawi (ESCOM), the national electric enterprise in the country, was established through reorganization of the then, existing body simultaneously with the national independence in 1964. The power generation capacity of ESCOM at the time of its establishment consisted of coal thermal (7,000 kW) at Blantyre, hydro (600 kW) at Zomba and diesel (Total: 6,595 kW) at Blantyre, Zomba, Lilongwe, Mzuzu, Fort Jonston (Mangochi) with a total of 14.2 MW.

Since its inception, ESCOM has been grappling with hydro-power development in River Shire flowing through the southern part of the country. Beginning with the start of operation of the first power station (24 MW) in Nkula Fall A in 1966, it commenced operation of the Tedzani Fall (40 MW) in 1973 and that of the Nkula Fall B (80 MW) in 1980, thereby expanding power generation facilities greatly. Meanwhile in 1968, it started electric power exports to Mozambique. In order to deal with the rapid increase of power demand in Lilongwe, the new capital, it completed the Nkula-Dedza-Lilongwe 66 kV transmission line in 1972 and the Nkula-Salima-Lilongwe 132 kV transmission line in 1977, thereby realizing the north-south interconnection of power supply systems. Subsequently, it has been improving its power distribution network and promoting rural electrification until now.

Due to the development of new hydro power sources and realization of the interconnected power system, old, inefficient small-scale diesel power generators installed at demand centers in various locations as well as the coal thermal power station at Blantyre were abolished one after another. As power sources linked to the entire power system to provide reserve power in emergency, a series of small-scale diesels at Karonga, Mzuzu, etc. and the gas turbine at Blantyre (15 MW) were newly introduced subsequently, but it is only the hydro power plant at Zomba (600 kW) that is still working now among all the power generation facilities existent at the time of ESCOM's establishment.

4-2 Organization of the Electricity Supply Commission of Malawi (ESCOM)

ESCOM is under the control of Ngwazi Dr. H. Kamuzu Banda, the life president. The Commission consists of nine members including Mr. F.Z. Pelekamayo, chairman, the PS of Ministry of Trade, Industry and Tourism, PS Ministry of Finance, decides on the operational policy, power development plans, system expansion programs and other important matters.

As for actual operational business, a management team including Mr. R.E.G. Offord, ESCOM's general manager, is in charge of operations in various fields (See Fig. 4-1).

Since its establishment, ESCOM has been exerting efforts for employment and training of Malawi officials. Accordingly, high-ranking Malawi officials, who accounted for only 25% in 1970, amounted to 98% in 1988, while foreigners totalled 4 (See Table 4-1).

4-3 Present Power Supply Systems

Power supply systems of ESCOM can be broadly divided into the southern power supply system centered around Blantyre in the south, the central power supply system in and around Lilongwe, the new capital, and the northern power supply system, which covers the area north of Chintheche. These power supply systems are connected each other with national power line network. Now, the systems for Karonga and Chitipa, the northernmost parts of the country, remain the only independent power supply systems, but these are also planned to be incorporated in the northern power supply system sooner or later (See Fig. 4-2).

As for the scale of the system, the southern power supply system, which consumes 74.5% of the total energy consumption, is the biggest, and the central and northern systems aggregately consume no more than 25.5% of the total. Although no data is available regarding the peak demand for each area, if such peak demand for each system is estimated on the basis of the peak demand for the interconnected systems and energy sold for respective areas, the peak demand supposedly reached 71 MW in the case of the southern power supply system and a total of

24 MW for the central/northern systems at the end of 1988 (See Table 4-2).

4-3-1 Power Generation Facilities

The installed capacity, including stand by thermal plants, of the entire power generation facilities of ESCOM as of December 1986 was 169 MW. A characteristic of ESCOM's electric power supply systems is that power sources are concentrated on the southern part of the country. The hydro-electric power plants located in the reaches of River Shire in the south accounted for 85.2% of the total power generation capacity in the nation and provided as much as 99.8% of the total power supply (See Table 4-3).

4-3-2 Power Transmission, Distribution and Substation Facilities

The total length of transmission and distribution facilities in ESCOM's power supply systems as of December 1988 was 6,182 km of overhead cables and wires and 209 km of underground cables, while the capacity of substations totaled 787 MVA (See Table 4-4).

ESCOM, which has been positively promoting the national transmission network connection program for more than 10 years until now, completed the incorporation of the system for Lilongwe, the capital, in the national network in 1972 and subsequently linked independent systems of Mzuzu, Mangochi Salima, Mtuthama and Kasungu to the trunk system one after another. Since the per-capita power consumption barely reached 57 kWh/year in 1986, it is the real state of affairs that more than 95% of the total population have not yet been benefited by electricity. Such being the case, promotion of rural electrification programs and improvement/reinforcement of power transmission/distribution networks for that purpose are major tasks to be achieved hereafter.

4-4 Electricity Charges

4-4-1 Electricity Tariff Schedule

Present electricity tariff has been in force since 1985. It comprises the fixed charge and proportional charge, which are set for each category of demand as shown in Table 4-5.

4-4-2 Average Selling Rate

Evolution of the average unit price of sold power is shown in Table 4-6. As clearly indicated in the table, ESCOM revised electricity tariff repeatedly, but the average unit sales price in terms of 1987 price has been almost at a fixed level since 1973, and based on actual figures between 1973 and 1986, the figure for the entire system was fairly low at 10.37 Tambala/kWh (4.7 cent/kWh). In the case of the national average, which includes the unit price for the independent system of Karonga, the figure was somewhat higher at 10.59 Tambala/kWh (4.8 Cent/KWh). This was due to the fact that, as mentioned in the preceding section concerning the tariff schedule, diesel-related extra charges are applied to the independent system of Karonga.

Table 4-1 Employment Statistics

Year	Senior Staff Expatriate	Senior Staff Malawian	Senior Staff Sub-Total	Junior Staff	Temporary Workers	Total
1976	32(25.0%)	96(75.0%)	128(100%)	859	322	1,309
1977	25(18.9%)	107(81.1%)	132(100%)	981	294	1,407
1978	25(17.4%)	119(82.6%)	144(100%)	1,087	384	1,615
1979	23(15.6%)	124(84.4%)	147(100%)	1,227	422	1,796
1980	20(11.6%)	153(88.4%)	173(100%)	1,387	503	2,063
1981	17(9.9%)	154(90.1%)	171(100%)	1,432	418	2,021
1982	13(7.5%)	160(92.5%)	173(100%)	1,324	452	1,949
1983	10(5.7%)	165(94.3%)	175(100%)	1,346	484	2,005
1984	10(5.7%)	165(94.3%)	175(100%)	1,346	484	2,005
1985	10(6.2%)	151(94.8%)	161(100%)	1,385	495	2,041
1986	5(3.0%)	162(97.0%)	167(100%)	1,342	591	2,100

Source : ESCOM Annual Report

Table 4-2 Demand Trend in each Region

Year	Energy Sold (MWh)				Peak load (MW)			
	S.R.	C.R.	N.R.	Total	S.R.	C.R.	N.R.	Total
1973	163,999(92.13)	12,953	1,052	178,004(100)	32.065	2.532	0.206	34.803
1974	174,115(90.55)	16,943	1,219	192,277(100)	35.815	3.485	0.251	39.551
1975	212,339(89.91)	22,428	1,408	236,175(100)	43.651	4.611	0.289	48.551
1976	223,430(88.31)	28,024	1,547	253,001(100)	44.721	5.609	0.310	50.640
1977	229,473(86.49)	34,199	1,648	265,320(100)	44.733	6.667	0.321	51.721
1978	245,462(85.19)	40,412	2,250	288,124(100)	46.547	7.663	0.427	54.637
1979	279,011(84.45)	48,123	3,250	330,384(100)	51.515	8.885	0.600	61.000
1980	291,034(82.20)	59,202	3,805	334,041(100)	55.023	11.193	0.719	66.935
1981	274,541(79.95)	65,029	3,815	343,386(100)	53.991	12.789	0.750	67.530
1982	275,609(77.02)	77,506	4,712	357,827(100)	54.859	15.427	0.938	71.224
1983	304,057(77.20)	84,521	5,297	393,875(100)	56.718	15.766	0.988	73.472
1984	303,835(74.85)	95,577	6,518	405,930(100)	63.409	19.947	1.360	84.716
1985	299,572(75.12)	91,821	7,422	398,815(100)	61.550	18.865	1.525	81.940
1986	318,209(74.45)	100,538	8,659	427,406(100)	70.728	22.346	1.925	94.990
Annual Growth Rate (%)								
73-86	5.2%	17.1%	17.6%	7.8%	6.3%	18.2%	18.8%	8.0%
76-86	3.6%	13.6%	18.8%	6.4%	4.7%	14.8%	20.0%	6.5%

Source : ESCOM Annual Reports

Notes : (a) Figures in parenthesis show the percentage share of the total.

(b) Peak Loads were calculated by the JICA mission under the condition described in item 4-3.

(c) S.R. …Southern Region

C.R. …Central Region

N.R. …Nothern Region including Karonga

Table 4-3 Plant Capacity as at 31st December, 1988

Type	Location	Installed Capacity(kW)	Date Installed	No. and Unit Capacity(kW)	Annual Energy Generation(MWh)
Gas Turbine	Blantyre	15,000(8.9%)	1975	1×15,000	25(0.0%)
Diesel		10,200(5.6%)			1,389(0.3%)
	Karonga	990	1980	2× 120	
			1988	3× 250	
	Mzuzu	2,250	1974	1× 250	
			1975	1× 150	
			1980	1× 1,100	
			1983	1× 750	
	Kasungu	360	1972	2× 85	
			1974	1× 85	
			1979	1× 105	
	Lilongwe	5,400	1972	1× 3,000	
			1978	1× 1,100	
			1980	1× 1,300	
	Chitipa	300	1988	2× 150	
	Mtunthama	900	1980	1× 240	
			1981	1× 65	
			1981	1× 120	
			1981	1× 235	
			1984	1× 240	
Hydro		144,600(85.6%)			511,137(99.7%)
	Nkula Fall-A	24,000	1966	2× 8,000	
			1967	1× 8,000	
	Nkula Fall-B	80,000	1980	2×20,000	
			1981	1×20,000	
			1986	1×20,000	
	Tedzani Fall	40,000	1973	2×10,000	
			1976	1×10,000	
			1977	1×10,000	
	Zomba	600	1953	1× 300	
			1954	1× 300	
Total		169,800(100.0%)			512,551(100.0%)

Source : ESCOM Annual Report 1986 and data presented by ESCOM

Table 4-4 Details of Transmission, Distribution and Substation
As at 31st December, 1988

Gacilitis	Southern Region	Central Region	Northern Region	Isolated station Karonga	Chitipa	Total
Overhead Lines (km)	3,078.504	2,209.106	590.847	63.029	4.50	5,972.99
132kV Lines	165.02	175.57				340.59
66kV Lines	347.01	525.73	193.30			1,093.04
33kV Lines	950.368	362.907	131.173			1,444.448
11kV Lines	833.79	670.47	114.25	32.96	4.50	1,655.974
400/230 Volts Lines	782.316	474.429	152.124	30.069	-	1,428.938
Underground Cable(km)	106.281	88.631	11.793	1.58		208.585
33kV Cable	2.616	0.035	0.034			2.685
11kV Cable	51.713	22.292	2.635	0.03		76,970
400/230 Volts Cable	51.952	66.304	9.124	1.55		128.93
Substations (kVA)	595,285	159,442	29,090	2,421.00	600	786,838
Interbus Transformers 132/66KV	50,000					50,000
Step-down 132/ 66/11kV		25,000				25,000
Step-down 66/ 33kV	90,000	10,000	10,000			110,000
Step-down 66/ 11kV	64,000	43,000				107,000
Step-down 33/ 11kV	68,000	3,500	5,550			77,050
Step-down 33/0.4/0.23kV	29,310	7,880	3,025			40,215
Step-down 11/0.4/0.23kV	117,975	66,962	7,515	1,421		193,873
Step-down 3.3/0.4kV					200	200
Step-up 0.4/3.3/11kV		3,100	3,000	1,000	400	7,500
Step-up 11/ 66kV	126,000					126,000
Step-up 11/132kV	50,000					50,000

Source : ESCOM Annual Report 1986 and data presented by ESCOM

Table 4-5 Electricity Tariff Schedule

1. Residential	
a) Area not included in High Density Residential Area	
Fixed charge	M.Kw 6.78/month
Unit charge	
For each of the first 225kWh	M.Kw 0.107/kWh
For each in excess of 225kWh	M.Kw 0.077/kWh
b) High Density Residential Area	
Fixed charge	M.Kw 1.35/month
Unit charge	
For each of the first 150kWh	M.Kw 0.068/kWh
For each in excess of 150kWh	M.Kw 0.101/kWh
2. Other than Residential	
a) Consumer with an average maximum demand of less than 25kVA	
Fixed charge	M.Kw 6.78/month
Unit charge	
For each of the first 600kWh	M.Kw 0.125/kWh
For each in excess of 600kWh	M.Kw 0.077/kWh
b) Consumer with an average maximum demand of 25kVA or more	
Fixed charge	M.Kw 17.00/month
Demand charge	
For each of the first 60kVA	M.Kw 17.00/kWh
For each of the next 240kVA	M.Kw 15.58/kWh
For each in excess of 300kWh	M.Kw 12.32/kWh
Unit charge	M.Kw 0.021/kWh

Note : For electricity supply from isolated diesel power station, an additional unit charge will be requested in case of the diesel fuel price exceeding 22 tambala per liter.

Table 4-6 Energy Sold and Revenue per kWh
(Interconnected System)

Year	Number of Consumer	Energy Sold (MWh)	Revenue per KWh Current Price(T/kWh)	Revenue per KWh 1987 Price(T/kWh)	GDP Deflater 1987=100
1973	12,157(12,814)	175,431(178,004)	2.12(2.15)	10.60(10.75)	20.0
1974	13,876(14,312)	191,057(192,277)	2.12(2.15)	8.95(9.07)	23.7
1975*	15,000(15,553)	234,469(236,175)	2.39(2.42)	9.30(9.42)	25.7
1976*	15,899(16,587)	250,802(253,001)	2.60(2.71)	9.29(9.68)	28.0
1977*	17,929(18,495)	263,672(265,320)	3.06(3.15)	9.59(9.87)	31.9
1978*	18,995(19,670)	285,873(288,124)	3.77(3.84)	11.64(11.85)	32.4
1979	20,460(21,250)	327,135(330,384)	3.85(3.98)	11.36(11.74)	33.9
1980	21,835(22,889)	350,153(354,041)	4.22(4.38)	10.68(11.09)	39.5
1981	22,842(24,424)	338,654(343,386)	4.99(5.22)	10.85(11.35)	46.0
1982*	25,453(25,694)	354,692(357,827)	5.52(5.67)	11.00(11.29)	50.2
1983*	26,663(26,926)	393,489(393,875)	5.91(5.93)	10.55(10.59)	56.0
1984*	28,649(28,974)	405,378(405,939)	6.54(6.58)	10.27(10.33)	63.7
1985*	30,987(31,337)	398,132(398,815)	8.01(8.07)	11.06(11.15)	72.4
1986	33,110(33,496)	426,513(427,406)	8.03(8.10)	10.02(10.11)	80.1
1987		466,744			100.0
1988		476,268			
Average				10.37(10.59)	

Source : ESCOM Annual Reports
GDP is to be refered to Table 3-2,

Notes : (a) Date for 1987 and 1988 are promptly reported value
(b) Date in bracked show the value for all Malawi including isolate systems
(c) ESCOM rivaised Electricity Tariff Schedule in the year with asterisk

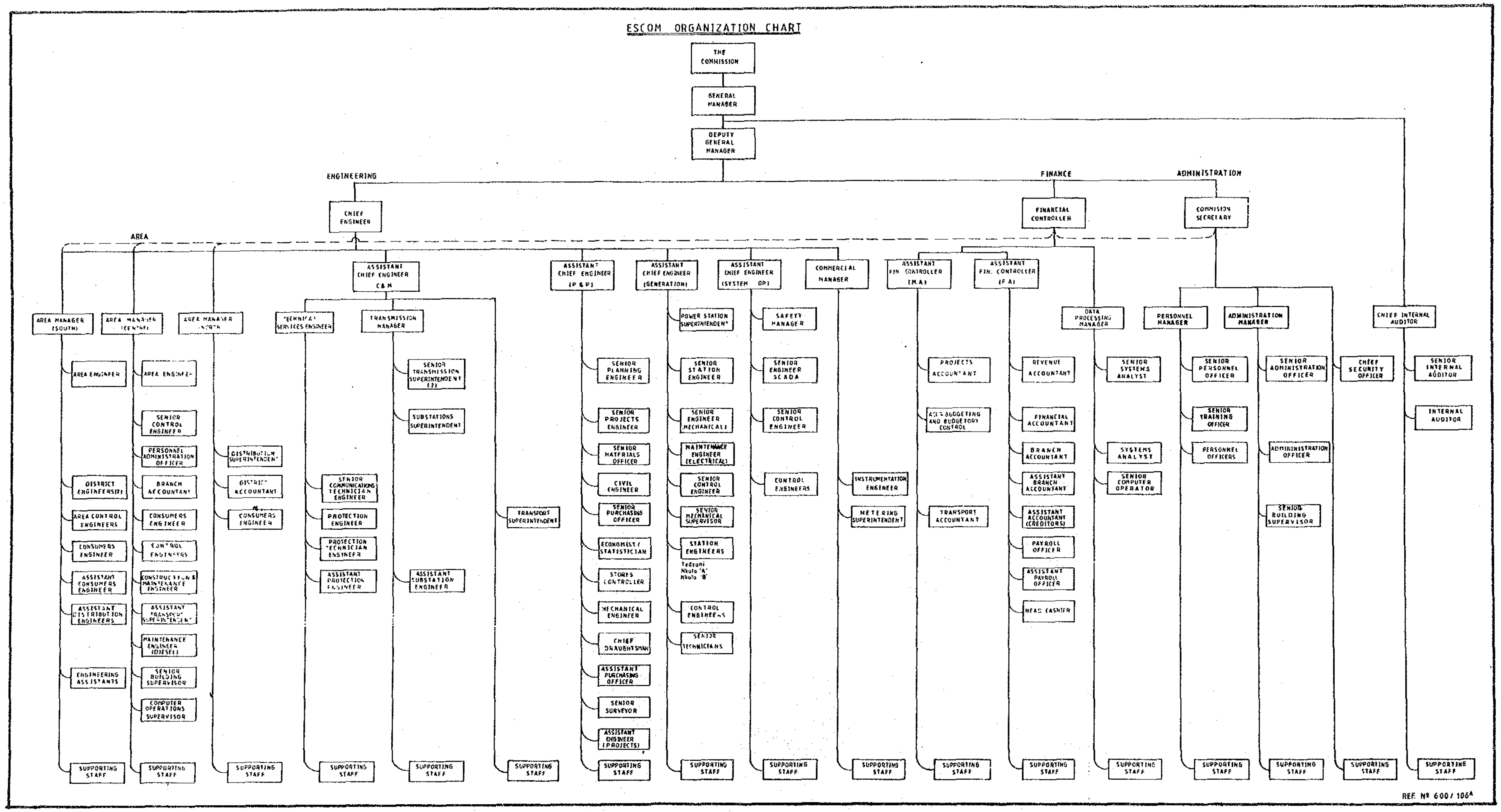

Fig 4-1 ORGANIZATION CHART OF ESCOM HEAD OFFICE

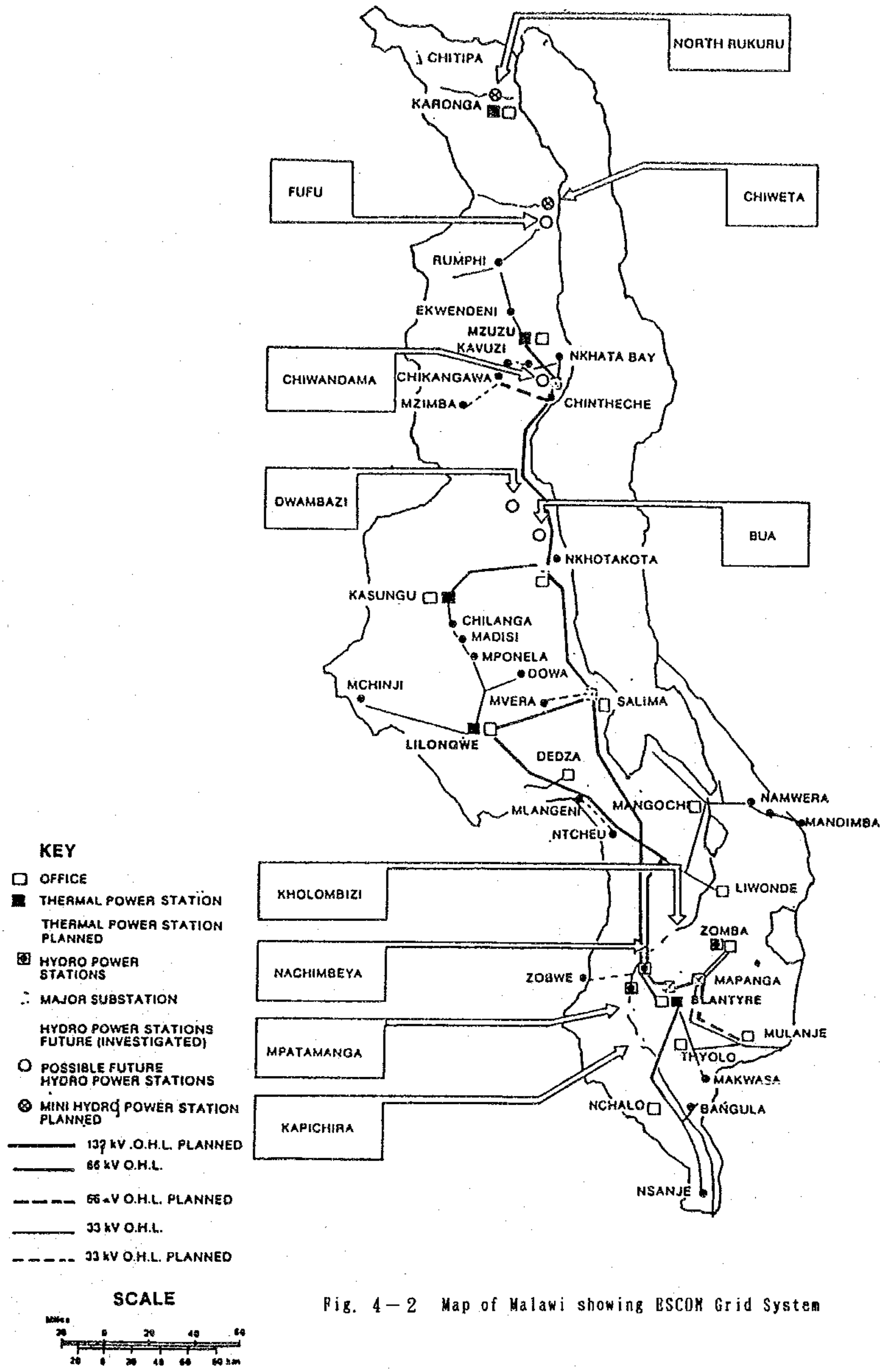

Fig. 4－2 Map of Malawi showing ESCOM Grid System

CHAPTER 5 DEMAND FORECAST

CHAPTER 5 DEMAND FORECAST

5-1 Changes of Demand and Supply

5-1-1 Annual Energy Generation and Peak Load

In the 15 year period between 1973 and 1988, annual energy generation by ESCOM's supply systems increased from 192.3 GWh to 580.6 GWh at a annual growth rate of 7.6%, while the peak load grew from 34.3 MW to 101.0 MW at an annual increase rate of 7.5%. If the reviewed period is divided into 5 years segments, however, energy generation, which was rapidly augmented at an annual rate of 9.9% in the first five year period (between 1973 and 1978), posted an annual growth rate of no more than 5.3% in the 1983-1988 period, indicating a substantial demand slowdown in recent years (See Table 5-1).

A similar slowing-down trend of demand can be also observed in the peak load, which can be termed as strongly reflecting overall economic stagnation resulting from the cutting-off of the Beira and Nacala routes.

5-1-2 Load Factor and System Loss Ratio

The Load factor (Lf) was seen varying considerably over the years as it ranged from 61.5% to 69.6%. As a result of economic stagnation, however, it has remained at a somewhat high level of 65% in recent years, and this trend is believed to continue for some time into future.

The overall system loss ratio, which includes in-house power consumption at power stations and transmission/distribution loss, averaged 12.0% in 1973-1988. In terms of time series, some temporary improvement was achieved in 1978, the year after the completion of the north-south linkage transmission line of Nkula-Salima-Lilongwe (132 kV) in 1977, as the ratio declined to 7.4% on the strength of the linkage. Subsequently, however, the situation deteriorated continually, and the actual ratio in last year (1988) reached 18.0%.

5-2 Demand Forecast by ESCOM

A future demand forecast is the basis for formulating a power development program and a system reinforcement program. ESCOM also made a detailed forecast in its "Study to Update ESCOM's Least Cost Development Programme" (Apr. 1988: Prepared by Kennedy & Donkin Power Systems Ltd., England).

According to this report, if the economic development progresses as in the standard case, energy generation is expected to grow at a yearly rate of 8.6%, and the peak load at a rate of 8.7% in the 19 years between 1986 and 2005. These figures are somewhat higher than those in the past 15 years between 1973 and 1988, as the actual annual growth rate in the 15 years period was 7.6% for energy generation and 7.5% for peak load. (See Table 5-2)

ESCOM has made several power demand forecast so far, including a predicted power sales annual increase of 8.3% during the 15 years period from 1985 to 2000 and the predicted power consumers is predicted to be 6.3%. (Refer to Table 5.3)

In addition to the power demand forecast by the power system, it is also predicted that the annual rate of increase during 12 years period from 1985 to 1997 for the central power system, the northern power system, and total of central and north power system will be 5.6%, 11.5%, and 6.8%, respectively. (Refer to Table 5-4)

5-3 Power Demand Prediction by JICA Survey Mission

5-3-1 Methodology

The JICA survey mission has decided in the present power demand forecast in an attempt to forecast by means of Multiple Regression Analysis, the idea of which is outlined hereunder:

It is well-known that just as average human height depends on human race, age and sex, so the power demand has some correlation with GDP and other economic indicators.

Table 5-1 Peak Load and Annual Energy Generation
(Interconnected System)

Year	Energy Generated (MWh)	Peak Load (kW)	Load Factor (%)	Energy Sold (MWh)	System Losses (MWh)
1973	192,296(195,296)	34,300	64.0	175,431(178,004)	8.8(8.9)
1974	211,949(213,336)	39,300	61.6	191,057(192,277)	9.9(9.9)
1975	262,684(264,681)	48,200	62.2	234,469(236,175)	10.7(10.8)
1976	280,143(282,729)	50,200	63.7	250,802(253,001)	10.5(10.5)
1977	293,936(296,942)	51,400	65.3	263,672(265,320)	10.3(10.6)
1978	308,702(311,413)	54,210	65.0	285,873(288,124)	7.4(7.5)
1979	354,622(358,299)	60,400	67.0	327,135(330,384)	7.8(7.8)
1980	385,658(389,879)	66,200	66.5	350,153(354,041)	9.2(9.2)
1981	383,415(388,964)	66,600	65.7	338,654(343,386)	11.7(11.7)
1982	406,187(409,388)	70,600	65.7	354,692(357,827)	12.7(12.6)
1983	447,821(448,270)	73,400	69.6	393,489(393,875)	12.1(12.1)
1984	469,577(470,192)	84,600	63.4	405,378(405,930)	13.7(13.7)
1985	475,585(476,402)	81,800	66.4	398,132(398,815)	16.3(16.3)
1986	511,546(512,551)	94,800	61.6	426,513(427,406)	16.6(16.6)
1987	560,858( )	97,200	65.9	466,744( )	16.8( )
1988	580,572( )	101,000	65.6	476,268( )	18.0( )
Annual Growth Rate (%)					
73-78	9.9 (9.8)	9.6		10.3 (10.1)	
78-83	7.7 (7.6)	6.2		6.6 (6.5)	
83-88	5.3 (4.6)	6.6		3.9 (4.5)	
73-88	7.6 (7.7)	7.5		6.9 (2.8)	
Average					
73-78			63.6		9.6(9.7)
78-83			66.6		10.2(10.2)
83-88			65.4		15.6(14.7)
73-88			65.0		12.0(11.3)

Source : ESCOM Annual Report
Notes : (a) Date for 1987 and 1988 are promptly reported value.
(b) Figures in bracket show the value for all Malawi including isolated system.

Table 5-2 Demand Forcast by ESCOM
(Interconnected System)

Year	Energy Generated (GWh) Low Case	Base Case	High Case	Peak Demand (MW) Low Case	Base Case	High Case	Load Factor (%) Low	Base	High
1985	475.59	475.59	475.59	81.80	81.80	81.80	66.4	66.4	66.4
1986	511.55(7.6)	511.55(7.6)	511.55(7.6)	94.80(15.9)	94.80(15.9)	94.80(15.9)	61.6	61.6	61.6
1987	555.24(8.5)	555.24(8.5)	555.24(8.5)	97.81(3.2)	97.81(3.2)	97.81(3.2)	64.8	64.8	64.8
1988	579.40(4.4)	592.60(6.7)	592.60(6.7)	103.28(5.6)	105.85(8.2)	105.85(8.2)	64.0	63.9	63.9
1989	606.91(4.7)	636.58(7.4)	641.38(8.2)	108.30(4.9)	114.09(7.8)	115.03(8.7)	64.0	63.7	63.7
1990	627.53(3.4)	678.42(6.6)	686.16(7.0)	112.33(3.7)	122.27(7.2)	123.78(7.6)	63.8	63.3	63.3
1991	654.00(4.2)	736.05(8.5)	740.33(7.9)	117.32(4.4)	133.37(9.1)	134.21(8.4)	63.6	63.0	63.0
1992	666.48(1.9)	771.37(4.8)	783.42(5.8)	119.21(1.6)	139.63(4.7)	141.98(5.8)	63.8	63.1	63.0
1993	680.76(2.1)	808.53(4.8)	832.69(6.3)	121.53(1.9)	146.30(4.8)	150.99(6.3)	63.9	63.1	63.0
1994	714.70(5.0)	873.41(8.0)	912.52(9.6)	127.57(5.0)	158.22(8.1)	165.78(9.8)	64.0	63.0	62.8
1995	753.44(5.4)	949.29(8.7)	1149.16(26.0)	134.59(5.5)	172.26(8.9)	196.29(18.4)	63.9	62.9	66.8
1996	806.43(7.0)	1045.47 10.1)	1346.62(17.2)	144.53(7.4)	190.56(10.6)	219.18(11.7)	63.7	62.6	70.1
1997	864.65(7.2)	1144.53(9.5)	1516.34(12.6)	155.66(7.7)	209.61(10.0)	246.89(12.6)	63.4	62.3	70.1
1998	927.30(7.2)	1253.95(9.6)	1683.79(11.0)	167.40(7.5)	230.42(9.9)	278.91(13.0)	63.2	62.1	68.9
1999	995.65(7.4)	1375.79(9.7)	1876.97(11.5)	180.21(7.7)	253.64(10.1)	315.94(13.3)	63.1	61.9	67.8
2000	1070.43(7.5)	1511.72(9.9)	2100.10(11.9)	194.19(7.8)	279.50(10.2)	358.73(13.5)	62.9	61.7	66.8
2001	1152.72(7.7)	1663.80(10.1)	2358.33(12.3)	209.45(7.9)	308.35(10.3)	408.22(13.8)	62.8	61.6	65.9
2002	1242.20(7.8)	1832.91(10.2)	2656.08(12.6)	226.09(7.9)	340.50(10.4)	465.42(14.0)	62.7	61.4	65.1
2003	1338.57(7.8)	2020.10(10.2)	2998.58(12.9)	244.24(8.0)	376.35(10.5)	531.59(14.2)	62.6	61.3	64.4
2004	1443.45(7.8)	2228.22(10.3)	3393.92(13.2)	264.03(8.1)	416.32(10.6)	608.11(14.4)	62.4	61.1	63.7
2005	1557.61(7.9)	2459.96(10.4)	3850.37(13.4)	285.61(8.2)	460.88(10.7)	696.62(14.6)	62.3	60.9	63.1
Annual Growth Rate (%)									
1986-2005	6.0	8.6	11.2	6.0	8.7	11.1			
Average									
1986-2005							63.4	62.5	65.1

Source : Study Report to update ESCOM'S Least Cost Development Programme (Apr. 1988) Prepared by Kennedy & Donkin Power Systems Ltd. England

Notes : (a) Date for 1985 above represent actual results

(b) Figures in bracket show the growth rate to the previous year

Table 5-3 Sales & Consumer Forecastet by Area/Load Center

	No. of Consumer				Consumption (MWh)			
Year	S.R.	C.R.	N.R.	Total	S.R.	C.R.	N.R.	Total
1985	18,998	10,429	1,430	30907	305189	90485	6890	402564
1986	19,540	10,940	1,629	32109	327033	98524	7683	433240
1987	20,445	11,684	1,758	33887	350474	110333	9319	470126
1988	21,389	12,492	1,923	35804	368528	121602	11628	501758
1989	22,303	13,340	2,244	37887	385317	140425	13387	539129
1990	23,440	14,336	2,607	40383	403549	155646	15568	574763
1991	24,819	15,485	2,805	43109	428900	176642	17679	623221
1992	26,112	16,619	3,000	45731	450444	190967	18504	659915
1993	27,462	17,843	3,207	48512	472810	206651	21017	700478
1994	29,173	19,294	3,442	51909	510016	231434	23697	765147
1995	31,064	20,910	3,704	55678	553102	260769	26856	840727
1996	33,093	22,658	3,989	59740	600916	294137	30445	925498
1997	35,091	24,459	4,277	63827	649738	329017	34184	1012939
1998	37,225	26,399	4,586	68210	702813	368298	38390	1109501
1999	39,486	28,498	4,919	72903	761404	412515	43120	1217039
2000	41,901	30,754	5,278	77933	826254	462296	48443	1336993
Annual Growth	5.41%	7.48%	8.85%	6.36%	6.87%	11.49%	13.89%	8.33%

Source : ESCOM

Notes : (a) Southern Region includes Balaka, Liwonde, Mangochi and Ntcheu Export to neighbouring country.

(b) Central Region includes Lilongwe, Dedza, Kasungu, Mtunthama, Nkh-otakota, Salima and Chikangawa.

(c) Northtern Region including Mzuzu and Karonga.

Table 5-4 Load Forecast for Central and North -Low Case-

Year	Peak Load (MW) Central	North	Total
1985	20.2	3.7	23.9
1986	22.1	5.3	27.4
1987	25.3	6.7	32.0
1988	25.1	7.1	32.2
1989	26.3	8.5	34.8
1990	27.6	9.0	36.6
1991	29.0	9.5	38.5
1992	30.4	10.1	40.5
1993	32.0	10.7	42.7
1994	33.6	11.3	45.0
1995	35.3	12.0	47.3
1996	36.8	12.7	49.5
1997	38.7	13.7	52.4
Annual Growth	5.6%	11.5%	6.8%

WPA/FTM

13 December 1988

Source : ESCOM

When n sets of data consisting of m number of parameters (X_1, X_2, X_3 --- Xm) and corresponding solution (Y) are obtained, the following equations can be determined by expanding the data in the following simultaneous equations and obtaining each coefficient.

$$Y1 = b0 + b1x11 + b2x21 + \cdots\cdots + b3X31$$
$$Y2 = b0 + b1x12 + b2x22 + \cdots\cdots + b3X32$$
$$Y3 = b0 + b1x13 + b2x23 + \cdots\cdots + b3X33$$

$$Yn = b0 + b1x1n + b2x2n + \cdots\cdots + b3X3n \quad \cdots\cdots\cdots\cdots (5\text{-}1)$$

Since the number of data (n) is usually much more than (m + 1) which is the number of unknowns (b0, b1, b2, b3, --- bm), the coefficients (b0, b1, b2, b3, --- bm) are not determined.

The method which has been utilized for the purpose of solving the above contradiction is the method referred to as multiple regression analysis. In order to obtain the best unbiased estimate of the coefficients (b0, b1, b2, b3, --- bm) by means of least square estimate, the greatest number of data (n), the stronger the obtained correlation. The coefficients thus obtained are designated as partial regression coefficients in terms of mathematics, and calculated by use of a computer. Because of their difficult definition and complicated calculation, a detailed explanation is omitted in this paper. However, the degree of approximation between an observed value (Y) and a calculated value (Y') can be measured by calculating the following corrlation factor.

$$R = \frac{\Sigma\ \{(Yn-\bar{Y})(n' - Y')\}}{\{\Sigma\ (Yn-\bar{Y})^2 \times \Sigma\ (Yn' - \bar{Y}')^2\}^{0.5}} \quad \cdots\cdots\cdots\cdots (5\text{-}2)$$

Where,

Yn : Value of Y at n

Yn': Value of Y' at n

$\bar{Y}$: Average of Y

$\bar{Y}'$: Average of Y'

5-3-2 Power Demand Forecast Viewed from the Correlation with Years Elapsed

(1) Idea

Between annual electric energy generation and peak load there exists a close relationship, which can be expressed as follows by use of the data in the past:

$$P = E/(8,760 \times Lf) \quad \cdots\cdots (5\text{-}3)$$

$$E = C(1 + r)^n \quad \cdots\cdots (5\text{-}4)$$

From the above equations (5-3) and (5-4),

$$\log.E = \log.C1 + n \times \log.(1 + r1) \quad \cdots\cdots (5\text{-}5)$$

$$\log.P = \log.C2 + n \times \log.(1 + r2) \quad \cdots\cdots (5\text{-}6)$$

Where,

P : Peak load

E : Annual electric energy generation

Lf : Load factor

n : Years elapsed

C, C1, C2 : Constant

r, r1, r2 : Annual average net increase rate

The forms of the equations (5-5) and (5-6) thus obtained completely coincide with the form of the equation (5-1) as shown herein before, suggesting that a detailed analysis and forecast are made possible by means of multiple regression analysis.

(2) Result of Analysis

The logarithm of peak load (P), that is, log P, and that of annual electric energy generation (E), that is, log E were used as solutions along with years elapsed (n) as a parameter, and were subjected to multiple regression analysis of two variables with the result as shown in Table 5-3.

The result shows the correlation factors of Rl = 0.9886 for annual electric energy generation (E) and Rp = 0.9892 for peak load (P), each indicating a fairly strong correlation. However, the load factor (Lf) is characterized by a slight annual increase tendency. As mentioned in the above 5-1-2, the cause of such tendency is attributable to the economic stagnation for the last several years. When the commercial and industrial demand is revitalized in urban districts, however, the load factor will turn to leveling-off or downhill course. In forecasting power demand for the future, therefore, the peak load (P) shall be calculated by the equations (5-4') and (5-3') on the basis of the assumption that the electric energy generation (E') will increase in future at the same rate as before, but the load factor will remain constant at the average in the past (Lf = 65.0% from Table 5-1).

Table 5-5 Results of Simulation by 1 Element Multiple Regression (Interconnected System)

		Energy (GWh)				Peak Load (MW)				Load
		Record	Estimate			Record	Estimate			Factor
Year	n	E(GWh)	log.E	E' (GWh)	E/E'	P (MW)	log.P	P' (MW)	P/P'	Lf' (%)
1973	0	192.3	5.259	217.3	0.89	34.3	3.535	38.9	0.88	63.8
1974	1	211.9	5.356	232.8	0.91	39.3	3.671	41.6	0.98	63.9
1975	2	262.7	5.571	249.4	1.04	48.2	3.875	44.5	1.08	64.0
1976	3	280.1	5.635	267.2	1.05	50.2	3.916	47.5	1.06	64.2
1977	4	293.9	5.683	286.3	1.03	51.4	3.940	50.8	1.01	64.3
1978	5	308.7	5.732	306.7	1.01	54.2	3.993	54.4	1.00	64.4
1979	6	354.6	5.871	328.6	1.08	60.4	4.101	58.1	1.04	64.6
1980	7	385.7	5.955	352.1	1.10	66.2	4.193	62.1	1.07	64.7
1981	8	383.4	5.949	377.2	1.02	66.6	4.199	66.5	1.00	64.8
1982	9	406.2	6.007	404.2	1.01	70.6	4.257	71.1	0.99	64.9
1983	10	447.8	6.104	433.0	1.03	73.4	4.296	76.0	0.97	65.0
1984	11	469.6	6.152	463.9	1.01	84.6	4.438	81.2	1.04	65.2
1985	12	475.6	6.165	497.0	0.96	81.8	4.404	86.9	0.94	65.3
1986	13	511.5	6.237	532.5	0.96	94.8	4.552	92.9	1.02	65.4
1987	14	560.9	6.330	570.6	0.98	97.2	4.577	99.3	0.98	65.6
1988	15	580.6	6.364	611.3	0.95	101.0	4.615	106.2	0.95	65.7

Note : log.E' = 5.3811 + 0.069n ………………………………………… (5-5')

∴ E' = 217.26(1 + 0.0714)n (GWh) ……………………………… (5-4')

Re = 0.9886

log.P' = 3.6606 + 0.067n ………………………………………… (5-6')

∴ P' = 38.88(1 + 0.0693)n (MW)

Rp = 0.9892

Lf' = 100 x E'/(8.76 X P') (%) ……………………………… (5-3')

(3) Result of Forecast

As the equation (5-4') to be used to obtain electric energy generation (E') has been determined in Table 5-5, the peak load (P') from 1988 to 2005 is predicted using the equation (5-3') and (5-4') with the result as shown in Table 5-6.

Table 5-6 Demand Forecast by 1 Element Multiple Regression (Interconnected System)

Year	n	Energy Estimate E' (GWh)	Peak Load Estimate P' (MW)	Year	n	Energy Estimate E' (GWh)	Peak Load Estimate P' (MW)
1988	15	611.3	107.4	1997	24	1,137.2	199.7
1989	16	654.9	115.0	1998	25	1,218.3	214.0
1990	17	701.7	123.2	1999	26	1,305.3	229.2
1991	18	751.8	132.0	2000	27	1,398.5	245.6
1992	19	805.5	141.9	2001	28	1,498.4	263.2
1993	20	863.0	151.6	2002	29	1,605.0	281.9
1994	21	924.6	162.4	2003	30	1,720.0	302.1
1995	22	990.6	174.0	2004	31	1,842.8	323.6
1996	23	1,061.4	186.4	2005	32	1,974.4	346.8

Note : $E' = 217.26 (1 + 0.0714)^n$

$P' = 1,000 \times E'/(8,760 \times 0.65)$

5-3-3 Power Demand Forecast by Multi-variate Multiple Regression Analysis

Although the power demand forecast as shown in Table 5-6 is effective in case that the demand trend in the past is directly applicable to that in future, it does not reflect the political intention in future of the governmental authorities concerned. The multivariate multiple regression analysis to be used for power demand forecast as described hereunder is trying to respond to such request and forecast power demand in future by means of attaching importance to the trend in the past, but at the same time, taking into account the correlation between the economic indicators based on the national development plan and the power demand. The content is detailed below:

(1) Idea

When four (4) elements consisting of GDP (G), population (M), number of consumers (C) and average unit selling price of electricity (R) are considered as controlling factors of power demand (E), the regression equation (5-1) can be rewritten as follows:

$$Bn = b0 + b1Gn + b2Mn + b3Cn + b4Rn \quad \cdots\cdots\cdots (5\text{-}1')$$

Where,

b0, b1, b2, b3, b4	:	Partial regression coefficient
E	:	Electric energy generation
En	:	Electric energy generation in nth year
G	:	GDP
Xn	:	GDP in nth year
M	:	Population
Mn	:	Population in nth year
C	:	Number of consumes
Cn	:	Number of consumers in nth year
R	:	Average unit selling price of electricity
Rn	:	Average unit selling price of electricity in nth year

In view of the above, GDP, population, number of consumers, and average unit selling price of electricity each in future can be forecasted as G', M', C' and R', respectively from the data in the past. Furthermore, if the above-mentioned equation (5-1') can be determined, the electric energy generation in future can be forecasted by use of the same equation.

(2) Various Values used in Calculation

(a) GDP and Population

The relationship among GDP, population and years elapsed is obtained in the same manner as that in 5-3-2, using GDP from 1973 to 1987 (Price in 1987) and population as shown in page 3-4 and Table 3-2 with the result shown below:

Table 5-7 Results of Simulation by 1 Element Multiple Regression (GDP and Population)

		GDP (K mil)				Population (million)			
		Record		Estimate		Record		Estimate	
Year	n	G	log. G	G'	G/G'	M	log. M	M'	M/M'
1973	0	1,820	7.507	1,969	0.924	4.79	1.567	4.89	0.980
1974	1	1,947	7.574	2,027	0.961	5.10	1.629	5.04	1.012
1975	2	2,061	7.631	2,087	0.988	5.24	1.656	5.20	1.008
1976	3	2,186	7.690	2,148	1.018	5.37	1.681	5.36	1.002
1977	4	2,282	7.733	2,211	1.032	5.54	1.712	5.53	1.002
1978	5	2,471	7.812	2,276	1.086	5.68	1.737	5.70	0.996
1979	6	2,550	7.844	2,343	1.088	5.86	1.768	5.88	0.997
1980	7	2,545	7.842	2,412	1.055	6.05	1.800	6.07	0.997
1981	8	2,409	7.787	2,483	0.970	6.23	1.829	6.26	0.995
1982	9	2,480	7.816	2,556	0.970	6.41	1.858	6.46	0.992
1983	10	2,566	7.850	2,631	0.975	6.62	1.890	6.66	0.994
1984	11	2,682	7.894	2,709	0.990	6.84	1.923	6.87	0.996
1985	12	2,794	7.935	2,788	1.002	7.06	1.954	7.09	0.996
1986	13	2,873	7.963	2,870	1.001	7.28	1.985	7.31	0.996
1987	14	2,866	7.961	2,955	0.970	7.50	2.015	7.54	0.995

Note : $\log G' = 7.5855 + 0.029n$

$G' = 1{,}969.4\,(1 + 0.0294)^n$ (K million)

$Rg = 0.9446$

$\log M' = 1.5861 + 0.031n$

$M' = 4{,}885\,(1 + 0.0315)n$ (million)

$Rm = 0.9991$

Hence, GDP and population in and after 1988 shall be forecasted in accordance with the above equations as "base case".

On the other hand, in the "Statement of Development Policies 1987 - 1996" issued by the Office of the President and Cabinet, Malawi noted that net economic growth rate in future is forecast at 3.8% from 1987 to 1991 and at 4.2% after 1991, and a population increase rate of 3.3% from 1987 to 1991 is predicted to rise to 3.4% after 1991, all of them being rather on the high side (Refer to Table 3-2). The case in accordance with the above Statement of Development Policies after 1988 was taken as "high case".

(b) Number of Consumers and Average Unit Selling Price of Electricity

The relationship between the number of consumers, average unit selling price of electricity, and year elapsed is obtained in the same manner as that in 5-3-2, using the number of consumers from 1973 to 1986 and the average unit selling price of electricity (converted by 1987 price) as shown in page 4-10 and Table 4-6 with the result shown below:

Table 5-8 Results of Simulation by 1 Element Multiple Regression
(Consumer and Revenue per kWh : Interconnected System)

		Number of Consumer ('000)				Revenue per KWh (Tambla/KWh)			
		Record		Estimate		Record		Estimate	
Year	n	C	log.C	C'	C/C'	R	log.R	R'	R/R'
1973	0	12.16	2.498	12.84	0.947	10.60	2.361	9.79	1.083
1974	1	13.88	2.630	13.83	1.004	8.95	2.192	9.87	0.907
1975	2	15.00	2.708	14.89	1.007	9.30	2.230	9.95	0.935
1976	3	15.90	2.766	16.03	0.992	9.29	2.230	10.02	0.927
1977	4	17.93	2.886	17.26	1.039	9.59	2.261	10.10	0.950
1978	5	19.00	2.944	18.59	1.022	11.64	2.454	10.19	1.142
1979	6	20.46	3.018	20.01	1.022	11.36	2.430	10.27	1.106
1980	7	21.84	3.084	21.55	1.013	10.68	2.358	10.35	1.032
1981	8	22.84	3.129	23.21	0.984	10.85	2.384	10.43	1.040
1982	9	25.45	3.237	24.99	1.018	11.00	2.398	10.52	1.046
1983	10	26.66	3.283	26.91	0.991	10.55	2.356	10.60	0.995
1984	11	28.65	3.355	28.97	0.989	10.27	2.329	10.68	0.962
1985	12	30.99	3.434	31.20	0.993	11.06	2.403	10.77	1.027
1986	13	33.11	3.500	33.60	0.985	10.02	2.305	10.86	0.923

Note : $\log.C' = 2.5525 + 0.074n$

$C' = 12.839(1 + 0.0768)^n$ ('000)

$Rc = 0.9982$

$\log.R' = 2.2812 + 0.008n$

$R' = 9.988(1 + 0.0080)^n$ (Tambala/kWh)

$Rr = 0.4099$

The result shows a quite high value of 7.68% for annual rate of increase in the number of consumers, a consequence of the endeavor by ESCOM positively addressing rural electrification. Since the above tendency is expected to continue in future, the number of consumers and average unit selling price of electricity in and after 1988 shall be forecast in accordance with the above equations, and the same equation shall be applied to both the "base case" and "high case".

(3) Result of Analysis

When the electric energy generation (E') as obtained in Table 5-5 is used as a solution, and GDP (G') and population (M') as obtained in Table 5-7, and the number of consumers (C') and average unit selling price of electricity (R') as obtained in Table 5-8 are used as parameters, the result of multi-variate multiple regression analysis is shown below:

Table 5-9 Results of Simulation by 4 Elements Multiple Regression (Eneregy Generated : Interconnected System)

Year	n	Energy Estimate E' (GWh)	GDP Estimate G' (K mil.)	Population Estimate M' (mil.)	Consumer Estimate C' ('000)	Revenue Estimate R' (T/KWh)	Energy (Adjusted) E'' (GWH)	E''/E
1973	0	217.3	1,969	4.89	12.84	9.79	217.1	1.001
1974	1	232.8	2,027	5.04	18.83	9.87	232.6	1.000
1975	2	249.4	2,087	5.20	14.89	9.95	249.3	1.000
1976	3	267.2	2,148	5.36	16.03	10.02	267.1	1.000
1977	4	286.3	2,211	5.53	17.26	10.10	286.2	1.000
1978	5	306.7	2,276	5.70	18.59	10.19	306.6	1.000
1979	6	328.6	2,343	5.88	20.01	10.27	328.5	1.000
1980	7	352.1	2,412	6.07	21.55	10.35	352.0	1.000
1981	8	377.2	2,483	6.26	23.21	10.43	377.2	1.000
1982	9	404.2	2,556	6.46	24.99	10.52	404.1	1.000
1983	10	433.0	2,631	6.66	26.91	10.60	433.0	1.000
1984	11	463.9	2,709	6.87	28.97	10.68	463.8	1.000
1985	12	497.0	2,788	7.09	31.20	10.77	497.0	1.000
1986	13	532.5	2,870	7.31	33.60	10.86	532.5	1.000
1987	14	570.6	2,955	7.54	36.18	10.94	570.7	1.000
1988	15	611.3	3,042	7.78	38.95	11.03	611.4	1.000

Note : $E' = 217.26\ (1 + 0.0714)^n$ $\quad M' = 4.885\ (1 + 0.0315)^n$

$G' = 1,969.4\ (1 + 0.0294)^n$ $\quad R' = 9.788\ (1 + 0.0080)^n$

$C' = 12.839\ (1 + 0.0768)^n$

$E'' = 11.8644 + 0.005G' + 18.2881M' + 13.18C' - 6.46R'$

$R = 1.0000$

(4) Result of Forecast

Using equation to obtain electric energy generation (E") determined in Table 5-9, the forecast from 1988 to 2005 is made as follows:

Table 5-10 Energy Demand Forecast by 4 Elements Multiple Regression Analysis (Interconnected System) -Base Case-

Year	n	GDP Estimate G' (K mil.)	Population Estimate M' (mil.)	Consumer Estimate C' ('000)	Revenue Estimate R' (T/kWh)	Energy (Adjusted) E'' (GWH)	Peak Load (Adjusted) P'' (MW)
1988	0	3,042	7.78	38.95	11.03	611.4	107.4
1989	1	3,131	8.02	41.95	11.12	655.2	115.1
1990	2	3,223	8.28	45.17	11.21	702.3	123.3
1991	3	3,318	8.54	48.64	11.30	752.7	132.2
1992	4	3,415	8.81	52.37	11.39	806.7	141.7
1993	5	3,516	9.08	56.39	11.48	864.5	151.8
1994	6	3,619	9.37	60.72	11.57	926.8	162.8
1995	7	3,726	9.66	65.39	11.66	993.6	174.5
1996	8	3,835	9.97	70.41	11.76	1,065.4	187.1
1997	9	3,948	10.28	75.82	11.85	1,142.3	200.6
1998	10	4,064	10.61	81.64	11.95	1,225.0	215.1
1999	11	4,183	10.94	87.91	12.04	1,313.7	230.7
2000	12	4,306	11.29	94.66	12.14	1,409.0	247.5
2001	13	4,433	11.64	101.93	12.23	1,511.3	265.4
2002	14	4,563	12.01	109.76	12.33	1,621.3	284.7
2003	15	4,697	12.39	118.19	12.43	1,739.3	305.5
2004	16	4,836	12.78	127.27	12.53	1,866.2	327.7
2005	17	4,978	13.18	137.04	12.63	2,002.3	351.7
Annual Growth Rate (%)		2.94	3.15	7.68	0.80	7.23	7.23

Note : $G' = 3,042(1 + 0.0294)^n$ $M' = 7.78(1 + 0.0315)^n$

$C' = 38.95(1 + 0.0768)^n$ $R' = 11.03(1 + 0.0080)^n$

$$E'' = 11.8644 + 0.005G' + 18.2881M' + 13.17955C' - 6.45954R'$$

$$P'' = 1,000 \times E''/(8,760 \times 0.65)$$

Table 5-11 Energy Demand Forecast by 4 Elements Multiple Regression Analysis (Interconnected System) -High Case-

Year	n	GDP Estimate G' (K mil.)	Population Estimate M' (mil.)	Consumer Estimate C' ('000)	Revenue Estimate R' (T/kWh)	Energy (Adjusted) E'' (GWh)	Peak Load (Adjusted) P'' (MW)
1988	0	3,042	7.78	38.95	11.03	611.5	107.4
1989	1	3,158	8.04	41.95	11.12	655.8	115.2
1990	2	3,277	8.30	45.17	11.21	703.0	123.5
1991	3	3,402	8.58	48.64	11.30	753.9	132.4
1992	4	3,545	8.87	52.37	11.39	808.5	142.0
1993	5	3,694	9.17	56.39	11.48	867.1	152.3
1994	6	3,849	9.49	60.72	11.57	930.2	163.4
1995	7	4,011	9.81	65.39	11.66	997.8	175.2
1996	8	4,179	10.14	70.41	11.76	1,070.2	188.0
1997	9	4,355	10.49	75.82	11.85	1,148.2	201.7
1998	10	4,537	10.84	81.64	11.95	1,231.6	216.3
1999	11	4,728	11.21	87.91	12.04	1,321.4	232.1
2000	12	4,927	11.59	94.66	12.14	1,417.7	249.0
2001	13	5,133	11.99	101.93	12.23	1,521.2	267.2
2002	14	5,349	12.39	109.76	12.33	1,632.2	286.7
2003	15	5,574	12.82	118.19	12.43	1,751.6	307.6
2004	16	5,808	13.25	127.27	12.53	1,879.7	330.1
2005	17	6,052	13.70	137.04	12.63	2,017.3	354.3
Annual Growth Rate (%)		4.13	3.38	7.68	0.80	7.27	7.27

No :

$G' = 3,042(1 + 0.0380)^{n}$ .... For 1988-1991

$G' = 3,402(1 + 0.0420)^{(n-3)}$ .... For 1991-2005

$M' = 7.78(1 + 0.0330)^{n}$ .... For 1988-1991

$M' = 8.58(1 + 0.0340)^{(n-3)}$ .... For 1991-2005

$C' = 38.95(1 + 0.0768)^{n}$

$R' = 11.03(1 + 0.0080)^{n}$

$E'' = 11.8644 + 0.005G' + 18.2881M' + 13.17955C' - 6.45954R'$

$P'' = 1,0000 \times E''/(8,760 \times 0.65)$

5-3-4 Power Demand Forecast in Central and Northern Systems

The electric power systems in Malawi are connected with each other nationwide except in Karonga and Chitipa, the utmost northern part, rendering it difficult to accurately predict the power demand by each district from the existing data.

In view of the above condition, our power demand forecast is carried out by use of the demand share by district as shown in Table 4-2 in page 4-6 as well as the result of power demand in the national level as obtained in the above 5-3-3.

Table 5-12 Results of Simulation by 1 Element Multiple Regression
(Percentage Share by Area in Energy Demand)

Year	n	Record (%) SR	Record (%) C&NR	Estimate (%) SR'	Estimate (%) C&NR'
1973	0	92.13	7.87	92.39	7.61
1974	1	90.55	9.45	90.89	9.10
1975	2	89.91	10.09	89.40	10.59
1976	3	88.31	11.69	87.91	12.08
1977	4	86.49	13.51	86.42	13.57
1978	5	85.19	14.81	84.93	15.06
1979	6	84.45	15.55	83.44	16.55
1980	7	82.20	17.80	81.95	18.04
1981	8	79.95	20.05	80.46	19.53
1982	9	77.02	22.98	78.97	21.02
1983	10	77.20	22.80	77.48	22.52
1984	11	74.85	25.15	75.98	24.01
1985	12	75.12	24.88	74.49	25.50
1986	13	74.45	25.55	73.00	26.99

Table 5-13 Demand Forecast for Central & Northern Region -Base Case-

Year	n	C&NR (%)	Generate (GWh)	Load (MW)
1987	14	28.48	162.5	28.5
1988	15	29.98	183.3	32.2
1989	16	31.47	206.2	36.2
1990	17	32.96	231.5	40.7
1991	18	34.45	259.3	45.5
1992	19	35.94	289.9	50.9
1993	20	37.43	323.6	56.8
1994	21	38.92	360.7	63.3
1995	22	40.41	401.6	70.5
1996	23	41.90	446.4	78.4
1997	24	43.39	495.7	87.1
1998	25	44.89	549.9	96.6
1999	26	46.38	609.3	107.0
2000	27	47.87	674.5	118.5
2001	28	49.36	746.0	131.0
2002	29	50.85	824.4	144.8
2003	30	52.34	910.4	159.9
2004	31	53.83	1004.6	176.4
2005	32	55.32	1107.7	194.5

Note : SR' = 92.39 - 1.491n
C&NR' = 7.61 + 1.491n

SR … Percentage Share of Southern Region
C&NR … Percentage Share of Central & Northern Region

5-3-5 Conclusion

(1) As can be seen from the results of multiple regression analysis, so far as the present state is concerned, that the power demand constitution in Malawi depends greatly upon an increase in the number of power consumers, resulting in a weak correlation between the power demand and GDP. It is impossible, therefore, to forecast power demand in the remote future when demand constitution may be changed by the widespread nationwide electrification. However, it is believed that our forecast remains valid for about 10 years into the future.

(2) Although the result of power demand forecast in the interconnected systems is somewhat lower than those forecast by ESCOM (Table 5-2), there is not much difference between the two. Future demand is considered to increase along the intermediate between the values in the following table:

Table 5-14 Comparison with ESCOM's Demand Forecast for Whole Country

-Base Case-

Year	Energy Generated (GWh)		Peak Load (MW)		Load Factor (%)	
	ESCOM	JICA	ESCOM	JICA	ESCOM	JICA
1988	592.6	611.5	105.9	107.4	63.9	65.0
1989	636.6	655.3	114.1	115.1	63.7	65.0
1990	678.4	702.3	122.3	123.3	63.3	65.0
1991	736.1	752.7	133.4	132.2	63.0	65.0
1992	771.4	806.7	139.6	141.7	63.1	65.0
1993	808.5	864.6	146.3	151.8	63.1	65.0
1994	873.4	926.9	158.2	162.8	63.0	65.0
1995	949.3	993.7	172.3	174.5	62.9	65.0
1996	1045.5	1065.4	190.6	187.1	62.6	65.0
1997	1144.5	1142.4	209.6	200.6	62.3	65.0
1998	1254.0	1225.0	230.4	215.1	62.1	65.0
1999	1375.8	1313.7	253.6	230.7	61.9	65.0
2000	1511.7	1409.0	279.5	247.5	61.7	65.0
2001	1663.8	1511.3	308.4	265.4	61.6	65.0
2002	1832.9	1621.3	340.5	284.7	61.4	65.0
2003	2020.0	1739.4	376.4	305.5	61.3	65.0
2004	2228.2	1866.2	416.3	327.7	61.1	65.0
2005	2456.0	2002.4	460.9	351.7	60.9	65.0
Growth Rate(%)	8.73	7.23	9.03	7.23		

Table 5-15 Comparison with ESCOM's Demand Forecast at Lilongwe with North area

Year	Energy Generated (GWh)		Peak Load (MW)		Load Factor (%)	
	ESCOM	JICA	ESCOM	JICA	ESCOM	JICA
1987	119.7	162.5	28.8	28.5	42.7	65.0
1988	133.2	183.3	29.0	32.2	47.2	65.0
1989	153.8	206.2	31.3	36.2	50.5	65.0
1990	171.2	231.5	33.3	40.7	53.4	65.0
1991	194.3	259.3	37.0	45.5	57.6	65.0
1992	209.5	289.9	42.0	50.9	59.1	65.0
1993	227.7	323.6	46.0	56.8	60.9	65.0
1994	255.1	360.7	50.0	63.3	64.7	65.0
1995	287.6	401.6	57.0	70.5	69.4	65.0
1996	324.6	446.4	64.0	78.4	74.9	65.0
1997	363.2	495.7	72.0	87.1	79.1	65.0
1998	406.7	549.7	80.0	96.6		65.0
1999	455.6	609.3	90.0	107.0		65.0
2000	510.7	674.5	106.0	118.5		65.0
2001		746.0		131.0		65.0
2002		824.4		144.8		65.0
2003		910.4		159.9		65.0
2004		1004.6		176.4		65.0
2005		1107.7		194.5		65.0
Growth Rate(%)	11.8%	11.3%	10.5%	11.3%		

Notes : (1) Energy forecasted by ESCOM on a consumption base and forecast by JI on a generation base.

(2) Peak load forecast by ESCOM is base case and forecast by JICA is ba case.

CHAPTER 6 IMPLEMENTATION OF PROJECT

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6-1 Project Plan

The electric power sources in Republic of Malawi are concentrated along the Shire River basin in the south of the country. The north and center of the country wherein the Capital City Lilongwe is situated has no large power source, and depends on Nkula A power station and Nkula B power station for the supply of electric power through a single circuit 66 kV steel pole transmission line and a single circuit 132 kV wooden pole transmission line, respectively. Therefore, in the event of a power supply cut due to an accident to any transmission line, extreme load restriction are inevitable.

The present project is being formulated for the purpose of establishing a stable power supply as well as coping with the prospective increase in power demand in the central and north region of the country by means of constructing the transmission line connecting Nkula B power station and Lilongwe B substation.

6-1-1 Summary of Transmission Facilities

The 132 kV transmission line under planning is summarized as follows:

(1)	Section	:	Nkula B P/S - Sharpevale S/S - Lilongwe B S/S
(2)	Overall length	:	250 km, approx.
(3)	Voltage	:	132 kV
(4)	System	:	AC, 3 phase, 3 wire
(5)	Frequency	:	50 H_Z
(6)	Number of circuits	:	Single circuit (double circuit designed, single circuit string)
(7)	Conductor	:	ACSR 605 MCM (Peacock)
(8)	Overhead ground wire	:	AC 55 mm^2

(9) Insulator : 11 units per string of suspension insulator of ball and socket type with a diameter of 254 mm

(10) Support : Self-supporting square steel-tower with double circuits vertical formation

(11) Grounding system : Direct grounding

6-1-2 Summary of Substation Equipment

New and expansion plans for the substation are follows:

(1) Expansion for Nkula B power station

(a) Expanding the outlet of single circuit 132 kV transmission line, including switchgear, control systems, protective systems and foundations.

(b) The year of commissioning: 1992

(2) Expansion for Lilongwe B substation

(a) Expanding the outlet of single circuit 132 kV transmission line, including switchgear, control systems, protective systems, and foundations.

(b) Expansion for 132 kV pipe-bus

(c) The year of commissioning: 1992

(3) New Installation of Sharpevale substation

(a) Output capacity : 25 MVA

(b) Transformer capacity: 3 phase, 132/66/33 kV, 25 MVA - one set

(c) Scale of substation

i) 132 kV line side

- Bus system : Double bus (pipe-bus)
- Outlet of transmission line: 6 sections (6 circuits)
- Bus equipment : One (1) section
- Main transformer in primary side: One (1) section

ii) 66 kV line side

- Bus system : Single bus (pipe-bus)
- Outlet of transmission line: 2 sections (2 circuits)
- Main transformer in secondary side: One (1) section

iii) 33 kV line side

- Indoor, cubicle switchgear
- Number of cubicles : 5 panels

6-1-3 Meteorological Conditions

The meteorological conditions to be applied in the preliminary design have been determined to be as follows by use of the available meteorological data along the route of the 132 kV transmission line along with the existing design conditions in the Republic of Malawi with ESCOM as a reference.

The positions of meteorological observation which were used for the investigation, and the obtained data are exhibited in Fig. 6-1 and Table 6-1, respectively.

Temperature,	highest:	+ 40°C
	average:	+ 20°C
	lowest :	± 0°C
Humidity,	average:	70%
Wind velocity, max. :		36 m/s

Rainfall,	max. :	260 mm/month
	average:	80 mm/month
	min. :	1 mm/month
IKL,	max. :	140 days/year
	average:	123 days/year
	min. :	102 days/year

Seismic acceleration: 0.2 G, approx.

6-2 Preliminary Design of Transmission Line

6-2-1 Route of 132 kV Transmission Line

(1) Outline of the Transmission Line Route

The area between Nkula B power station and Balaka is a gently sloped land varying from 350 to 730 m above sea level, with scattered bushes and alternating savannah and cultivated fields. An existing 132 kV transmission line and a National Highway road (Route M-6) run along the planned route, thus making the route easily accessible.

The area between Balaka and Sharpevale substation is a gently sloped hilly area 730 to 620 m above sea level, with alternating bushes and cultivated fields. The area has an existing 132 kV transmission line and a National Highway road (Route M-17) running along the planned route, thus making the route easily accessible.

The area between Sharpevale and Golomoti is a gently sloped hilly area varying from 620 to 530 m high above sea level, with alternating bushes and cultivated fields as above. The area has an existing 132 kV transmission line and a National Highway road (Route M-17) running along the planned route, thus making the route easily accessible.

In the area between Golomoti and Nkhoma (Route D-21), the route runs up a hillside 530 to 1,670 m above sea level, with occasionly steep mountains with forests and bushes. The survey for the route should be carried out carefully for long-span points and locations with great difference in altitude. This area has few roads except for many walking tracks, and is rather difficult to reach in term of line construction.

The area between Nkhoma and the Lilongwe B substation is an undulating hilly area 1,280 m to 1,100 m above sea level, with alternating bushes and cultivated fields.

The area has few roads except for many walking tracks, and is rather difficult to reach in term of the construction.

Figure 6-1 and Figure 6-2 show the location and route of proposed 132 kV transmission line.

6-2-2 Redefining of the Construction Criteria

(1) Assumed Conditions

The following conditions were assumed in the preliminary design.

(a)	Route	:	Nkula B P/S - Sharpevale S/S - Lilongwe B s/s
(b)	Total length	:	Approx. 250 km
(c)	Voltage	:	132 kV
(d)	Capacity of transmission	:	30 MW (at Lilongwe B s/s)
(e)	Conductor size	:	To result in voltage loss less than 10% and transmission loss less than 5% at a power factor of 0.98.
(f)	Number of circuit	:	Single
(g)	Tower	:	Lattice-type tower (designed for double circuits)

(2) Wind Load

The maximum wind velocity for the 132 kV transmission line area was estimated as 36 m/s from the wind data of the area given in Table 6-2 (airport data), based on the life of the tower and a return period of thirty-five (35) years. The wind pressure for the line with these conditions is calculated by the following formula.

$$P = 1/2 \cdot \rho V^2 \cdot C \qquad (6\text{-}1)$$

Where

P : Wind Pressure for wire (kg/m^2)

ρ : Air density ($kg \cdot s2 \cdot m^4$)

V : Maximum wind velocity (m/s)

C : Air resistance coefficient

The wind pressure value for each object was derived by the formula as follows:

Conductor	:	81 kg/m^2 (C = 1.0)
Overhead ground wire	:	90 kg/m^2 (C = 1.1)
Insulator unit	:	114 kg/m^2 (C = 1.4)
Tower	:	270 kg/m^2 (C = 1.65 x 2)

For the wind pressure on aerial cable reduction ratios of 100% for those less than 200 m and 60% for those more than 300 m span were assumed.

6-2-3 Insulation Designs

The insulation was designed by taking into account an assumed basic condition of the 132 kV transmission line for nominal voltage with effective grounding system (direct grounding), together with switching surge voltage and commercial-frequency abnormal voltage.

This results in the requirement of nine (9) units insulator pieces per string; however, eleven (11) units per string should be the actual number considering the lack of data for contamination losses and consistency with existing lines.

The permissible salt deposition for this number of insulators is approximately 0.35 mg/cm^2.

Table 6-3 lists the recommended insulator characteristics.

Table 6-3 Characteristics of Insulator Unit

Items	Units	Contents
IEC Type		U120BS
Type		Ball and Socket
Quality		Porcelain or glass
Diameter	mm	254
Unit Spacing	mm	146
Creepage distance	mm	292
Electromechanical Failing Load	kg	12,000
Puncture Voltage	kV	110
Ball and Socket Size	mm	16A
Net Weight	kg	5.5

6-2-4 Lightning-proof Designs

Since the area for the 132 kV transmission line has extremely high isokeraunic level (IKL's) maximum is 140 days. The overhead ground wire should be a two (2) line wire throughout the line route with a shelding angle of less than fifteen (15) degrees in order to reduce direct lightning hits of lightnings on the line.

The arcing horn must be attached to the insulator strings to prevent damage to the insulator.

The grounding resistance of the tower should be made less than ten (10) ohms, in order to reduce back flashover.

The transmission line is designed and constructed as double circuit steel tower line. On the double circuit line, it is supposed that the fault due to lightning strinking on one circuit will extended to neighboring circuit. In fact, data in Japan (line voltage among 187 kV, 220 kV, 275 kV and 500 kV and period of from 1980 to 1985) shows the fault extended to both circuits accounts less than 15% of total fault numbers caused by lightning strik. To clear these faults, high speed auto-reclosing system (single and multi phase reclosing) is adopted and percentage of fault clearing by this system without power flow interruption reaches about 80 to 90% of fault numbers.

The transmission line, therefore, will design and construct to provide two (2) grounding wires, arcing horn and high speed single phase auto-reclosing system as a part of line protection relay system (single and 3 phase reclosing system will be adopted at the time of second circuit conductor winding).

6-2-5 Clearance between Conductor

The recommended clearances between conductors, and between conductor and overhead ground wire are as follows:

(1) Clearance between Conductors

$$D = 0.5 \sqrt{f + I} + \frac{u}{150} \qquad (6\text{-}2)$$

where

- D : Clearance between conductors (m)
- f : Maximum sag (m)
- I : Length of insulator string (m)
- U : Maximum operation voltage (kV)

Calculation by the formula results in 3.8 m

(2) Clearance between the Conductor and the Overhead Ground Wire

By assuming a lightning current of 60 kA, the minimum clearance between conductor and overhead ground wire is derived from Fig. 6-3, resulting in 4.5 m for the standard span and 6.5 m for the Long span.

6-2-6 Design of Conductor

Based on an overall assessment of factors such as transmission capacity, corona troubles, current capacity in case of failures, economical factors, handling ease in construction works and previous experiences in Malawi, ACSR 605 MCM (Peacock) is recommended for the project.

The characteristics are shown in Table 6-4, outline of the design is as follows:

(1) Transmission Capacity

$$P = \sqrt{3}\ E\ I\ \mathrm{Cos}\phi \qquad (6\text{-}3)$$

where

E : Transmission voltage (kV)

Cos ϕ : Power factor

I : Permissible current (A) <Formula>

$$I = \sqrt{\frac{[hw + (hr - \frac{Ws}{\pi\,\theta})\eta]\cdot d\cdot\theta\cdot\pi}{r}} \qquad (6\text{-}4)$$

d : Diameter of conductor (cm)

θ : Permissible temperature rise (°C)

hr : Coefficient of heat dissipation through radiation (w/°C, cm^2)

$$hr = 0.00056\ \frac{[\frac{273 + T + \theta}{100}]^4 - [\frac{273 + T}{100}]^4}{\theta}\ (W/℃, cm^2) \quad (6\text{-}5)$$

T : Ambient temperature (°C)

hw : Coefficient of heat dissipation through convective heat conduction

$$hw = 0.00572 \frac{\sqrt{\frac{V}{d}}}{\left[273 + T + \frac{\eta}{2} \right]^{0.123}} \quad (W/°C, cm^2) \qquad (6\text{-}6)$$

V : Wind velocity (m/sec)

r : Alternating current resistance of conductor at actual temperature conditions (ohm/cm^2)

Ws : Solar radiation (W/cm^2)

η : Ratio of radiation coefficients of wire and black body

These conditions result in a transmission capacity of Peacock conductor (605 MCM ACSR) of approximately 80 MW at 65°C, which fulfills the requirement of 30 MW.

(2) Momentary Current Carrying Capacity

Permissible current for the conductor in accidents such as ground short-circuiting is determined by the following formula, neglecting the heat dissipation from the conductor because of momentary current follow:

$$I = 93 \frac{S}{\sqrt{t}} \qquad (A) \qquad (6\text{-}7)$$

where

I : Instantaneous current capacity (A)

S : Cross-sectional area of conductor (mm^2) (aluminum part only)

t : Current impression time (sec)

The permissible instantaneous current of Peacock conductor with a current duration of two (2) sec is 20.1 (kA), which is greater than the possible failure current of 20 kA.

(3) Maximum Surface Gradient at Conductor Surface

The maximum potential gradient at conductor surface is expressed by the formula:

$$G_{max} = \frac{0.4343V}{r \cdot \log_{10} \frac{De}{r}} \qquad (6\text{-}8)$$

where

Gmax : Maximum potential gradient on conductor surface (kV/cm)

V : Voltage to ground (kV)

r : Radius of conductor (cm)

De : Equivalent inter-wire clearance

Calculation by the formula results in Gmax of the Peacock conductor of approximately 11 (kV/cm), which is not significant in terms of corona losses or radiation troubles.

(4) Design of Tension and Sag

The working conditions need to be determined from maximum and usual working tensions. The maximum working tension was assumed to be more than 2.5 times the safety factor for minimum tensile strength of the conductor and usual tension for standard span (at annual average temperature and no wind) to be less than twenty percent (20%) of minimum tensil strength of the conductor.

Table 6-5 shows the results.

Each supporting point must be equipped with a damper for reducing fatigue caused by conductor vibrations. Also, the base of suspension clamps should be equipped with armor-rods.

Table 6-4 Characteristics of Conductor

Items		Units	Contents
Code name			Peacock
Type			ACSR
Size		MCM	605
Composition	Alumi.	Nos/mm	24/4.034
	Steel	"	7/2.69
Diameter		mm	24.21
Calculated sectional area	Alumi.	mm^2	306.7
	Steel	"	39.78
	Total	"	345.78
Unit weight		kg/km	1,161
Rated strength		kgf	9,800
DC resistance at 20°C		Ω /km	0.09413
Coeff. of linear exp.		1/°C	20×10^{-6}
Modulus of elasticity		kgf/mm^2	8,000

Table 6-5 Dip and Tension at each Assumption (605 MCM)

Assumption	Conditions		s = 200 m		s = 350 m		s = 600 m	
	Temp (°C)	Wind (kg/m^2)	Tension (kg)	Dip (m)	Tension (kg)	Dip (m)	Tension (kg)	Dip (m)
1	0	81	3550 (36.26)	3.21	-	-	-	-
2	0	48.6 (81x0.6)	-	-	2768 (28.24)	9.15	2646 (27.0)	28.11
3	20	0	2039 (20.81)	2.85	1900 (19.39)	9.36	1841 (18.79)	28.37
4	65	0	1369 (13.97)	4.24	1597 (16.3)	11.13	1722 (17.57)	30.34

Note: ( ) is percent.

6-2-7 Design of the Overhead Ground Wire

The use of Aluminium clad steel wire (AC) of 55 mm^2 diameter is recommended for the overhead ground wire due to from the consideration of momentary current capacity, protection of low tension voltage lines against ground short-circuiting accidents, mechanical characteristics and economical factors. Table 6-6 shows the characteristics.

The outline of the design is described below.

(1) Momentary Current Capacity

The momentary current carring capacity for the overhead ground wire is given by the following formula by neglecting the heat dissipation from the wire.

$$I = 91 \frac{S}{\sqrt{t}}$$

where

I : Momentary current capacity (A)

S : Cross-sectional area of overhead ground wire (mm^2)

t : Current impression time (sec)

The calculation from above formula results in momentary current capacity of 10.2 (kA) for AC 55 mm^2 overhead ground wire, which satisfies the design condition of the ground short-circuiting current in the case of current divided to two (2) wires.

(2) Design of Tension and Sag

The overhead ground wire installation conditions are determined from the between the usual working tension and relaxation ratio against between conductor and overhead ground wire sag.

The design was examined by assuming the maximum tension to be more than 2.5 times the safety factor for minimum tensile strength of the overhead ground wire, usual tension for standard span (at annual average temperature and no wind) to be less than twenty-five percent (25%) of the minimum tensile strength, and usual relaxation ratio of the overhead ground wire sag against the conductor sag (dg/dc) to be less than 80%.

Table 6-7 shows the results.

Each supporting point should be equipped with a damper for reducing fatigue caused by wire vibrations.

Table 6 − 6

Characteristics of OHGW

Items	Units	Contents
Type		AC
Nominal sectional area	mm^2	55
Composition	Nos/mm	7/3.2
Diameter	mm	9.6
Calculated sectional area	mm^2	56.29
Unit weight	kg/km	318.6
Rated strength	kgf	4,560
Coef. of liner exp.	1/℃	13.9×10^{-6}
Modulas of elasticity	kgf/mm^2	12,900

Table 6 − 7

Dip and Tension at each assumption (AC 55 mm^2)

Assumption	Conditions		s = 200m		s = 350m		s = 600m	
	Temp (℃)	Wind (kg/m^2)	Tension (kg)	Dip (m)	Tension (kg)	Dip (m)	Tension (kg)	Dip (m)
1	0	90	1500 (32.69)	3.07	−	−	−	−
2	0	54 (90×0.6)	−	−	1147 (25.15)	8.13	1050 (23.03)	26.07
3	20	0	972 (21.32)	1.64	690 (15.13)	7.07	572 (12.54)	25.07
4	45	0	788 (17.28)	2.02	622 (13.64)	7.84	553 (12.13)	25.92

6-2-8 Design of Supporting Structure

The 132 kV transmission line Project to link Nkula B Power Station and Lilongwe B substation is planned with building single circuit line as a first stage and in future more one single circuit installation, however, the following three options are feasible for future addition of a line:

(1) Build a one circuit line at initially and build another as an independent one circuit line in the future

(2) Build a double circuit tower but use only one circuit line for the present; the second circuit line can be installed in the future

(3) Build a double circuit tower with two circuit conductors installed

Judging from future prospects of demand and the necessary investment efficiency, the option (2) is recommended here.

6-2-9 Design of Foundation of Supporting Structure

The foundation of supporting structure must be designed according to the soil conditions, which should be examined through geological surveys.

Geological surveys for the construction of the 132 kV transmission lines are necessitary to ensure reliability, for obtaining information on the most economical construction of supporting structures and for construction safety; results of the survey are crucial in the economical and safety aspects of the construction work of overhead transmission lines, thus making it crucial to choose an appropriate method for the survey.

"Hand-Auger-Boring" to be followed by the "Standard Penetration Test" is recommended as the survey method for the 132 kV overhead transmission line.

The sites to be surveyed should be at the angle-tower sites, river-crossing towers and every two (2) km points in the straight-line parts, with a boring depth of five (5) m and with standard penetration test positions of 1.5 m, 3 m and 4.5 m deep from the ground surface.

(1) Shape of the Foundation

Judging from the results of the field survey for the 132 kV transmission line, either "the Pad Type" or "the Rock Anchor Type" can be adopted for the foundation.

6-3 Preliminary Designing of Substations

6-3-1 Location of Substations

Locations of transmission line terminal stations and new substations were determined as follows:

(1) Terminal Station on Nkula Side

As the terminal point on the Nkula side under This Transmission Project, the Nkula A Power Station (Primary voltage: 66 kV) or the Nkula B Power Station (Primary voltage: 132 kV) are conceivable. Since the voltage of more than 132 kV will be necessary in view of the transmission capacity and the length of this transmission line, however, it was decided to terminate the line from Nkula B Power Station and additionally utilize the existing switchyard structure in an expansion area planned to be used.

(2) Terminal Point on Lilongwe Side

As the terminal point on the Lilongwe side under this Transmission Project, the Lilongwe A Substation (Primary voltage: 66 kV) or the Lilongwe B Substation (Primary voltage: 132 kV), both already established, are conceivable. Since the switchyard space for additional construction has been secured within the Lilongwe B Substation and also since the Primary voltage is 132 kV, the Lilongwe B Substation was chosen as the terminal point.

(3) New Establishment of Sharpevale Substation

Considering that the planned transmission is long-distance one and giving thought to future needs for reinforcing the northern power system, connection with the existing (132 kV) transmission line between Nkula and Salima, linkage with the 66 kV system in the Dedza area and power transmission to the resort area around Lake Malawi, it was decided to establish a new substation in the Sharpevale area, the median point of the planned transmission line.

The Sharpevale Substation projected will be located almost in the middle of the power transmission route connecting the Nkula B Power Station and the Lilongwe B Substation. It is situated at a point about 110 km apart from the Nkula B Power Station and around 140 km from the Lilongwe B Substation.

The planned site of the Substation is about 8 km apart from nearby Sharpevale village along National Highway M6 in the direction of Blantyre. At the planned site of the substation 200 m from the road towards the mountain side, there are no rock exposures nor marshy land nor small streams. It is flat, tilled ground.

As for the location of the substation, refer to Fig. 6-7.

(4) Environment around Projected Substations

All of Nkula B Power Station, the Lilongwe B Substation and the new establishment point of Sharpevale Substation have no problems in their surroundings nor experience pollution.

6-3-2 Scale of Substation and Circuit Configuration

With the demand forecast and system analysis results of This 132 kV Overhead Transmission Line Project taken into consideration, the scale and circuit composition are set as follows:

(1) Expansion of the Nkula B Power Station

(a) 132 kV transmission line terminal equipment 1 circuit

i)	Circuit breaker:	145 kV	800 A	20 kA	1 unit
ii)	Disconnector :	145 kV	800 A	20 kA	3 units

(2) New Establishment of Sharpevale Substation

(a) 132 kV transmission line terminal equipment 2 circuits

(b) Main transformer 1 unit

(c) 132 kV bus 1 set

(d) 66 kV bus 1 set

(e) Control, protection equipment 1 set

(f) Control building 1 set

(g) Items of the main equipment

i) Main transformer: 132 kV/66 kV/33 kV, 25 MVA, auto transformer equipped with OLTC 1 unit

ii) Circuit breakers: 145 kV 800 A 20 kA 4 units

iii) Disconnectors : 145 kV 800 A 20 kA 10 units

(3) Expansion of the Lilongwe B Substation

(a) 132 kV Transmission Line Terminal Equipment 1 circuit

i) Circuit breaker : 145 kV 800 A 20 kA 1 unit

ii) Disconnector : 145 kV 800A 20 kA 3 units

The circuit configuration for each substation mentioned above is shown in the attached drawings Fig. 6-8, Fig. 6-10, and Fig. 6-14.

(4) Configuration of the Sharpevale Substation

(a) Site of the Sharpevale Substation

If the final stage of the Sharpevale Substation is assumed to be as follows, the site for the projected substation will be about 13,300 m^2 (93.5 m x 142 m):

i)	132 kV transmission lines	6 circuits
ii)	132 kV bus-tie circuit	1 circuit
iii)	Main transformer	1 bank
iv)	66 kV transmission lines	2 circuits
v)	33 kV transmission lines	3 circuits
vi)	Control building	1 set

Since the new substation location is on flat, tilled land, the ground preparation level will be about 30 cm higher than the surface of existing National Road M-6 to prevent water flooding. Also, an access road with the total length of about 70 m will be constructed between the National Road and the entrance of the substation.

(b) Main Transformer

The capacity of the main transformer was set at 25 MVA, with consideration given to results of the demand forecast and standardization of the unit capacity. It was also decided to equip the transformer with an on load tap changer.

Since the main coil will be connected directly with the earthed systems on both the 132 kV and 66 kV sides, an economical auto transformer was chosen. As for the tertiary coil, a 33 kV delta connection was selected in consideration of a possible 33 kV distribution line to Mangochi and Monkey Bay.

As for the main transformer, either 3 single-phase units or 1 three-phase unit will be adopted. when a comparison is made between a bank consisting of 1 three-phase unit and another bank of the same capacity comprising 3 single-phase units, the price of the three-phase unit is about 80% of that for the single-phase units. Moreover, the total weight will be smaller in the case of the three-phase unit, and therefore, its base construction cost will be lesser.

Even when the reliability of the system is reviewed, the faulty ratio of recent transformers is quite low. Also since the necessity for the establishment of a spare transformer is negligible even in consideration of lightning hazards, adoption of a three-phase device was determined.

(c) Transmission Line Terminal Equipment

Since the 132 KV transmission line will be one circuit for the π turning-in for the time being, it was decided to install the transmission line terminal equipment for 2 circuits. As for 66 kV transmission lines, the terminal equipment for 2 circuits were installed on the assumption that 2 lines will be terminated in the future.

For the study of the scale of substation and land acquisition, the equipment for 4 line circuits were assumed while consideration was given to the possible termination of the existing 132 kV transmission line between Nkula B and Salima in the π manner and the future second circuit.

(d) Bus Connection System

Since the Sharpevale Substation will be an important substation between Nkula B and Lilongwe B, adoption of the double bus system, useful for inspection of the equipment, convenient system operation and prevention of total stoppage due to a fault in the bus, was adopted.

As regards the bus on the 66 kV side, the single bus system was employed.

(e) Anti-pollution Design

The Sharpevale Substation will be located at an altitude of approximately 670 m amid tilled land, and there is no industrial plant causing contamination nearby. Furthermore, the atmosphere there is quite good. Accordingly, no consideration will be given to anti-pollution designs.

(f) Control Building

For the purposes of accommodating the boards necessary for supervising and controlling for equipment, the relay protection board and telecommunications equipment and securing an office space, it was decided to construct a control building. The layout of the planned control building is shown in the attached dwg. Fig. 6-16.

(g) VHF Antenna

In order to use VHF telecommunications equipment for the maintenance of transmission lines, it was decided to install an antenna within the area of the substation (or beside the substation).

(h) Arrangement Drawing of Equipment

Arrangement of the equipment for each substation is shown in the attached drawing Fig. 6-11, Fig. 6-12, and Fig. 6-13.

6-3-3 Supervisory Control System

(1) Nkula B Power Station

Since the terminal equipment for one transmission line circuit under This Project is to be added to the existing facilities in the Nkula B Substation, it was decided to get the supervisory control of the transmission line terminal equipment to be added so as to agree with the existing method. The supervisory control method will be the direct control system.

At the Nkula B Power Station, the control panel for the transmission line terminal equipment, to be added, has been installed within the power station control room. The operation circuits and meters that can be used will be applied to the purpose.

(2) Lilongwe B Substation

Since the space for the transmission line terminal equipment, to be added, has already been secured within the Control Building in the Lilongwe B Substation, the new board will be established there. The shape of the new board will be the enclosed type.

(3) Sharpevale Substation

At the Sharpevale Substation, the direct supervisory control system will be adopted as in the case of the already established facilities, while the shape of the board will be the duplex type.

(4) SCADA System

Since ESCOM adopt the SCADA system, the data and information to the load dispatching station within the site of Chichiri Power Station in Blantyre, transmission of data and information will be implemented through establishment of RTU (remote terminal unit) regarding data and information in the Sharpevale Substation.

6-3-4 Transmission Line protection System and Bus Protection System

Since the transmission line of This Project is an important transmission line of the Republic of Malawi, the following protection system was adopted while giving consideration to improvement of transmission reliability:

(1) Transmission Line Protection System

(a) 132 kV Transmission Line

i) Directional comparison system with distance elements (Permissible over reach, with 3 mho element)
ii) Single/three-phase auto-reclosing to be implemented
iii) All static type

(b) 66 kV Transmission Line

i) Distance relay, static type
ii) Low-speed auto-reclosing to be implemented
iii) Overload relay

(c) 33 kV Transmission Line

i) Directional grounding relay
ii) over-current relay

(2) Bus Protection System

The following protection system will be employed.

(a) 132 kV Bus

i) voltage differential relay (high impedance type), all static type.

(b) 66 kV Bus

i) Current differential relay, static type

(3) Transformer Protection System

The following protection system will be employed.

(a) Voltage differential relay (high impedance type), all static type

(b) Overload relay

(c) Mechanical relay (Buchholtz relay, temperature relay)

6-3-5 Insulation Coordination, Lightning Protection Design

The insulation designing of the main bus in the substation was decided to be similar to that for transmission line.

The insulation strength shall be such as to satisfy the following values with regard to the 132 kV directly grounding system, and it is designed to deal with the abnormal voltage by the lightning arresters.

(1) Insulation Coordination

(a) As the system voltage of This Project, the following values will be adopted:

- Transmission line voltage

Trunk system:	:	132 kV
Secondary system	:	66 kV
Distribution system:		33 kV

(b) For the BILs (basic insulation level) of the already-installed equipment for respective system voltage, the following values are employed.

- BIL

132 kV	;650 kV
66 kV	;350 kV
33 kV	;200 kV

(c) Based on the above, the following values are employed in consideration of insulation coordination and the IEC standard value as the BILs to be adopted for the substations under This Project.

- BILs to be applied:

132 kV	;650 kV
66 kV	;350 kV
33 kV	;220 kV

(d) Since the BILs corresponding to respective system voltage have been selected, the clearance required for the layout of substation equipment is fixed as follows. These values are the same as the figures applied to existing substations and power stations.

Voltage	132 kV	66 kV	33 kV	11 kV
Standard clearance Between phase	1,270 mm	690 mm	480 mm	200 mm
To earth	1,470 mm	790 mm	480 mm	250 mm
Live part-person	3,500 mm	3,050 mm	3,050 mm	2,590 mm
Lowest part of insulator to earth	2,450 mm	2,450 mm	2,450 mm	2,450 mm

(e) For purposes of equipment insulation protection against abnormal voltage entering a substation, and securing standard clearance, a surge arrestor will be installed in the substation. Specifications and rating of the surge arrestor will be described in item (2) Lightning Protections Design.

(2) Lightning Protection Design

(a) Installation of Surge Arrester and Selection of their Rating

For protection of substation equipment against entry of the abnormal voltage generated in electric power systems (lightning surge, switching surge, abnormal voltage of power frequency), surge arresters will be installed. Along the transmission line route between Nkula B and Lilongwe B, lightning occurs frequently as seen in the substantial number of days in which lightning strikes (IKL=123), and the frequency of lightning surge entry is at a fairly high level. From the viewpoint of protecting the equipment, therefore, it was decided to install a lightning arrester at the transmission line terminal and also establish them at both ends of the transformer.

As the rating for surge arrestor, the following values will be adopted.

(Surge arrester rated voltage = Grounding coefficient Tolerance Highest voltage / $\sqrt{3}$)

132 kV circuit equipment	Rated lightning arrester voltage $1.25 \times 1.15 \times 145/\sqrt{3} = 120$ A 120 kV surge arrester will be adopted.
66 kV circuit equipment	Rated surge arrester voltage $1.25 \times 1.15 \times 72.5/\sqrt{3} = 60$ A 60 kV surge arrester will be adopted.
33 KV circuit equipment	Rated lightning arrester voltage $1.25 \times 1.15 \times 36/\sqrt{3} = 29.8$ A 30 kV lightning arrester will be adopted.

Discharge current: For 132 kV, 66 kV: 10 kA
33 kV: 5 kA

The surge arrester will be of gapless (Zinc oxide), explosion-proof and self-standing type.

(b) As the countermeasure for direct lightning strikes on the substation, the method of lightning shielding by means of overhead grounding-wires will be adopted. As overhead grounding-wires, aluminium-clad stranded steel wires will be used.

6-3-6 Grounding Design

For the purposes of grounding the substation equipment and reduction of potential rise upon entry of lightning, the mesh grounding system will be adopted.

As for the grounding of surrounding fences, the grounding separate from that of the grounding mesh will be adopted because of safety for persons touching the surrounding fence upon lightning striks.