REPUBLIC OF TUNISIA

REPORT ON

KASSEB PUMPED-STORAGE PROJECT

NOVEMBER 197[illegible]

JAPAN INTERNATIONAL COOPERATION AGENCY

REPORT ON

KASSEB PUMPED-STORAGE PROJECT

PREFACE

The government of Japan, in response to a request of the Government of the Republic of Tunisia, agreed to conduct a feasibility study on the Kasseb Pumped-Storage Power Project and the Japan International Cooperation Agency (JICA) conducted the study.

The Agency, recognizing the importance of the electric power generation project in the Social and Economic Development Plan of the country, dispatched a preliminary survey team to Tunisia in 1977.

Following the above team the Agency sent another 8 man survey team headed by Mr. Yutaka Ishiyama (EPDC) to Tunisia to conduct a feasibility study of the project for a period of 35 days from January 18 to February 21, 1978.

As a result, a feasibility study report has now been completed for submission to the Tunisian Government.

I hope this report will prove to be useful to the long range electric power development of Republic of Tunisia and will contribute to its economic and social development and to the deeping of friendly relations between our two countries.

I wish to express my sincere thanks to the persons concerned of the Tunisian Government and the Société Tunisienne de l'Électricité et du Gaz (STEG), for they so kindly extended to the Japanese study teams.

November, 1978

Shisaku Hogen
President
Japan Internatinal Cooperation Agency

LETTER OF TRANSMITTAL

Mr. Shinsaku Hogen
President
Japan International Cooperation Agency

Dear Sir:

Submitted herewith is a Feasibility Report on the Kasseb Pumped-Storage Power Generation Project in the Republic of Tunisia.

In the Republic of Tunisia, power generation, transmission and distribution for the entire country is being performed by Société Tunisienne de l'Electricité et du Gaz (STEG), and the power stations of the country, with the exception of a number of remote locations, are connected by 150 kV and 90 kV transmission lines (with 225 kV trunk transmission lines presently being constructed). The power system is still of small scale, and the firm outputs of power stations of the entire country as of the end of March 1978 were 190 MW for steam power stations, 210 MW for diesel power stations, and 20 MW for hydroelectric power stations, or only a total of approximately 420 MW, but with the Socio-Economic Development Plan of the Government as a background, electric power demand is indicating a growth rate of approximately 12% annually, and it is estimated that 10 years from now peak power demand will exceed 1,000 MW.

With such a situation as the background, construction of Sousse Steam Power Station, 300 MW (150 MW × 2 units), 5 gas turbine power stations, 154 MW, and Sidi Salem Hydro-electric Power Station, 36 MW (firm output 20 MW), a total of 747 MW in firm output, is being carried out within the framework of the Fifth Socio-Economic Development plan (1977-1981) currently under way, but it is thought necessary for a base load steam power station of 150 MW to be further constructed around 1983.

Meanwhile, the daily load curve in Tunisia shows a ratio of peak load of 2 to off-peak load of 1. It was because of this that the concept for materialization of the Kasseb Pumped-Storage Power Generation Project was brought up to cope with the rapidly increasing power demand during peak hours and to make effective steam power station facilities for base load operation.

Beside the fact that Kasseb Pumped-Storage Power Station will have the merits in performance of being capable of coping most rapidly with load variations during peak hours, the 225 kV transmission lines to be constructed between Kasseb and M'Nihla, and Tajerouine as part of this Project will contribute greatly to improvement in stability and reliability of the national power transmission network. In comparison of a gas turbine project considered as an alternative with the Kasseb Project, whereas the implementation of the former would necessitate an enormous additional investment for increasing gas supply pipeline facilities, the latter not only will require no such additional investment, but rather will raise the utility factor of gas pipelines and lead to reduction in the cost of supplying gas.

According to this present Report, two alternatives are studied for Kasseb Pumped-Storage Power Station in the form of an upstream alternative and a downstream alternative depending on the location of the outlet, but the ultimete output is planned in both cases for 350 MW with start of operation scheduled to be made in stages from 1985 to 1989. Regarding the total construction cost including transmission line and substation facilities, it is estimated that the upstream alternative will cost 81.3 million Dinars (472 hundred million yen in Japanese currency), and the downstream alternative 92.7 million Dinars (538 hundred million yen). The total construction cost in this case will correspond to approximately double that for alternative gas turbines, but when future increases in commodity prices are considered, and the service life of 50 years which is more than 3 times that of gas turbine is taken into account, it may be concluded that Kasseb Pumped-Storage Power Station will be economically more advantageous than gas turbine. Further, in the case of the Kasseb Project, the civil work construction cost expended in domestic currency will, along with raising the technological level of Tunisia, contribute to future growth in GNP through infinite cycles of reinvestment.

Field investigations for this Project were carried out jointly from January 18 to February 21, 1978 with the dedicated cooperation of the technical staff of STEG. During this period, with the cooperation of the Ministry of Agriculture, the Ministry of Construction, the Ministry of Planning, the Ministry of Mining and Energy, and the Water Supply Corporation (SONEDE) of the Tunisian Government and others, it was possible to obtain various data and information needed for planning to a more or less satisfactory degree.

It is wished to express our heartfelt gratitude to all those persons concerned at the various agencies of Tunisia mentioned above, and to the Japanese Embassy in Tunisia, the Ministry of International Trade and Industry, and the Ministry of Foreign Affairs for their untiring and magnificent assistance during the period of investigation.

Yours faithfully,

November 1978

Yutaka Ishiyama

Yutaka Ishiyama, Chief
Mission for Kasseb
Pumped-Storage Project

INTRODUCTION

I. PURPOSES OF INVESTIGATION

The economy of Tunisia, through a number of aggressive socio-economic development plans since independence, has been showing steady progress in development. Development of electric power which comprises an important basis for economic growth is being carried out by Société Tunisienne de l'Electricité et du Gaz (STEG), and the electric power demand during peak hours which is showing rapid growth annually, is estimated to reach approximately 1,000 MW around 1985 to 1986. In order to meet this peak demand, STEG had conceived of the Kasseb Pumped-Storage Power Generation Project, and preliminary investigations had been carried out.

This present study, based on the request of the Government of the Republic of Tunisia, concerns examination of existing data on the Kasseb Pumped-Storage Power Generation Project and collection of supplemental data and information through field investigations to carry out a feasibility study of the Project.

II AUTHORIZATION AND HISTORY

Preliminary studies for this Project had been carried out by STEG since 1972, and at the request of STEG, MECASOL of France made a geological survey, and in 1974-1975, TECSULT International of Canada prepared a preliminary design for the Project and submitted a report.

As a result of examination of these past studies, the Government of the Republic of Tunisia requested the Government of Japan in July 1976 to conduct a Feasibility Study of the Project. The Japanese Government, on receiving the request, examined the existing reports, and as a result, and with the understanding of the Tunisian side, made a study of the entire scope of the electric power development program of Tunisia as a first stage, seeking out the position that the Kasseb Pumped-Storage power Generation Project would occupy in the program, following which, a Feasibility Study was made as a second stage.

The First Survey Team carried out field investigations from February 10 to March 5, 1977, and in October of the same year, a " The Republic of Tunisia - Report on Electric Power Development Plan" was prepared. This report was submitted to the Tunisian Government and STEG the same month through the Embassy of Japan in Tunisia.

The Second Survey Team carried out field surface reconnaissances, collected required data, and held discussions with STEG and other agencies concerned for a period of 35 days from January 18 to February 21, 1978. This present Report was prepared in Japan based on the above investigations, and it should be added that the cooperation and assistance of the engineers concerned of the Construction Department, Power Generation Department and the Economic Investigation Department as STEG Headquarters were extremely helpful in completion of the Report.

The Second Survey Team was comprised of 8 specialists, whose names and assignments are as given below.

Yutaka Ishiyama, Chief, EPDC, Civil Engineering

Tetsuro Kobayashi, EPDC, Economics

Kazuo Nakagawa, EPDC, Civil Engineering

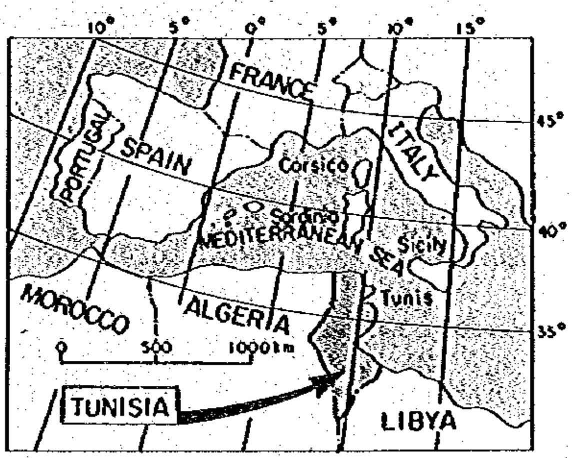
Katsue Iino, EPDC, Civil Engineering

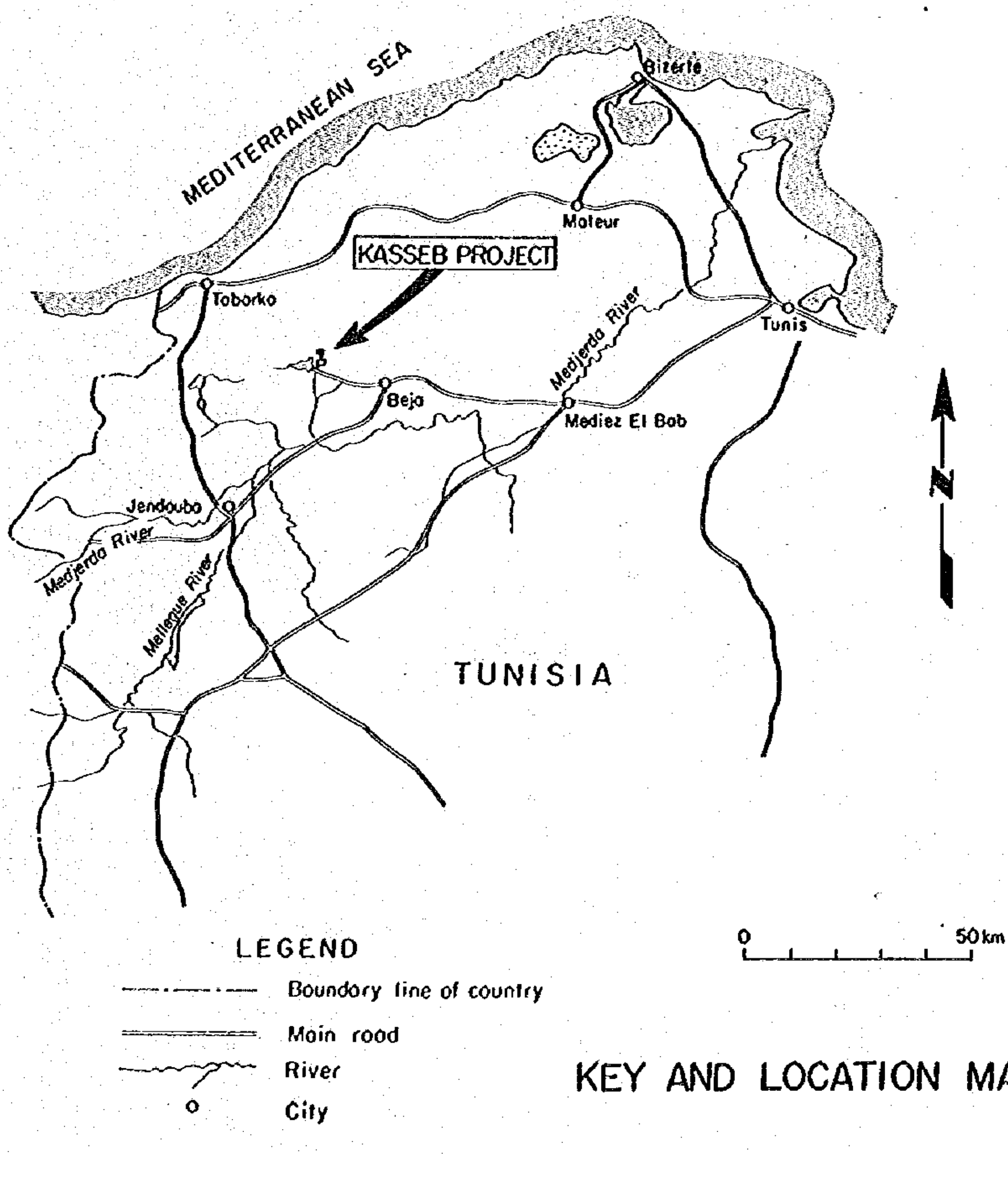
Masahiro Shibata, EPDC, Geology

Tatsuo Tomabechi, EPDC, Power Transmission

Katsuhiko Yamamoto, EPDC, Electrical Engineering

Mitsuru Suemori, JICA, Coordinating





KEY AND LOCATION MAP

CONTENTS

CHAPTER 1. OUTLINE OF PROJECT

CHAPTER 1 OUTLINE OF PROJECT

1.1 PUMPED-STORAGE POWER STATION

1.1.1 Planning

The Project Area is situated approximately 20 km northwest of Beja, approximately 100 km west of the capital Tunis. The pumped-storage power station would unilize the reservoir of the existing Kasseb Dam as its lower reservoir, while a reservoir made by constructing a fill-type dam in a gorge between Djebel Bou Sattar and Djebel El Fahama would be utilized as the upper reservoir.

The upper reservoir, because of the relation with saddle (geological investigations incompleted) at its south part of elevation of 435 m,is considered to have a limit 430 m as the high water surface level.
The minimum elevation of the reservoir is approximately 400 m but in consideration of deposit from the marl layers of the slopes accompanying water level fluctuations due to pump-up and power generation, the minimum water level of the reservoir is planned at an elevation of 412 m. The effective storage capacity in case of high water level at El. 430 m and low water level at El. 412 m will be 5.04 million m^3.

The existing Kasseb Reservoir which is the lower reservoir has a high water level at El. 288.6 m and this dam is being managed by Tunisian Water Supply Corporation (SONEDE) as a water supply dam, with the water supplied at constant 1.25 m/sec as standard, but hereafter, it is planned for 1.40 m^3/sec to be supplied.

According to our examination based on the hydrological data (18-year period from 1943 to 1961) used by the Soviet Union in the feasibility study for the existing Kasseb Dam of catchment area of 101.0 km^2, average annual precipitation of approximately 800 mm, annual inflow of 45.1 million m^3 and total storage of approximately 76 million m^3, the maximum drop in water level from high water level will be 12.7 m. Therefore, adding an allowance in depth of 2.3 m the lower reservoir available drowdown for the Kasseb Pumped-Storage Power Generation Project was set at 15 m. Further, in carrying out design, it was decided to design also for the case of available drawdown of 20 m as previously set.

As for the catchment area of the upper reservoir, it is only 1.3 km^2 and although there is one narrow steam flowing down, the annual inflow is a small quantity of 1.04 million m^3, and this will be ignored in the power generation plan.

Regarding the location of the outlets, in past studies a proposal for providing them at a gentle slope of 10° to 15° at a point of the left bank upstream from the existing Kasseb Dam had been adopted, but at this location sedimentation mainly from the El Brik River will be of concern. Therefore, it was decided to study two alternatives, adding a location approximately 800 m downstream from the first one at a slope of approximately 45°. They will be named respectively Upstream Alternative and Downstream Alternative.

Based on the above topographical and hydrological conditions, and in addition, taking into consideration the duration of peaking time of approximately 4 hours, the pumped-storage power generation plan for the Kasseb site will be the following.

Tableau 1-1 CARACTERISTIQUES GENERALES

Item	Variante amont	Variante aval	Variante aval (Référence)
Marnage dans le réservoir inférieur	15 m	15 m	20 m
Réservoir supérieur (cote NGT)			
Retenue normale	430 m	430 m	430 m
Niveau minimum d'eau	412 m	412 m	412 m
Niveau d'eau moyen pondéré	424 m	424 m	424 m
Réservoir inférieur (cote NGT)			
Retenue normale	288,6 m	288,6 m	288,6 m
Niveau minimum d'eau	273,6 m	273,6 m	268,6 m
Niveau d'eau moyen pondéré	281,0 m	281,0 m	281,0 m
Hauteur de chute nette pondérée	137,4 m	134,5 m	134,5 m
Débit équipé maximum	304 m^3/sec	310 m^3/sec	310 m^3/sec
Puissance totale installée	350 MW	350 MW	350 MW

1.1.2 Geological Conditions

The bedrock of the dam site on the left-bank side from upstream to downstream consists of outcropped marl, alternations of limestone and marl, and limestone, while on the right-bank side a marl layer is distributed. As for the vicinity of the dam axis marl is predominantly distributed.

The reservoir area consists mostly of cultivated fields, with topsoil and a plastic gravel-bearing clay layer distributed to a thickness of 0.5 to 3.5 m. These will serve as a kind of blanket against permeability. Further, at the right-bank side, it is estimated that a fault exists roughly perpendicular to the dam axis.

1.1.3 Main Structuer

The headrace tunnels will pass through a limestone formation comprising the nucleus of the El Fahama mountain mass to reach the powerhouse area, and on both sides of this formation there are alternations of marl and limestone. Although it would be possible for powerhouse excavation to be performed in these alternations, the geological conditions are inferior to the limestone formation, and the powerhouse structure should be built in the limestone formation as far as practicable. In any event, the powerhouse will be an underground type because of the topographical and geological conditions.

The tailraces, in case of the upstream alternative, will pass through marl, and a according to results of boring investigations up to now there are pressurized ground water layers at places added to which the rock character is soft, so that in excavation work it will be necessary for extreme care to be taken in preventing loosening of the tunnel walls. In the case of the downstream alternative, the tailraces would pass inside the west skirt of Djebel El Fahama, in which case, while avoiding contact with the marl formation, it will be necessary to be careful of misalignment due to faulting. Further, at the outlet site of the downstream alternative the strata indicate strikes and dips which are roughly parallel to the slope, and in excavation work it will be necessary to be careful of exfoliation sliding along bedding planes.

The powerhouse equipment is planned for a 75MW group of two units, and 100MW group of two units, a total of 350 MW. The motor-generators are to be of semi-umbrella type, with input of pump-turbines being 90 MW for the 75MW unit and 120 MW for the 100 MW unit. The main transformers are to be of 3-phase, indoor, forced-oil, water-cooled type and are to be installed inside the powerhouse similarly to the main equipment. Control of generators is to be by a one-man control system, and remote operation is to be done from a distribution panel room provided adjacent to the outdoor switchyard.

1.2 TRANSMISSION LINES

Transmission lines are to be constructed from Kasseb Power Station to M'Nihla Substation, 225 kV, 1 circuit, 110 km, and from Kasseb to Tajerouine Substation, 225 kV, 1 circuit, 120 km. The conductor is to be ACSR 410 mm^2, overhead ground wire is to be 70-mm^2 zinc coated wire, and insulators are to be ∅254, 12-string suspension insulators. Grounding is to be by a direct grounding system. Supports are to be single-circuit type steel towers.

If the transmission line between Kasseb and M'Nihla were to be planned for double-circuit the construction cost would be considerably reduced, but for stability of supply and improving reliability of transmission lines the M'Nihla - Kasseb - Tajerouine route was selected, and interconnecting this with the 225kV line connecting M'Nihla - Oueslatia - Tajerouine, a 225kV grid will be completed for the northern region of Tunisia. Further, the telecommunication system is to be a power line carrier system.

1.3 TIME OF COMISSIONNING

This project will be developed in four steps as follows:

1st step	April, 1985	1st unit 75 MW
2nd step	January, 1986	2nd unit 75 MW
3rd step	January, 1988	3rd unit 100 MW
4th step	January, 1989	4th unit 100 MW

1.4 TOTAL CONSTRUCTION COST

The total construction cost of this Project (not including interest during construction) estimated as of March 1978 will be as follows:

Tableau 1-2 COUTS TOTAUX DES AMENAGEMENTS

(Milliers de Dinars)

Description	Variante amont	Variante aval
Centrale de pompage turbinage		
– Travaux de génie civil	29.670	41.575
– Matériel hydromécanique	13.403	11.914
– Appareillage électrique	23.337	23.337
Ligne de transport et les postes	7.517	7.517
Coûts directs	73.927	84.344
Ingénierie et administration	7.400	8.400
Coûts totaux des aménagements	81.327	92.744
Monnaie domestique	20.670	25.784
Devises étrangères	60.657	66.960
Coût unitaire de construction	232 DT/kW	265 DT/kW

In the previous report, it had been estimated that the total construction cost would be approximately 58,332,000 Dinars, but due to changing of the powerhouse to an underground type in consideration of the geological conditions, and detailed re-examination of the unit costs of civil works in view of economic conditions as of March 1978, the result of re-estimation was that there will be a fairly large increase in the total construction cost.

RESEAU DE TRANSPORT
SITUATION EN 1987

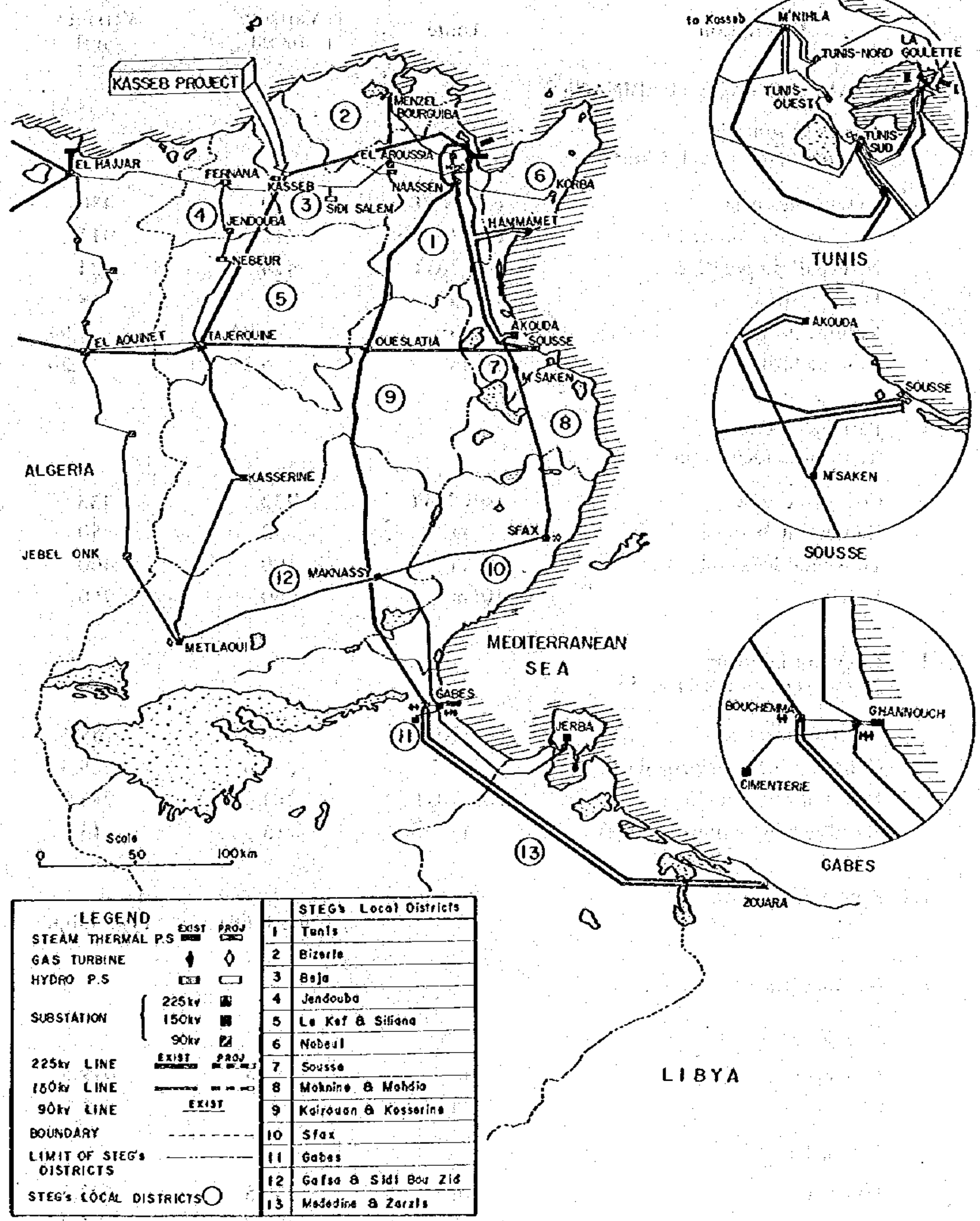


Tableau 1-3 CARACTERISTIQUES GENERALES

Description	Unité	Variante amont	Variante aval
1. CENTRALE POMPAGE TURBINAGE			
1.1 Réservoir supéieur (bassion versant de 1,3 km²)			
Retenue normale	cote NGT	430	430
Niveau minimum de l'eau	cote NGT	412	412
Niveau d'eau pondéré	cote NGT	424	424
Marnage utile	m	18	18
Volume utile	10^6 m³	5,04	5,04
Volume brut	10^6 m³	6,36	6,36
1.2 Barrage supérieur (type en enrochements)			
Cote de la crête	cote NGT	433	433
Hauteur du barrage	m	50	50
Longueur de la crête	m	400	400
Volume	10^3 m³	960	960
1.3 Réservoir inférieur (bassin versant de 101 km²)			
Retenue normale	cote NGT	288,6	288,6
Cote de grille de la prise d'eau		268,6	268,6
Niveau d'eau pondéré	cote NGT	281,0	281,0
Marnage adopté pour le projet	m	15	15
1.4 Prise d'eau amont		Type tulipe	Type tulipe
1.5 Galerie d'amenée			
Galerie No. 1			
Longueur	m	855,5	619,5
Diamètre	m	6	6
Galerie No. 2			
Longueur	m	854,5	627,5
Diamètre	m	6,7	6,7

Description	Unité	Variante amont	Variante aval
1.6 Conduite forcée			
Conduites No. 1 et No. 2			
Longueur	m	100	100
Diamètre	m	6 – 3,9	6 – 3,9
Conduites No. 3 et No. 4			
Longueur	m	100	100
Diamètre	m	6,7 – 4,5	6,7 – 4,5
1.7 Chambre d'équilibre			
Longueur	m		55,4 x 2
Diamètre	m		7 x 2
1.8 Galerie de fuite			
Tunnels de diffuseur Nos. 1 et 2			
Longueur	m	100	100
Diamètre	m	4,5 – 6,5	4,2 – 6
Tunnels de diffuseur Nos. 3 et 4			
Longueur	m	100	100
Diamètre	m	5,4 – 7,5	4,8 – 6,7
Galerie de fuite No. 1			
Longueur	m	390	1.761
Diamètre	m	6,5	6
Galerie de fuite No. 2			
Longueur	m	390	1.720
Diamètre	m	7,5	6,7
1.9 Prise d'eau aval			
Type		Type trompe d'entrée	Type caisson à air comprimé

Description	Unité	Variante amont	Variante aval
2.0 Appareillage électrique			
Pompe-turbine			
(type Francis réversible à axe vertical)			
Puissance x no.de groupe	kW	76.600 x 2	76.600 x 2
	kW	102.200 x 2	102.200 x 2
Vitesse de rotation	tr/mn	214,3	214,3
Débit équipé maximum	m^3/sec	304	310
Chut utile	m	137,4	134,5
Alternateur-moteur			
(type semi-parapluie à axe vertical)			
Puissance x no. de groupe	kVA	89.800 x 2	90.900 x 2
	kVA	119.400 x 2	120.400 x 2
Facteur de puissance	%	84	83
Tension	kV	13,2	13,2
Fréquence	Hz	50	50
Transformateur de puissance			
(type triphasé, à refroidissement par circulation d'huile dans les hydroréfrigérants)			
Puissance x no.	kVA	99.800 x 2	100.900 x 2
	kVA	129.400 x 2	130.400 x 2
Tension	kV/kV	13,2/225	13,2/225
Raccordement		Triphasé [△Y]	Triphasé [△Y]

2. LIGNE DE TRANSPORT

Ligne Kasseb – M'Nihila (110 km) et Ligne Kasseb – Tajerouine (120 km)

Tension	: 225 KV
Fréquence	: Triphasé 3 fils – 50 Hz
Conducteur	: Al-Ac 410 mm^2
Fil de terre	: Câble d'acier galvanisé – 70 mm^2
Isolateur	: Isolateurs de suspension à 12 pièces en série – ϕ254
Support	: Pylône métallique du type un terne

CHAPTER 2. CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 2 CONCLUSIONS AND RECOMMENDATIONS

This Feasibility Report has the purpose of arriving at conclusions on examination principally of the items below.

(a) Determination of timing of commissioning of Kasseb Pumped-Storage Power Station

(b) Determination of part of load to be supplied by Kasseb Power Station

(c) Determination of available drawdown of lower reservoir

(d) Determination of high water level of the upper reservoir and dam axis

(e) Examination of sedimentation and selection of outlet location.

(f) Determination of maximum output and unit capacity of power station

(g) Selection of type of pump-turbine and method of starting for pump-up

(h) Selection of transmission line routes

(i) Estimation of total construction cost

(j) Economic analysis

2.1 CONCLUSIONS

2.1.1 Optimum Power Supply Structure and Timing of Commissioning of Kasseb Power Station

As long-range predictions of power demand STEG has made three different predictions of upper limit, lower limit and average in "Le marché de l'Électricité à Moyen et Long Terme" of December 1977. These forecasts all reflect the Tunisian Government's Socio Economic Development Plan now in progress, and seen from the past trend of increase, they may be said to be normal forecasts. However, compared with the rapid growth up to 1986 (14.2% average annual growth rate for 1977 to 1981, 13.7% for 1981 to1986), after 1986 the rate has been estimated at a considerably low level as seen from international standards. (The average forecast for 1986 to 1990 is 8.4%, and that for 1991 to 1996 is 6.7%. Therefore, EPDC has made a separate demand forecast based on the correlation between GNP growth rate and power consumption growth rate, and the intermediate values between the values between the values obtained by EPDC (13.8% average annual growth rate for 1977 to 1981, 12.6% for 1981 to 1986, 11.2% for 1986 to 1991, and 10.4% for 1991 to 1996) and the average forecast values of STEG were used as the basis of study. The comparisons of the average values of STEG and the values adopted for the present study are as indicated in 1.1.1

Meanwhile, with respect to reserve capacity on the side of supply capability meet demand, it was concluded that when the 225 kV interconnection with Algeria is completed (scheduled for 1980), the system reserve capacity will not fall below 15% until 1989 if there were to be reserve capacity of 150 MW, and morever, there will be no trouble about supply capability even if the international interconnection line were to broken.

As for the optimum power supply structure considering the shape of the load curve, it was concluded that it should be the following:

1985-1990	Peak supply capability	30%
	Middle supply capability	10%
	Base supply capability	75%
After 1990:	Peak supply capability	40%
	Middle supply capability	-
	Base supply capability	75%

Considering the above demand forecast and optimum system structure, and examining the timing for commissioning of the power sources required after 1983, the following conclusions are obtained.

Tableau 2-1 PROGRAMME D'EQUIPEMENT PROPOSE EN MOYENS DE PRODUCTION

Mise en service	Centrale	Puissance	Exploitation
Juillet 1983	Thermique vapeur "X"	150 MW	Base
Avril 1985	1er groupe de Kasseb	75 MW	Pointe
Janvier 1986	2e groupe de Kasseb	75 MW	Pointe
Août 1986	Thermique vapeur "Y"	150 MW	Base
Janvier 1988	3e groupe de Kasseb	100 MW	Pointe
Janvier 1989	4e groupe de Kasseb	100 MW	Pointe
Janvier 1989	Thermique vapeur "Z"	150 MW	Base
Janvier 1990	Nucléaire (ou thermique vapeur)	300 MW	Base
Janvier 1991	Turbine à gaz	100 MW	Pointe
Janvier 1992	Turbine à gaz	100 MW	Pointe
Janvier 1993	Nucléaire (ou thermique vapeur)	300 MW	Base
Janvier 1994	Turbines à gaz	200 MW	Pointe

2.1.2 Operating Mode of Kasseb Power Station

When considering the mode of operation of Kasseb Power Station it is necessary for the availability of natural gas in Tunisia to be examined. As presently forecast, the domestic consumption which will be made possible by the Algeria-Tunisia-Italy gas pipeline is estimated to be from 600 to 2,000 million cubic meters, while further, development of natural gas offshore of Gabes (Miskar) is being planned, but it is not necessarily clear what will be the quantity of gas available from these sources for power generation. Consequently, the three cases below were assumed in this Study.

Case "X" Case of natural gas being available in sufficient quantity to satisfy domestic demand. In such case the price of natural gas will be equal to its cost of supply (25 DT/TEP).

Case "Z" Case of natural gas being available to satisfy only a part of domestic demand. In such case the cost of natural gas will be equal to the international price (35 DT/TEP) or the price of alternative heavy oil (similarly 35 DT/TEP). Further, in this case, gas turbines will probably use gas-oil (50 DT/TEP).

Case "Y" Case of applying the assumption that the marginal cost of natural gas used during midnight offpeak hours should be cheaper than the cost during peak hours (approximately 1/2 of supply cost in Case "X").

Considered from the standpoints of the three cases above, the sequences of power station commissioning will be the following:

Order	Case "X"	Cases "YZ"
1	Steam power station	Steam power station
2	Hydro power station	Hydro power station
3	Ghannouch II (existing GT using natural gas)	Ghannouch II
4	Bouchemma (existing GT using natural gas)	Bouchemma
5	Gas turbine under construction (TG "A" -using natural gas)	Kasseb Pumped-Storage Power Station
6	Kasseb Pumped-Storage Power Station	TG "A" (gas-oil used in these cases)
7	Additional gas turbine (TG "B" -using natural gas)	TG "B" (gas-oil used in these cases)

The outputs of Kasseb Power Station during the 10-year period from start of operation according to the above sequences will be the following:

Year	Case "X"		Cases "YZ"	
	Generation (MW)	Reserve (MW)	Generation (MW)	Reserve (MW)
1985	0	75	75	0
1986	0	150	71	79
1987	0	150	150	0
1988	63	187	250	0
1989	77	273	275	0
1990	0	350	133	217
1991	109	241	263	87
1992	229	121	350	0
1993	141	209	295	55
1994	350	0	350	0

2.1.3 Determination of Available Drawdown of Lower Reservoir

Based on the data for the 18 year period from 1943 to 1961, considering the discharge for water supply from this dam to be 1.40 m^3/sec throughout the year as planned by SONEDE, an analysis of water level variation during the 18 year period was made, and as a result, it was indicated that the maximum drop in water level from high water level would be 12.7 m. Consequently, considering some amount of allowance, the available drawdown of the lower reservoir was set at 15 m. Considering relation with previous reports, however, preliminary designs and estimates of construction cost have been made in this Report for the two cases of available drawdowns of 15 m and 20 m.

2.1.4 Determination of High Water Level of Upper Reservoir and Dam Axis

In the vicinity of the right-bank abutment of the damsite there is a wide distribution of thick colluvial deposits containing conglomerate blocks hardened by limestone elements, and according to Borehole SB-4 these deposits reach to a depth as much as 15 m. Consequently, it was decided to move the dam axis upstream as much as practicable to come close to the roughly connecting SB-1, SB-2, SB-8 and SB-3.

In the reservoir area, there is a saddle at El. 433 m south of the upper reservoir, and up to now there has been no geological investigation made on this saddle. Because of this the high water level of the upper reservoir was set at El. 430 m. The entire reservoir area is covered by overburden comprised mostly of plastic clay and underlying cohesive marl, while topographically, between El. 400 m (bottom-most part of reservoir) and El. 410 m the storage capacity is comparatively small. Consequently, considering this topographical condition and the risk of sedimentation from marl layers at the slope due to large daily fluctuations in water level, and with some allowance taken into account, the low water level of the upper reservoir was set at El. 412 m.

2.1.5 Examination of Sedimentation and Selection of Outlet Location

In the past studies in Tunisia, the outlet location was selected at the left-bank side 1.55 km upstream of the existing Kasseb Dam at a gentle slope of 10° to 15°, but this site is close to the mouth of the El Brik River, while outlet bed height (in the 15 m available drawdown proposal) would be of equal bed-height with the original river bed, and it is thought there will be great risk of burying of the outlets due to sedimentation. Since measurements of sedimentation at the Kasseb lower reservoir where water impoundment was started in 1969 have not yet been made, it is not possible to make a quantitative judgement at this time, but in consideration of the sedimentation measurement data at several other reservoirs in Tunisia, sedimentation is considered to be a big problem in this reservoir. Consequently, in case this location is to be made the outlet site, it will be necessary for appropriate sedimentation countermeasures to be taken in order to prevent outlet burying.

Contrasted to the above Upstream Alternative, a Downstream Alternative where the outlet location would be approximately 800 m downstream at a 45° slope was considered, in which case concern over sedimentation can be completely eliminated. Regarding the powerhouse location, there will be a slight difference between the upstream and downstream proposals, but in either case, the powerhouse is to be provided in the lime-stone formation which comprises the nucleus of the El Fahama mountain mass. In the case of the Upstream Alternative, it will not be necessary to provide surge chambers, but in case of the Downstream Alternative, surge chambers must be provided part way along the tailraces.

Total construction cost of Downstream Alternative is, however, about 14% higher than that of Upstream Alternative.

2.1.6 Maximum Output and Unit Capacity

Comparative studies were made of the three proposals of maximum output of 350 MW, 300 MW and 250 MW, with peak duration time of approximately 4 hours, and it was judged that the 350 MW proposal would be the most advantageous.

Next, with respect to unit capacity, it is needless to say that unit cost per kW will be lower the larger the capacity, but in this case it must be determined considering harmony with the system (frequency variation) mainly during pump-up. Unit capacities of 75 MW for the No. 1 and No.2 units and 100 MW for the No. 3 and No.4 units were adopted for Kasseb Power Station, and it was confirmed that so long as the international interconnection line with Algeria is functioning the system frequency drop during starting of pump-up will be held within 0.5 Hz at all times. Further, in case the above interconnection line should be disconnected, if the frequency of the STEG power System were to be raised 0.5 Hz beforehand, it will be possible to hold frequency variation at the time of pump-up to 50.5 Hz to 49.43 Hz, and it is thought there will be no serious throuble caused customers with this degree of variation. In case the unit capacity of the No. 1 Unit is made large, for example, 100 MW, the frequency drop will greatly exceed 1.0 Hz, and not only will there be adverse effects to customers, but there will be a risk of a situation arising of the baseload thermal group completely stepping out. Consequently, it is considered that a reasonable arrangement will be unit capacities of 75 MW for the No. 1 and No. 2 units, and 100 MW for the No. 3 and No. 4 units.

2.1.7 Type of Pump-Turbine and Pump-up Starting System

The type of pump-turbine to be adopted is a reversible, vertical shaft Francis turbine. Other than this type, it would be possible for a diagonal-flow pump-turbine to be used, but the cost would be higher than the former, while the mechanical structure and control system will both be complex so that the former is to be adopted.

There are the following systems for starting pump-turbines for pumping:

- Control winding starting system
- Directly-coupled motor starting system
- Synchronised starting system
- Thyrister starting system

As a result of economic comparisons of the above systems, it was decided in this Study that a starting system employing starting motors should be adopted. With this system, in order to alleviate resistance torque of the pump-turbine at the time of starting the motor, adequate compressed air is to be injected into the draft tube to lower the water level and start the turbine.

2.1.8 Selection of Transmission Line Routes

The STEG Power System as of March 1978 was being operated at the three standard voltages of 225 kV, 150 kv and 90 kV, the greater part consisting of a 150 kV line covering the entire country in the form of a loop. At present, however, work is under way to extend the existing Ghannouch-Maknassy 225 kV line (constructed for 225 kV and being operated at 150 kV) to Naassen Substation, while 225 kV lines for Sousse-Oueslatia-Tajerouine and for Sousse-Naassen-M'Nihla are also under construction, and from around 1980 the power generated at Sousse Steam Thermal Power Station will be transmitted to load areas by these transmission lines.

In consideration of the above situation, for the route of the 225 kV transmission line appurtenant to the Kasseb Project, instead of the alternative of a double-circuit line between Kasseb and M'Nihla, the alternative of single circuit between Kasseb and M'Nihla and between Kasseb and Tajerouine was adopted. By doing so, the power transmission system of the northern part of Tunisia will become a strong grid system of 225 kV lines, and the reliability will be greatly improved.

2.1.9 Economics

It is needless to say that the initial investment for the Kasseb Pumped-Storage Power Generation Project will be larger than for an alternative gas turbine project. A comparison of the total construction costs of the two including appurtenant transmission lines, substation facilities, engineering fee and STEG administrative expenses would be as follows:

Item	Total Construction Cost (1000 DT)	Unit Construction Cost (DT/kW)
Kasseb Project		
-Upstream Alternative	81,328	232
-Downstream Alternative	92,745	265
Alternative Gas Turbine	49,228	124

However, in an economic comparison of the two, it will be necessary to note the difference in the costs of fuel used due to the difference in operating systems, and the greater influence of commodity price escalation on the gas turbine project of shorter service life (and consequently, more frequent equipment renewal).

- The pumping power for Kasseb Power Station will be supplied by Sousse Steam Thermal Power Station, and by the time Kasseb Power Station starts operation, it is thought both Sousse Steam Thermal Power Station and gas turbine power stations will be utilizing natural gas. In this case, in considering the cost of supplying natural gas, the capacity of the gas pipeline would be designed and constructed to handle the size of demand at the peak of gas consumption, and the more that the demand for gas at peak hours increases beyond the capacity of the pipeline, the more additional capital investment will be required, and the supply cost will be raised. In contrast, the more that gas demand increases during off-peak hours in the middle of the night, the higher will be the equipment utility factor to make the supply cost comparatively cheap. Therefore, the pumping power for Kasseb which will be generated during offpeak hours in the middle of the night will naturally be cheaper than the power of alternative gas turbine power stations which would be additionally operated for power generation at lighting time peaks.
- Meanwhile, although the problem of commodity price escalation is nothing new today, in recent years with the rapid increase in demand for finite resources such as petroleum, coal, natural gas, etc., the matter of inflation has become extremely serious. On looking at the world trend in construction prices, even during the period around 1950 when the economic situation was relatively quiet, prices rose at a rate of 5% annually in the U.S.A., while during the period of 1970 to 1977 including the oil crisis, practically every country in the world recorded price escalations averageing at least 7 to 10% annually. Consequently, for an economic comparison between two projects with differing equipment service lives to be realistic, it would be appropriate to take into account future rises in commodity prices, and in fact it is not realistic to assume that future costs of operation and maintenance and of equipment renewal will be the same as at present.
- The evaluation of a project would generally be done through the rate of internal return for the said project and the social discount rate normally applied in that

country, but such a social discount rate has not been set for Tunisia. However, judged from long-term interest rates of international financing institutions, it would be permissible to consider an annual rate from 8 to 10% as a standard.

As a result of economic analysis taking the above matters into consideration, the following conclusions were obtained on the Kasseb Pumped-Storage Power Generation Project:

(1) Case of Price Adjustments for Midnight Gas and Peaking Time Gas (It should be noted that the adjustment ratio is taken to be 1 : 2 in this Report, whereas the ratio of STEG for high-pressure general charges is 1:3.7-6 millime/kWh versus 22 millime/kWh)

So long as the annual commodity proce escalation rate continues at 2.3% or more in case of the Upstream Alternative of the Kasseb Project, and at 3.4% or more in case of the Downstream Alternative, the respective internal rates of return will be 8% or more, and the Kasseb Project will be more economical than the gas turbine project.

(2) Case of Assuming Cost of Gas Supply Equal for Both Offpeak and Peak, and of Power Cost Also Equal (Although not realistic)
So long as the annual commodity price escalation rate continues at 4.7% or more in case of the Upstream Alternative of the Kasseb Project, and at 5.8% or more in case of the Downstream Alternative, the respective internal rates of return will be 8% or more, and the Kasseb Project will be more economical than the gas turbine project. (Fig. 10.1,)

Although it is difficult to predict the rate at which commodity prices will actually rise in the future, judging from the fact that commodity price indices for manufactured goods in the U.S.A., West Germany, France and Japan have continued to rise at an average annual rate of 7.1% with 1970 as the basis, and that the World Bank, in its 1975 Report, has estimated commodity price increase rates up to 1987 as being 8-7% for machinery and equipment, 12-10% for civil works, and 10% for engineering, it should be permissible to consider that for a long time into the future price escalation at an annual rate of around 5-7% will continue.

Based on the above, it may be said that implementation of the Kasseb Pumped-Storage Power Generation Project will be adequately reasonable from an economic standpoint.

In view of the above circumstances, it is considered that the Kasseb Pumped-Storage Power Generation Project will be economically more advantageous compared with the alternative gas turbine project.

Designs of structures were rough in the previous report, and in estimation of the total construction cost the fact that there were many indeterminate factors was considered, and in economic analysis it was aimed only to obtain a rough outlook of the economics of the Kasseb Project.

In the economic analysis made under such circumstances (although the estimate of construction cost was on the relatively low side), since the internal rate of return was higher than 10% even when assuming commodity prices to be constant (benefit-cost ratio 1.06 in case of discount rate of 10%), further analysis - introduction of commodity price escalation - was omitted.

2.2 RECOMMENDATIONS

(1) Kasseb Pumped-Storage Power Station will not only be more advantageous economically than alternative gas turbines, but the civil works construction cost constituting approximately 55% of the construction cost will be disbursed inside Tunisia, while the level of the domestic construction technology will be substantially raised. Part of the expenditures in domestic currency will be retained as savings, and through infinite cycles of reinvestment, will be useful for building up future GNP. Therefore, it is desirable for this Project to be implemented so far as circumstances will permit.

(2) However, while the Project is judged as being advantageous economically in the long range, on the other hand, the initial investment is an enormous amount 14 times that of the alternative gas turbine project. The Kasseb Project as a power source for peak hours is a part of the overall investment plan of STEG including power generation, transmission, substation and other facilities, and whether this is to be implemented will of course be judged from the overall financial situation. Therefore, which of the Kasseb Project and the alternative gas turbine project is to be implemented should be determined based on an overall judgment of the financial situation of STEG in addition to long-range economy.

(3) In case implementation of the Kasseb Pumped-Storage Power Generation Project by STEG, since the outlet location in past studies will be seriously affected by sedimentation, the quantity of sedimentation in Kasseb Resservoir must be measured and investigated. It should be decided which of the Upstream Alternative and Downstream Alternative is to be adopted depending on the result of the investigation.

(4) When the STEG will decide to further carry out the investigation works for clarify the feasibility of the Project geological investigations and various tests must be carried out before starting on working designs to clarify the problematic points in design as have been pointed out on various parts of the Report. Preparation of detailed geological maps of the entire Project Area, proviking boreholes and test pits to find the permeability and bearing capacity of the dam foundation, boring and other measures to confirm the degree of watertightness of the reservoir and the condition of the foundation in the reservoir for the outlets should be done on a priority basis. Materials investigations should be carried out on core and fock materials through laboratory tests necessary for design.

CHAPTER 3. OPTIMUM ERECTRIC POWER DEVELOPMENT PROGRAM

CHAPTER 3 OPTIMUM ELECTRIC POWER DEVELOPMENT PROGRAM

3.1 BASIC CONDITIONS

3.1.1 Electric Power Development in Future Years

According to the electric power development program of STEG it is scheduled for 490 MW to be developed from 1977 to 1982, and with Sidi Salem Hydroelectric Power Station scheduled for start-up in November 1982, bidding for all projects has been completed and construction is going on. Therefore, the responsibility of the Survey Team was to formulate a plan for electric power development from 1983 and on taking into consideration existing power stations, power sources to be developed from 1977 to 1982, and the characteristics of demand, to determine the types of power sources to be developed and the sequence in which they should be developed.

A typical condition of daily load of the power system of STEG is as indicated in Fig. 3-1, and the ratios of peak, middle and base band-hours divided as an expediency are 28.5%, 7.5% and 64%, and it is considered that these ratios will not change for more than 10 years into the future. On dividing the power sources of STEG into peak, middle and base bands, the result will be as indicated in Table 3-1, and compared with the daily load curve of Fig. 3-1, the results will be as given below.

Graphique 3-1 COURBE DE CHARGE JOURNALIERE POUR LA DECENNIE 1981 - 1990

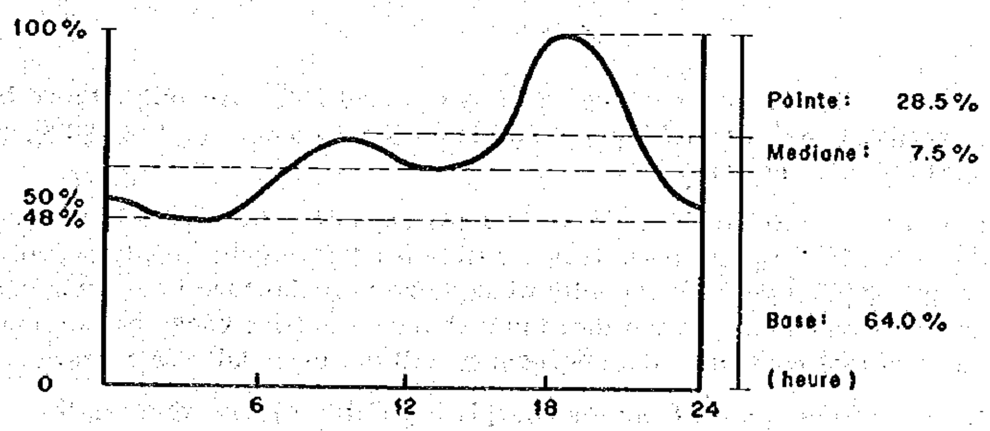


Tableau 3-1 REPARTITIONS DES MOYENS DE PRODUCTION A L'HORIZON 1982

Moyen de production		Puissance garantie (MW)	(%)	Rapport à la pointe (%)
Centrale de pointe				
– Centrales hydrauliques	(1)	40,0	4,8	6,7
– Turbines à gaz	(2)	198,0	23,4	33,0
Sous-total		238,0	28,2	39,7
Centrales médianes				
– Thermique vapeur moyenne	(3)	30,0	3,6	5,0
– Turbines à gaz (gaz naturel)	(4)	121,0	14,4	20,2
Sous-total		151,0	18,0	25,2
Centrales de base				
– Thermique vapeur nouvelle	(5)	300,0	35,6	50,0
– Thermique vapeur ancienne	(6)	153,0	18,2	25,5
Sous-total		453,0	53,8	75,5
Total		842,0	100,0	140,4

Note:
(1) Sidi Salem et 5 centrales existantes
(2) 22 MW x 9 unités
(3) La Goulette I
(4) Bouchemma et Ghannouch II
(5) Sousse
(6) Ghannouch I et La Goulette II

(a) It will suffice to have peaking capacity of about 29%. Actually, there is approximately 40% available, and this is quite adequate. (There is 28% against total effective power.)

(b) It will suffice to have middle load supply capacility of about 8%, but actually, there is 25%. In practice, it is possible for this middle supply capability to be operated as peaking capacity when there is a shortage in peaking capacity, and as base capacity when there is a shortage in base capacity, so that having more of this capability than necessary will not especially be a drawback.

(c) It will suffice to have base load supply capability of 64% whereas there is 76% and this may appear slightly excessive, but it includes the two units of Sousse which are of large capacity, and if there were to be outage of one of the units, the supply capability would be abruptly reduced to 59%. In effect, the appropriate ratio would be undercut.

With the above supply capability structure, there will of course be no problem until around 1982, but for securing the power for pump-up at Kasseb Pumped-Storage Power Station scheduled to be started up several years later, additional base supply capability will be required. The reason for this will be explained in detail in 3.2.1.

3.1.2 Reduction in Reserve Capacity through Interconnection

The power transmission plan of STEG in 1977 was greatly changed in 1978. In other words, the power system of STEG since its establishment had not been interconnected normally with adjoining Algeria and Libya. (However, there had been an agreement with Algeria that there would be interconnection by a two-circuit, 90-kV interconnecting line only in case of emergency.)

The plan has now been changed for interconnection at all times with Algeria from 1980 and with Libya from 1982, and STEG is carrying on concrete negotiations with the two countries. Moreover, these interconnections will be made at 225 kV, the maximum voltage in common for the three countries, and with a large interconnected capacity there will be merits for all parties such as savings in reserve capacity for the electric enterprises of these countries.

It will be described here what considerations were given in reducing the reserve capacity of STEG.

The following are the concepts with respect to the extent of reserve capacity that STEG should possess.

(1) Concept of Owning Maximum Reserve Capacity Permissible

This concept is that of owning a large reserve capacity even after the international interconnection lines with Algeria and Libya have gone into operation.

(a) In case of step-out of power sources within STEG this would be handled within STEG and emergency interchange is not to be received from other countries so far as possible.

(b) Considerations are to be given so that it will be of no concern whenever and for whatever reason the international interconnection lines should be cut off.

This concept considers the merits of interconnected transmission lines to be

(i) Emergency interchanges at times of infrequent large faults (large scale faults, double faults, etc.)
(ii) Instantaneous short-time interchange power when starting pump-up machinery,

and the thinking is not to look forward to very much effect from the interconnection lines. With such thinking, it will be necessary for reserve capacity of about 20%, the same as before interconnection.

(2) Concept of Owning Minimum Reserve Capacity Permissible

This concept is that of making use of the interconnection lines to the fullest extent and keeping reserve capacity owned by STEG to a minimum degree. In other words,

(a) When the largest unit in the STEG system steps out, the shortage is to be filled by receiving power in the form of interchange from Algeria and Libya. The scale of the Algerian system is approximately 3 times that of STEG, and if the reserve capacity ratio were to be 20%, the reserve capacity would be approximately 520 MW (870 MW x 3 x 0.2 = 522 MW), and even if it were to be assumed that there is no reserve capacity at all on the Tunisian side, demand and supply balance aggregating the two systems will be amply maintained while there would still be the reserve capacity of Libya.

(b) The capacity of the interconnected lines, when considering only Algeria ultimately, with 225 kV, 2 circuits, there would be 370 MW even if the capacity were to be estimated conservatively at 1.5 times a single circuit, and there would be a capacity of approximately 43% of the maximum demand of 870 MW of STEG at the end of 1985. The aim would be to heighten the utility factor of such a large-capacity interconnected line (the construction cost of which accordingly will be high), as much as possible.

If the reserve capacity ratio of STEG were to be estimated tentatively on the low side from the above thinking, this would correspond to a reserve capacity of approximately 44 MW at the end of 1985, and in case of step-out of a maximum-capacity unit of 150 MW, there would be a necessity for a net interchange power flow of 106 MW.

(3) Appropriate Reserve Capacity

As mentioned before, to possess a reserve capacity of 20% according to past criteria and in addition to construct interconnecting transmission lines would mean excessive investment, and the effects of these transmission lines would be extremely small.

On the other hand, with reserve capacity of 5% the frequency and duration of emergency interchange through the interconnected lines would be great, and it is thought the effects on interconnected Algeria and Libya will be considerable.

Consequently, the development plan was formulated with 150 MW as the appropriate reserve capacity up to 1989. This 150 MW, in effect, is the capacity of the largest unit in STEG, and this would mean that there would be no trouble caused to the other countries. In terms of reserve capacity ratio, it will not be lower than 15% at least until the end of 1989. In other words, the criteria of STEG for reserve capacity of 20% before interconnection will be reduced to 15% through interconnection. (See Fig. 3.5, Ratios of Base, Middle and Peak Supply Capabilities.)

3.1.3 Retirement Forecast of Thermal Power Generation Facilities

In formulation of an electric power development plan, it is necessary to determine the plan while considering the retirement of existing power generation facilities from the power system due to antiquation. With regard to this matter, the Survey Team, upon studies together with STEG, considered that the thermal power generation facilities indicated in Table 3.2 would be retired due to antiquation.

Regarding when these would be retired, it was considered that gas turbines would be taken out at the end of their serviceable lives according to their operating conditions, while for steam thermal stations, they would be retired in succession from 1983 after 3 steam thermal units of 150 MW become ready for operation. As a result, gas turbines for base supply after being used for 15 years, for peak supply for 15 years, and steam thermal after 25 years would be retired considering them to have been fully operated. (See 10.2.4(2) of Chapter 10.) However, it was considered that Ghannouch gas turbine generators (2 x 22 MW) only would have a service life of 16 years with retirement after the Kasseb No. 3 and No. 4 units, which are similarly peaking power sources, have been completed.

Tableau 3-2 CALENDRIER DE LA MISE HORS DE SERVICE DES CENTRALES THERMIQUES

Centrale	Groupe	Puissance garantie (MW)	Mise en service	Date de mise en retraite	Durée de service (ans)
La Goulette I	TV 1-4	30	1931–54	Juillet 1983	
Ghannouch II	TG 1	15	1971	Août 1986	15
Ghannouch II	TG 2 et 3	44	1973	Janvier 1989	16
La Goulette II	TV 1 et 2	48	1965	Janvier 1990	25
Tunis-sud	TG 1 et 2	44	Jan. 1975	Janvier 1990	15

3.2 OPTIMUM ELECTRIC POWER DEVELOPMENT PLAN

3.2.1 Development Schedule

As described in 3.1, when unit capacities of thermal, differentiation between base and peak, necessary reserve capacity, retirement of facilities are considered as a whole, the development plan would naturally become limited.

The optimum electric power development schedule would be as shown below.

(1) In case that Kasseb project is realized

Tableau 3-3 PROGRAMME D'EQUIPEMENT PROPOSE POUR LA PERIODE 1983 - 1989

Mise en service	Centrale	Puissance (MW)	Mode d'exploitation
Juillet 1983	Thermique vapeur "X"	150,0	Base
Avril 1985	1er groupe de Kasseb	75,0	Pointe
Janvier 1986	2e groupe de Kasseb	75,0	Pointe
Août 1986	Thermique vapeur "Y"	150,0	Base
Janvier 1988	3e groupe de Kasseb	100,0	Pointe
Janvier 1989	4e groupe de Kasseb	100,0	Pointe
Janvier 1989	Thermique vapeur "Z"	150,0	Base
	Sous-total	800.0 MW	
Janvier 1990	Nucléaire (ou thermique)	300,0	Base
Janvier 1991	Turbine à gaz	100,0	Pointe
Janvier 1992	Turbine à gaz	100,0	Pointe
Janvier 1993	Nucléaire (ou thermique)	300,0	Base
Janvier 1994	Turbine à gaz	200,0	Pointe
	Sous-total	1.000,0 MW	
	Grand-total	1.800,0 MW	

(2) In case that Kasseb project will not be realized

In this case gas turbines must be installed. The development schedule and installation places considering system operation in the years 1985÷1990 and the proposed gas pipeline would be the following:

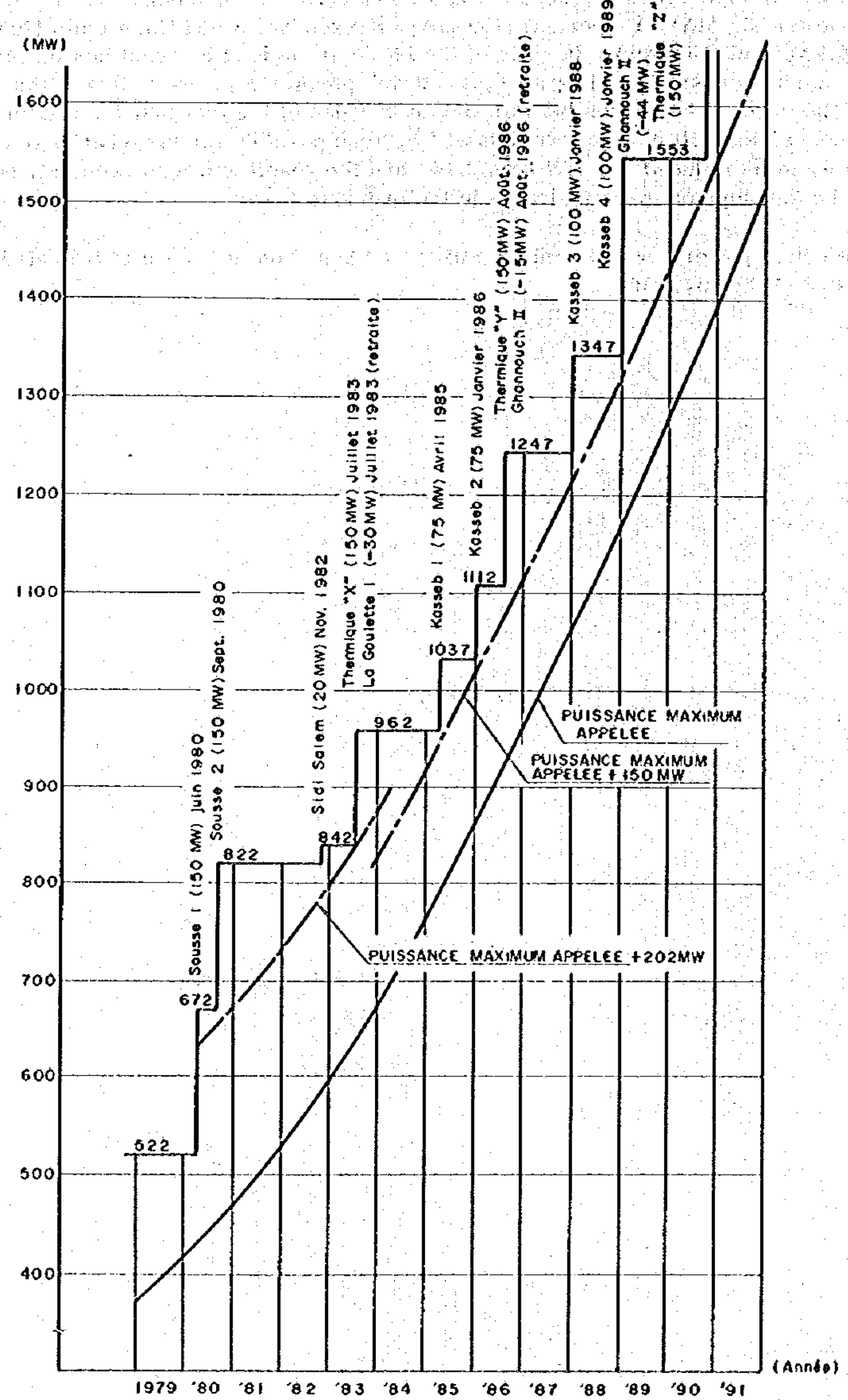
Date of commissioning	Installed capacity	Installation place
April 19859	76 MW x 1 unit	Goulette I
January 1986	76 MW x 1 unit	Sfax
January 1988	76 MW x 2 units	Sfax and Goulette I
January 1989	76 MW x 2 units	Metlaoui and Goulette I
Total	456 MW (6 units)	

If Kasseb project will be realized, the electric power development from 1983 to 1989 would be 800 MW of which there would be the peaking power source of Kasseb for 350 MW, but after 1983, base and peak supply capabilities would alternately be commissioned in roughly equivalent amounts.

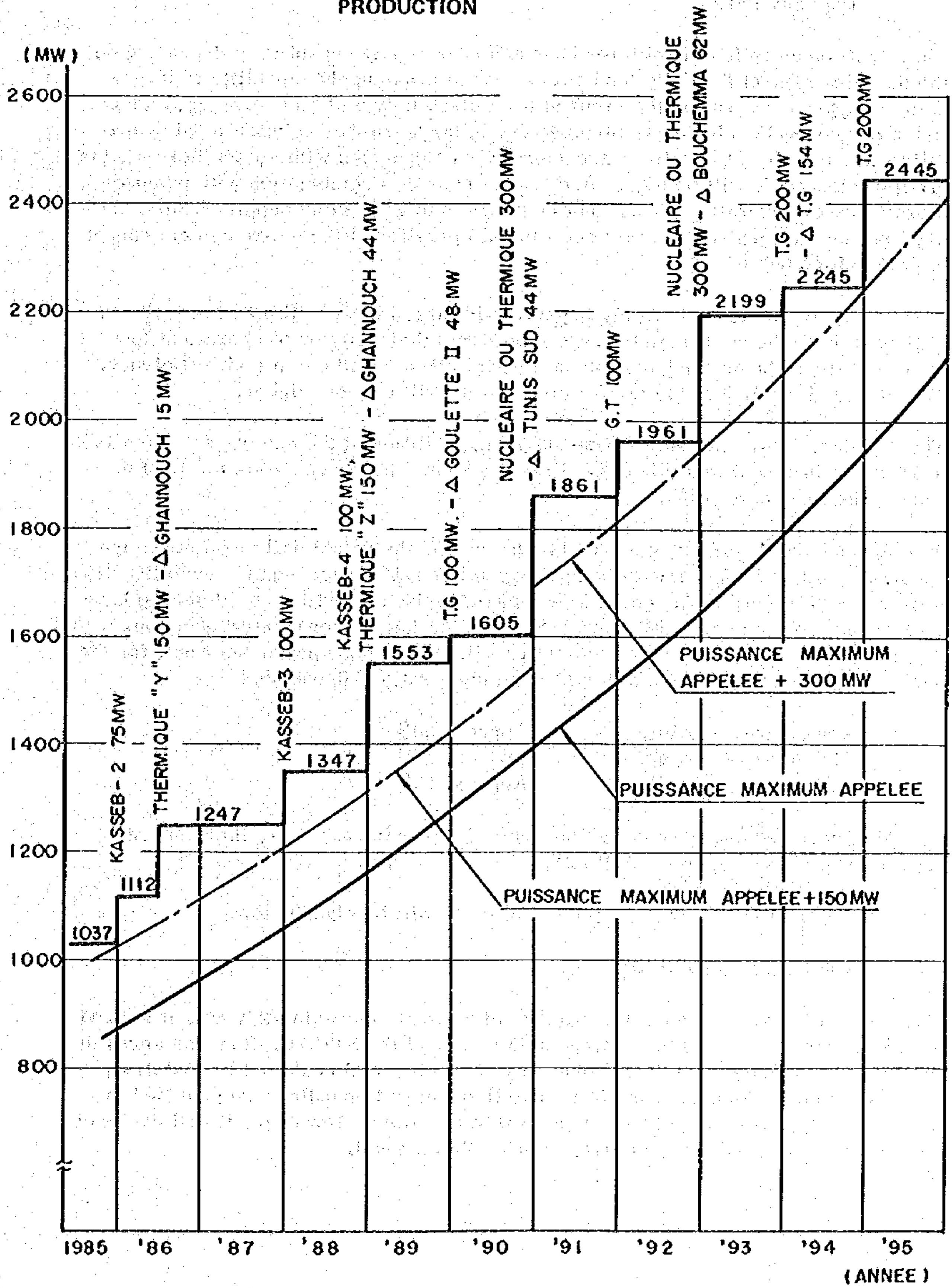
With respect to the sequence of electric power development, base thermal and peak hydro are to be developed in roughly equal capacities after the Sousse No. 1 and No. 2 units, in alternate sequence of X Thermal (150 MW), Kasseb No. 1 and No. 2 units (total 150 MW), Y Thermal (150 MW), Kasseb No. 3 and No. 4 units (200 MW), and Z Thermal (150 MW). In spite of the fact that the load forecast has increased, there is no necessity for stepping up the development tempo above that of the previous case. The reason for this is that because of the fact that international interconnection will now be made, it will become possible for the STEG's reserve capacity to be reduced 150 MW from 20%, and the result will approximately coincide with the development pace indicated in the previous case.

The electric power development plan prepared based on the above is indicated in Fig. 3.2 (A) and 3.2 (B)

Graphique 3-2 (A) PROGRAMME D'EQUIPEMENT EN MOYENS DE PRODUCTION



Graphique 3-2 (B) PROGRAMME D'EQUIPEMENT EN MOYENS DE PRODUCTION



3.2.2 Optimum Ratio between Base and Peak Supply Capabilities and Reserve Capacity Ratio

There will be an optimum ratio for base and peak supply capabilities depending on the definite shape of the daily load curve. When peak supply capability is larger than the appropriate ratio, the tariff of peak electricity will be expensive, and as in the case of STEG where gas turbines are in large number as peak supply capability, since their service lives are shorter in comparison with steam thermal, the tariff of electricity will be high. And, in the case of a combination with pumped-storage power generation, it will not be possible to adequately supply cheap midnight power for pump-up, so that economical operation of the entire system cannot be looked forward to.

In contrast, when the base supply capability is large, there will be a necessity to shut down base thermal (mainly large-unit steam thermal), or to operate at low load, and it will be unavoidable for operation to be carried out at poor efficiency. This means directly that the tariff of electricity will become higher.

The ratios of peak, middle and base supply capabilities at the end of year from 1983 to 1989 are indicated in Table 3.5. Fig. 3.3 shows the above ratios for 1980 to 1994 in the form of a graph.

A comparison will be made between this graph and the actual daily load curve (peak supply capability 28.5%, middle supply capability 7.5%, base supply capability 64%). Further, with regard to the conditions for comparison, it will be sufficient to have a reserve capacity of 150 MW from 1980 when the international interconnection with Algeria will be made, and since this will be limited to base power sources, for the period between 1985 and 1989, it will be an ideal ratio if there are

Peak supply capability	Approx. 30%
Middle supply capability	Approx. 10%
Base supply capability	Approx. 80%

with allowances adding base power sources of approximately 15%, the reserve capacity would be adequate at 150 MW.

An explanation of the various supply capabilities will be given below.

(1) Peak Supply Capabilities

There is excessive peak supply capability at present (approximately 40% at the end of 1982). This is thought to be because the scale of the STEG System was small in the past so that large-unit, high-efficienty steam thermal could not be installed, and gas turbines which are simple to install and easy to handle were provided in large number, and this could not be helped to an extent. However, it will not be of advantage to increase new gas turbines over this amount.

For several years from now it will be unnecessary to increase peak supply capability and it will suffice to commission a new peaking capacity, Kasseb Pumped-Storage Power Station, when the capacity decreases to less than 30%. The timing, as is clear from Fig. 3.3, will be April 1985.

(2) Middle Supply Capability

As shown in Table 3.5, there will be approximately 14% of middle supply capability at the end of 1985, but this ratio is not of much consequence. The reason is that middle supply capability, by its nature, can become a part of either peak or base supply capability. Moreover, since middle supply capability consists mostly of old facilities which are to be gradually retired, it tends to become decreased year by year, but supplementation will not be considered in particular. The reason is that although the suitable unit size of middle-supply thermal for the maximum unit of 150 MW of STEG is about 75 MW, since the scale of the entire STEG System is about 1,000 MW, if a 75 MW unit were to be adopted the ratio of the middle unit to the entire system would be large so that fine-tuned operation cannot be carried out, and is not advantageous. Rather, it would be more advantageous to operate a combination of base and peak supply which is similar to middle supply in nature as middle supply according to the condition prevailing at that time. For example, it would be possible to operate Goulette II, 47.5 MW x 2 and Sidi Salem, 20MW, as middle supply capability.

(3) Base Supply Capability

The ratio of pure base supply capability, because of the large unit size to be introduced, will be 90% or more when X Thermal is commissioned, 80% or more when Y Thermal is commissioned, and 70% when Z Thermal is commissioned, and although there will be a temporary increase, the trend macroscopically will be one of gradual decrease.

The low percentages will be 64.8% before start-up of Y Thermal, 64.4% at start-up of the No. 4 Unit of Kasseb. When middle supply capability is also added as base supply capability, the percentage will rise from 64.8 to 77.8% before start-up of Y Thermal, 64.4 to 69.7% at the time of start-up of the No. 4 Unit of Kasseb, for increases by several percentage points. As stated previously, it will be ideal if a base supply capability of 80% were to be available (if there is 80% at all times, the balance of demand and supply can be maintained even if one 150 MW unit were to step out), but actually, when slightly less than 70% is possessed, there will be no special problem other than at the time of step-out of a 150 MW unit. (See Chapter 4.)

(4) Closure

From the above, the optimum ratios of the various supply capabilities in 1985-1989 with reserve capacity of 150 MW, should aim for

Peak supply capability	30%	Total 115%
Middle supply capability	10%	
Base supply capability	75%	

Tableau 3-4 PUISSANCE MAXIMUM APPELEE ET LA PUISSANCE GARANTIE DES CENTRALES (1985 - 1994)

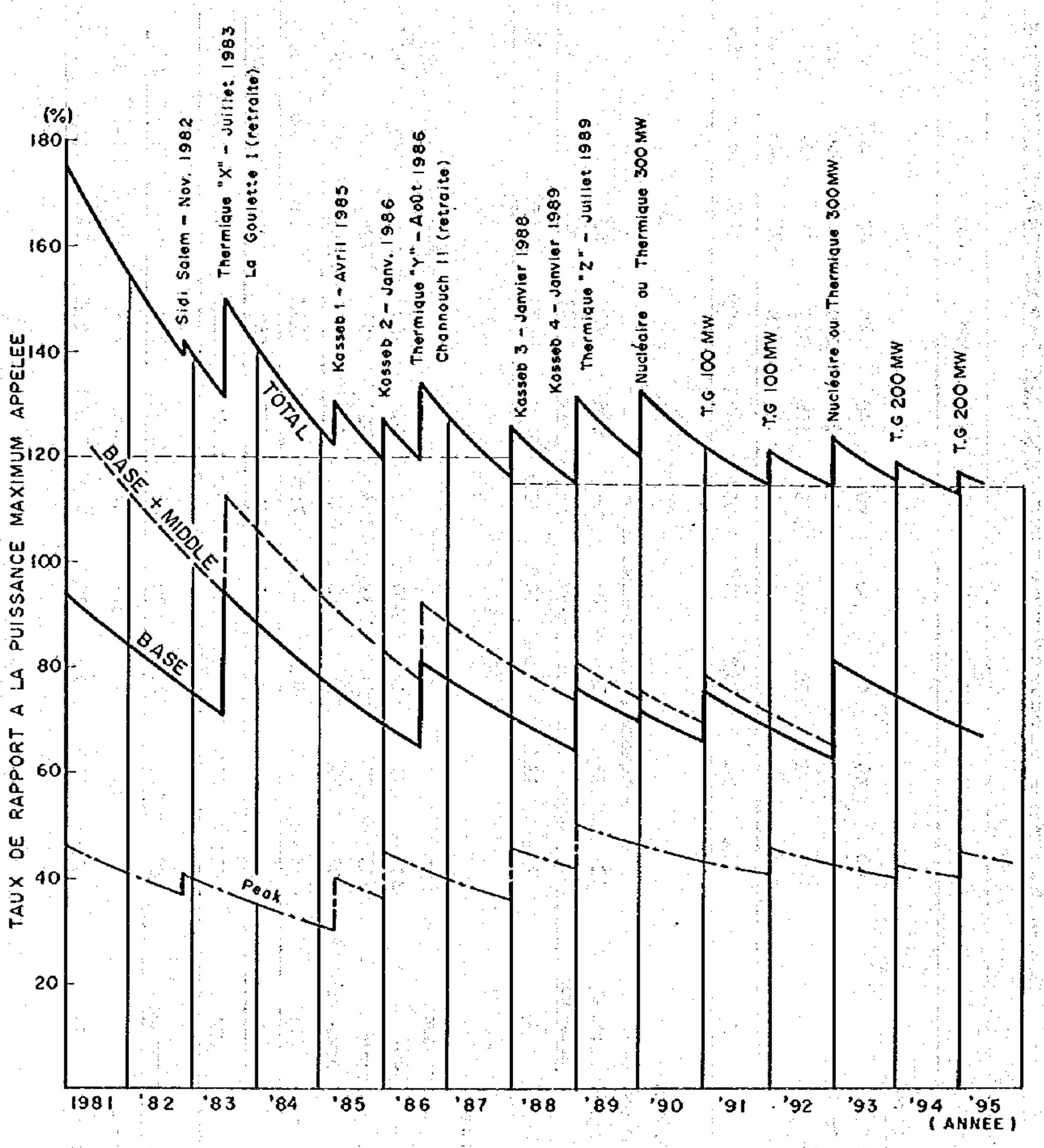
(MW)

Description		1985	1986		1987	1988	1989	1990	1991	1992	1993	1994
			Jan.-Juillet	Août-Déc.								
Puissance maximum appelée		870	920	970	1.060	1.160	1.280	1.390	1.520	1.640	1.790	1.940
Puissance totale garantie												
Base	Goulette II	95	95	95	95	95	95	47	47	47	47	47
	Ghannouch I	58	58	58	58	58	58	58	58	58	58	58
	Sousse	300	300	300	300	300	300	300	300	300	300	300
	Thermique vapeur "X"	150	150	150	150	150	150	150	150	150	150	150
	Thermique vapeur "Y"			150	150	150	150	150	150	150	150	150
	Thermique vapeur "Z"						150	150	150	150	150	150
	Nucléaire (ou thermique)							300	300	300	600	600
	Total	603	603	753	753	753	903	1.155	1.155	1.155	1.455	1.455
Pointe et médiane	TG (A)											
	Bouchemma	62	62	62	62	62	62	62	62	62	-	-
	Ghannouch II	59	44	44	44	44						
	Sous-total	121	106	106	106	106	62	62	62	62	-	-
	TG (B)											
	Tunis Sud	66	66	66	66	66	66	66	22	22	22	-
	Sfax	44	44	44	44	44	44	44	44	44	44	-
	Menzel Bourguiba	44	44	44	44	44	44	44	44	44	44	-
	Korba	22	22	22	22	22	22	22	22	22	22	-
	Metlaoui	22	22	22	22	22	22	22	22	22	22	-
	TG additionnelles								100	200	200	400
	Sous-total	198	198	198	198	198	198	198	254	354	354	400
	Total de TG	319	304	304	304	304	260	260	316	416	354	400
	Centrales hydrauliques											
	Total	40	40	40	40	40	40	40	40	40	40	40
	Centrale de Kasseb	75	150	150	150	250	350	350	350	350	350	350
	Total des centrales de pointe et médiane	434	494	494	494	594	650	650	706	806	744	790
Puissance totale garantie		1.037	1.097	1.247	1.247	1.347	1.553	1.805	1.861	1.961	2.199	2.245
Puissance de réserve		167	177	277	187	187	273	415	341	321	409	305
Taux par rapport à la puissance maximum appelée (%)	Centrales de base	69,3 %	65,5 %	77,6 %	71,0 %	64,9 %	70,5 %	83,0 %	76,0 %	70,4 %	81,3 %	75,0 %
	Pointe et médiane	49,8 %	53,7 %	50,9 %	46,6 %	51,2 %	50,8 %	46,7 %	46,4 %	49,1 %	41,6 %	40,7 %
	Total	119,1 %	119,2 %	128,5 %	117,6 %	116,1 %	121,3 %	129,8 %	122,4 %	119,5 %	122,9 %	115,7 %

Tableau 3-5 TAUX DE REPARTITION DES PUISSANCES GARANTIES PAR CATEGORIE

Centrales		1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Centrales de pointe													
– Hydrauliques		40	40	40	40	40	40	40	40	40	40	40	40
– Pompage turbinage		0	0	75	150	150	250	350	350	350	350	350	350
– Turbines à gaz		198	198	198	198	198	198	198	198	198	354	354	400
	Sous-total	238	238	313	388	388	488	588	588	644	744	744	790
	(%)	35,0	30,9	36,0	40,0	36,6	42,1	45,9	42,3	42,4	45,4	41,6	40,7
Centrales médianes													
– Thermiques moyennes		– exploitées comme centrales de base –											
– Turbines à gaz (gaz naturel)		121	121	121	106	106	106	62	62	62	62	-	-
	Sous-total	121	121	121	106	106	106	62	62	62	62	-	-
	(%)	17,8	15,7	13,9	10,9	10,0	9,1	4,8	4,5	4,5	3,8	-	-
Centrales de base													
– Nucléaire (ou thermique)		-	-	-	-	-	-	-	300	300	300	600	600
– Thermiques nouvelles		450	450	450	600	600	600	750	750	750	750	750	750
– Thermiques anciennes		153	153	153	153	153	153	153	105	105	105	105	105
	Sous-total	603	603	603	753	753	753	903	1.155	1.155	1.455	1.455	1.454
	(%)	88,8	78,3	69,3	77,6	71,0	64,9	70,5	83,0	76,0	70,4	81,3	75,0
	Total	962	962	1.037	1.247	1.247	1.347	1.553	1.805	1.861	1.961	2.199	2.245
	(%)	141,5	124,0	119,2	128,6	117,6	116,1	121,3	129,8	122,4	119,5	122,9	115,7
Puissance maximum appelée		680	770	870	970	1.060	1.160	1.280	1.390	1.520	1.640	1.790	1.940
Puissance de réserve		282	192	167	277	187	187	273	415	341	321	409	305
Taux de réserve	(%)	41,5	24,9	19,2	28,6	17,6	16,1	21,2	29,8	22,4	19,5	22,9	15,7

Graphique 3-3 TAUX DE REPARTITION DES PUISSANCES PAR CATEGORIE



as stated before, while further, since in the future from 1990 and after, middle supply capability will be retired and become smaller, it will be sufficient to consider

Peak supply capability	40%	Total 115%
Base supply capability	75%	

Further, these values are for the case of the form of the daily load curve not varying, but in the 1990s, since it is expected that the minimum value of off-peak power will become higher than 48% with progress made in industrialization, the value of 75% for base supply capability may be on the small side, but not on the large side.

Regarding the reserve capacity ratio, as can be seen from Table 3-5 and Fig. 3-3, since a reserve capacity of 150 MW was considered, when the cross section at year-end of heaviest load during the year is taken into account, the year of smallest reserve capacity will be 1988 with 16.1%, the next being 1987 with 17.6%, and even if there were to be outage in the international interconnection lines, it will be possible for ample balance to be maintained between demand and supply.

3.2.3 Necessity of 150 MW Steam Thermal in 1983

As previously described, the ratio of the base load in the daily load curve is 64%, whereas in 1982 the base supply capability will reach a level corresponding to approximately 76% of the maximum demand. However, if from among these one 150 MW unit of Sousse Steam Power Station were to step out, the base supply would be lowered to about 59%.

On the other hand, the peak power supply capability shows a high ratio of approximately 40% in 1982 compared with the appropriate ratio of 28.5%. Consequently, from the requirements of demand and supply, it is of course necessary for the new power source to be introduced in 1983 to be base power supply capability.

Considered from the energy situation of Tunisia, it would be conceivable for the two alternatives of large-scale steam thermal or gas turbine using natural gas to be used, and as a result of economic comparisons, it was decided to recommend commissioning of a 150 MW steam power station for the reasons given below.

(a) The unit construction cost is approximately 70% higher for steam thermal than for gas turbine, but the unit heat consumption rate will be approximately 75% of that of the latter (2,453 kcal/3,235 kcal), while regarding service life, whereas it is 15 years for gas turbine it is longer at 25 years for steam thermal, so that the unit generating cost per kWh in case of base supply operation will be lower for steam thermal than for gas turbine. (See 5.2.2(1) of the previous report for details of calculation.)

(b) Base supply capability as cheap as possible is required for power to perform pump-up to Kasseb Pumped-Storage Power Station in the midnight, and the scale of this base supply capability needs to be 150 MW x 3 units.

(c) Through addition of a new base supply capability of 150 MW, adverse effects on the system which would be caused by stepping out of one unit of the largest scale in the system due to faulting or shutting down for inspection and repairs will be eliminated.

(d) Based on considerations of various aspects such as optimum power source structure, securing of reserve supply capability, efficiency and power generating cost, the addition of one 150 MW unit is recommended.

3.2.4 Unit Capacity of Kasseb Pumped-Storage Power Station (Harmony with System - Frequency Drop)

The size of a unit is determined in consideration of such factors as transportation limitations, equipment manufacturing limitations, economy, and harmony with the electric power system. Of the above, as a result of reconnaissance of port facilities, roads and bridges, it is thought there will be no problem regarding transportation. Therefore, the unit size may be determined from the viewpoints of economy and harmony with the electric power system. The matter of harmony with the electric power system will be discussed here.

When considering a hydroelectric power station, its outage ratio (sum of faulting ratio and scheduled outage ratio) is extremely small compared with that of thermal, and there will be no problem of supply reliability. (According to the trial calculations in the previous report, at reserve capacity ratio of 20% and generator outage ratio of 3%, by adopting 350 MW/4 units, the probability of outage of whole Kasseb Power Station will be about once in 10 years.)

On the other hand, when as pumping equipment, since there is the pump characteristic of full-load operation within an extremely short period of time when switching to the system, it is necessary for an examination to be made especially of the night time when the capacity of the entire system is half that during peak time. In effect, it will be necessary to have a full understanding of how much the system frequency will drop when starting the pumps during this hourband.

STEG will have a strong interconnection with the systems of Algeria and Libya before January 1986 when Kasseb will be started up so that there will be no special problem regarding a drop in system frequency when pumping up water at Kasseb, the drop being considered to be about 0.5 Hz. With a drop of this degree there will be no inconvenience at all to customers.

Approximate Calculation of Frequency Drop

(1) Frequency Drop of The Power System at Start-up of Kasseb No. 1 Unit

Time: Midnight, April 1985
System Scale:
STEG Side: at Peak time, 790 MW
at Midnight time, at 1/2 of peak, 395 MW

Algerian Side: At 3 times STEG, 1,185 MW
Total: 395 MW x 4 = 1,580 MW

System Constant:
Rigorously, K = 8%/Hz

Pump-up Input:
Rigorously, 90 MW (75 MW unit)

The frequency drop Δf_{75} at the time of starting up the 75 MW unit will be

$$\Delta f_{75} = \frac{90}{1,580 \times 0.08} = 0.71 \text{ Hz}$$

In effect, this would be a frequency drop of the system from 50 Hz to 49.29 Hz, but this is not a realistic figure as it is for a case of no load-increase operation of thermal.

Now if the total capacity of thermal is 603 MW (150 MW x 3 + Goulette II, 95 MW, + Ghannouch, 58 MW) and a load increase of 7% in one minute is possible, the output increase Δp_g obtained in 80 seconds (time required for full load of pump) will be

$$\Delta p_g = 603 \times 0.07 \times \frac{80}{60} = 56.3 \text{ MW}$$

and the beforementioned frequency drop of 0.71 Hz will be reduced to a little over one half($\Delta f = \frac{0.71 \times 56.3}{90} = 0.44$) with the final result being 49.56 Hz so that the drop will be less than 0.5 Hz

(2) Frequency Drop of The Power System at Start-up of No. 3 Unit (January 1988)

At the time the No. 3 Unit is started up the scale of the power system will be increased by 23% ($\frac{1,070 \text{ MW}}{870 \text{ MW}}$) compared with that at the time of start-up of the No. 1 Unit, while the pump-up input will be increased by 33% ($\frac{120 \text{ MW}}{90 \text{ MW}}$), but the midnight load of the entire system including Algeria will have been increased to 2,140 MW. Therefore, the drop will be the following:

$$\Delta f_{100} = \frac{120}{2,140 \times 0.08} = 0.7 \text{ Hz}$$

This also will become less than 0.5 Hz when load-increase operation of thermal is considered and will be of no problem.

(3) Frequency Drop of The Power System at Start-up of No. 1 Unit in Case of Disconnection of International Interconnection Transmission Line

In such a case it will be necessary for power generation control to be made of base thermal equipment to raise the system frequency about 0.5 Hz beforehand. By doing so, it will be possible to keep the range of frequency variation within ±0.5 Hz, whereas if this were not done the frequency will drop from 50 Hz to aroung 49 Hz and the effects on customers will be undesirable.

If the generator output increase of thermal by load limiter were to be made 7%/min, since the base thermal supply capability as of April 1985 will be 603 MW as mentioned previously,

$$\triangle p_g = 603 \times 0.07 \times \frac{80}{60} = 56.3 \text{ MW}$$

Therefore, the shortage in power (90 - 56.3 = 33.7 MW) must be met by supply of the power system constant K.

With the system constant as K = 8%/Hz, the frequency drop corresponding to the above 33.7 MW of shortage in electric power will be the following:

$$\triangle f = \frac{-33.7}{395 \times 0.08} = 1.07 \text{ Hz}$$

Therefore, if the system frequency were to be raised beforehand by 0.5 Hz, the result would be 50.5 Hz → 49.43 Hz. It is thought a drop of this extent will be of no problem with respect to effects on customers and on operating limits of thermal equipment.

(4) Closure

As described above, if the unit capacity is selected to be 75 MW, starting of pumps will be possible even in the worst situation (disconnection of international interconnection line). However, if a unit size larger than this were to be selected, for example, a 100 MW No. 1 Unit, the system frequency variation will greatly exceed 1.0 Hz, and of more concern even before thinking of adverse effects on customers, there will be the risk of tripping of base thermal generators.

If the international interconnection line were to be sound, then the system frequency variation would be less than 0.5 Hz and there will be no problem.

Therefore, Kasseb Pumped-Storage Power Station, as described in 3.2, is to have two 75 MW units installed for Phase I of the Project, while from the standpoint of the power system it will be desirable for two 100 MW units to be installed in Phase II.

CHAPTER 4. OPERATION MODE AND GENERATING CAPACITY AND ANNUAL POWER PRODUCTION OF KASSEB POWER STATION

CHAPTER 4. OPERATION MODE AND GENERATING CAPACITY AND ANNUAL POWER PRODUCTION OF KASSEB POWER STATION

4.1 AVAILABLE VOLUME OF NATURAL GAS AND FUEL FOR GENERATION

In the STEG's electric power system, the available volume of natural gas is closely related with the operation made of power plants, especially with those of peaking plants.

Sequence of operation of Kasseb and gas turbine power plants will be differed whether the available fuel of gas turbine power plant, sharing a major part of peaking capacity with Kasseb Power plant, will be natural gass with relatively cheap cost or gas oil with expensive cost.

4.1.1 Available volume of natural gas

It is anticipated that the natural gas produced at El Borma suppling a major portion of domestic demand will be exhausted around 1985.

Instead, gas pipe line connecting between Algeria, Tunisia and Italy agreed for construction in April 1978 will be put into operation around 1981. With the commencement of this pipe line, it is anticipated that Tunisia can be supplied 0.6 to 2 billion cubic meters of natural gas per annum.

In addition, it is expected that the development of natural gas project at Miskar is de offshore of Gabes will be realized in the near future. Although production Capacity of natural gas at Miskar is not yet clear, it is estimated in the V Plan annual production will be around 1.5 to 3 billion cubic meters.

Out of the said available volume of natural gas, it is planned that 50% will be used for gas chemical industry and remaining 50% will be utilized for fuel for generation purpose.

On the assumption that minimum and maximum available natural gas will be 2.1 and 5 billion cubic meters per annum with the realization of International Pipe Line and Miskar Projects, 1.1 to 2.5 billion cubic meters of natural gas will be utilized for power generation evely year.

4.1.2 Natural gas consumption for generation

Natural gas consumption for generation will be 0.218 m^3/kWh for steam power plant and 0.300 m^3/kWh for gas turbine power plant on the following conditions;

fuel consumption rate for steam power plant (Unit capacity: 150MW)
.....2400 kcal/kWh

fuel consumption rate for gasturbine power plant (Unit capacity: 150 MW)
.....3300 kcal/kWh