Japan International Cooperation Agency (JICA)

Ministry of Electricity and Water
Sultanate of Oman

The Study on Demand Supply Management for Power Sector in Sultanate of Oman

Final Report

Main Report

November 1998

PROACT International, Inc.
Shikoku Research Institute, Inc.

Japan International Cooperation Agency (JICA)

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PREFACE

In response to a request from the Government of Sultanate of Oman, the Government of Japan decided to conduct the Study on Demand Supply Management on Power Sector in Sultanate of Oman and entrusted the study to Japan International Cooperation Agency (JICA).

JICA sent a study team led by Mr.Katsuhiko Otaki of Proact International Co.,Ltd. to Sultanate of Oman four times from October 1997 to September 1998.

The team held discussions with the officials concerned of the Government of Sultanate of Oman, and conducted related field surveys. After returning to Japan, the team conducted further studies and complied the final results in this report.

I hope this report will contribute to the promotion of the plan and to enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Sultanate of Oman for their close cooperation throughout the study.

November 1998

Kimio FUJITA
President
Japan International Cooperation Agency

November 1998

Mr.Kimio Fujita
President
Japan International Cooperation Agency
Tokyo, Japan

Dear Mr.Fujita:

Letter of Transmittal

We are pleased to submit to you the report of the Study on Demand Supply Management for Power Sector in Sultanate of Oman. The report reflects the advice and suggestions of the authorities concerned of the Government of Japan and your Agency as well as containing the Power Sector Master Plan, the results of analyses and recommendations. Also reflected are the comments from the officials of the Ministry of Electricity and Water of Sultanate of Oman, through the discussions in the Counterpart Team meetings for this Study held in Muscat from time to time during the study period.

This report presents, in particular, the potential viability of modifying existing gas turbines to accommodate water injection at Ghubrah, Rusail and Wadi Jizzi, the interconnection of the Muscat and Wadi Jizzi Systems, and also the Central Load Dispatching Center.

In view of importance of the power sector infrastructure in the metropolitan areas of Oman and the expected net benefit of such infrastructures are shown in the report, we recommend that specified plans be implemented as a top priority in the country.

We wish to take this opportunity to express our sincere gratitude to your Agency, the Ministry of Foreign Affairs and the Ministry of International Trade and Industry. We also wish to express our deepest gratitude to the Ministry of Electricity and Water and the authoritative government agencies concerned of Sultanate of Oman for the close cooperation and assistance extended to us during the period.

Very truly yours,

K. Otaki

Katsuhiko Otaki
Team Leader
The Study on Demand Supply Management
for Power Sector in Sultanate of Oman

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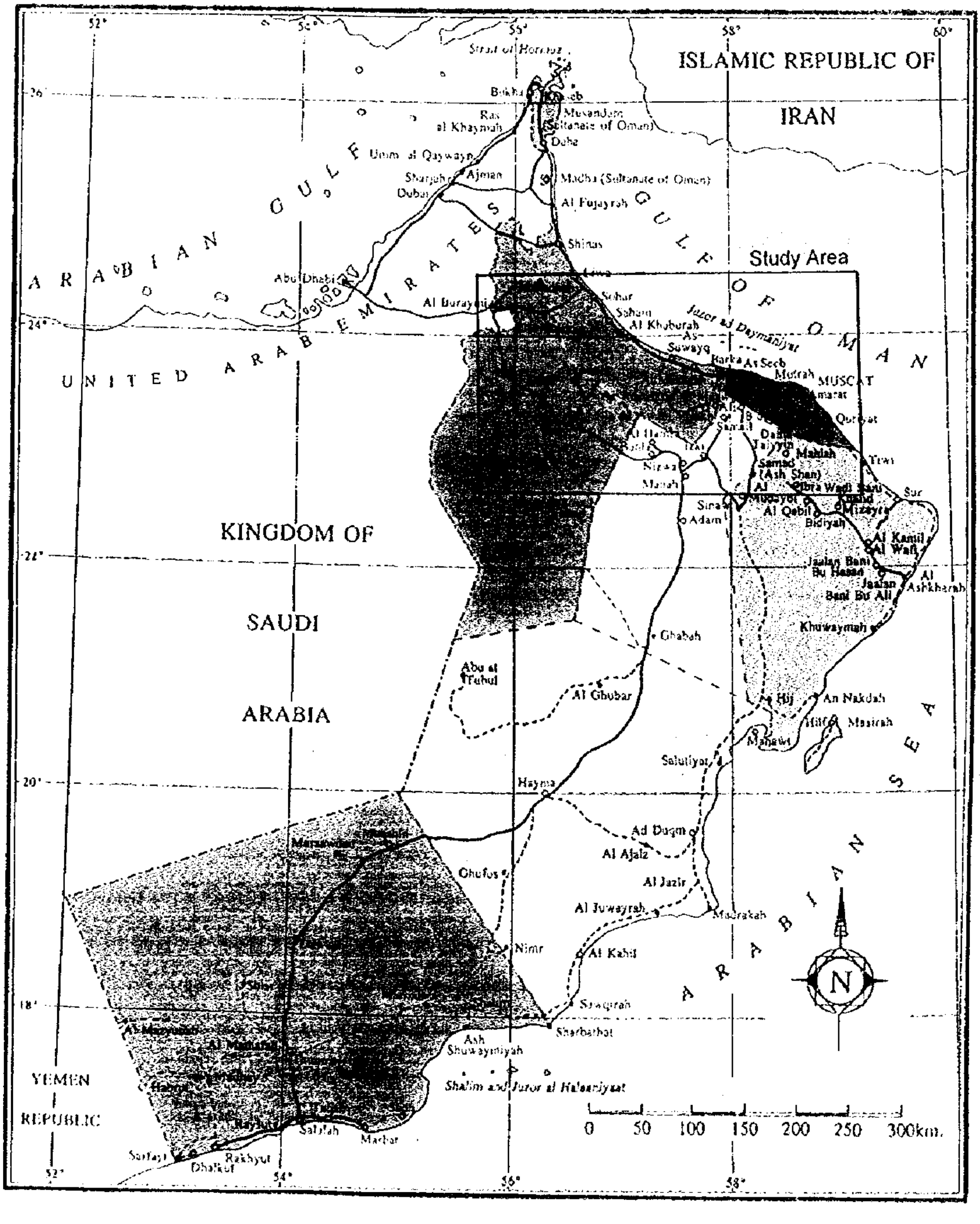
SULTANATE OF OMAN



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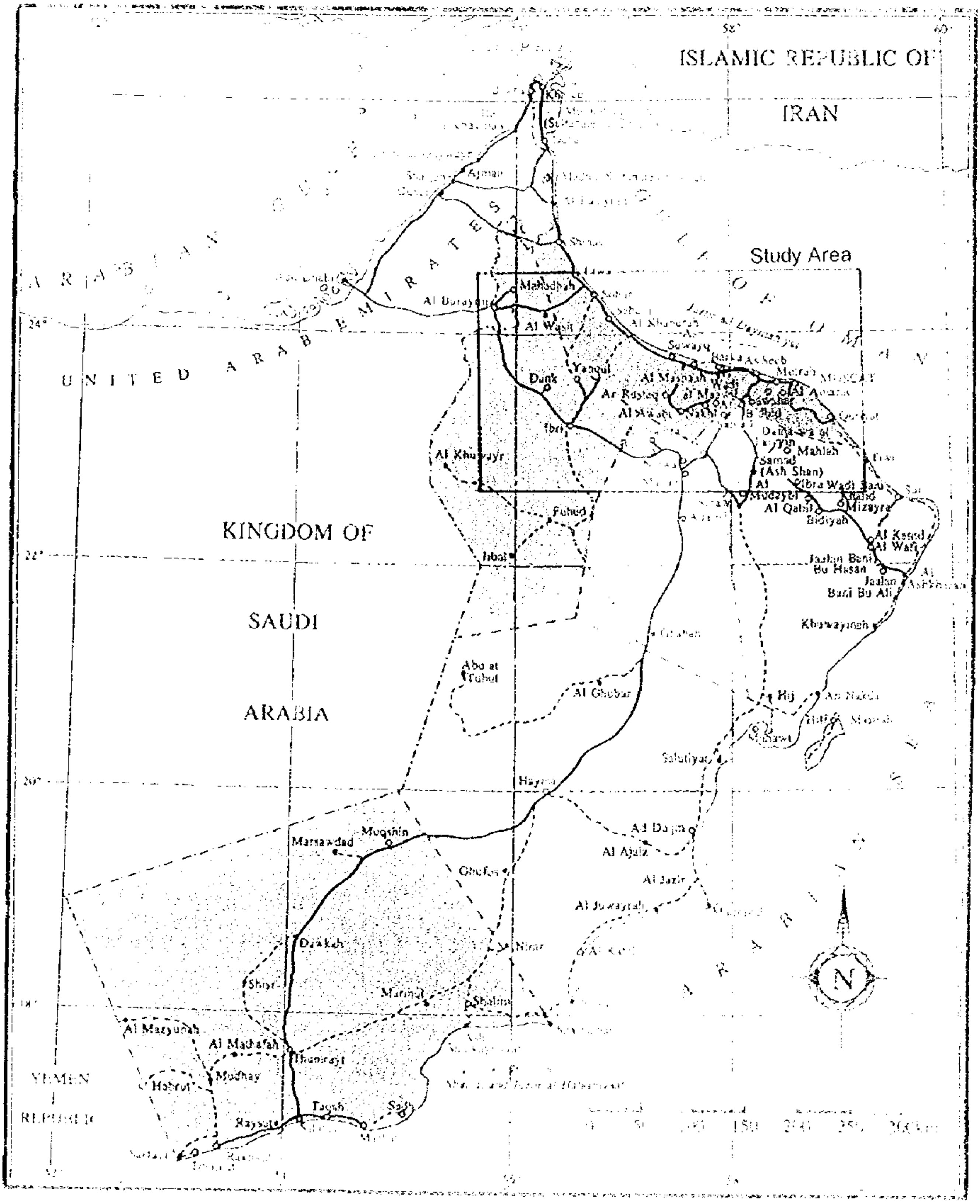


Chapter 1

Outline of Sultanate of Oman

1. Outline of Sultanate of Oman

1-1. Outline

1-1-1. Geography and Topography

The Sultanate of Oman occupies the South-Eastern corner of the Arabian Peninsula and borders Saudi Arabia and the United Arab Emirates in the West; the Republic of Yemen in the South; the Strait of Hormuz in the North and the Arabian Sea in the East. The coastline extends 1,700kilometers. The total area is approximately 309,500sq. kms. and it is the third largest country in the Arabian Peninsula.

The Sultanate of Oman has a variety of topographical features consisting of plains, wadis and mountains. The most important area is the coastal plain which represents about 3% of the total land area. The mountain ranges occupy about 15%. The Hajar range runs from Musandam in the North to Ras al Hadd, the extreme limit of the Arabian Peninsula. In the South, the Qara range attracts the monsoon, which brings unique weather conditions and creates a special environment in Dhofar. The remaining area which occupies 82% of the country is mainly sand and gravel desert.

1-1-2. Climate

The climate differs from one area to another. It is hot and humid in the coastal areas in summer; while it is hot and dry in the Interior with the exception of the higher mountains, which enjoy a moderate climate throughout the year. Rainfall is generally light and irregular; although heavy rains and thunderstorms sometime cause severe flooding. In the South, the Dhofar region has a moderate climate and the pattern of rainfall is more predictable with heavy monsoon rains occurring regularly between May and September.

1-1-3. Population

At the end of 1993 the total population of Oman was 2,018,074 of which 1,483,226 were Omanis (73.5%) and 534,848 were expatriates. The majority of expatriates are concentrated in the Capital area, where they represent 46% of the population. The population growth rate is quite high, 3.7% annually. The population under 15 years old represents more than 50 % of the total population.

In most other areas of the Sultanate Omanis make up 75% or more of the total population. The social is classified widely four tips, ① people who make a living by the sea, ② people who make a living by agriculture in Batinah and the Southern Region, ③ people who live in mountain area of Dhofar and Musandam, ④ the nomads in desert area.

1-2. Society and Economy

1-2-1. Economy

Oman's economy has been transformed by the export of oil since 1967. It is therefore hardly surprising that until 1986 when the oil price tumbled, crude oil accounted for 99% of all exports. However, by 1994 oil comprised only 38% of the GDP because of the growth in other sectors of the economy. Through consecutive Five-Year Development Plans, the Sultanate of Oman has witnessed an impressive record of economic and social achievements which are clearly reflected in the modern physical infrastructure, the considerably improved basic health and education system, and the overall standards of living of Omanis.

1-2-2. Fifth Five-Year Plan (1996-2000)

The Fifth Five-Year Plan is characterized by its historical importance in the Omani development process. This importance is primarily attributable to the fact that this plan represents a crossroads and a watershed between two highly important stages of economic and social development in the Sultanate. The Plan aims to maintain, at the minimum, the current level of per capita income in real terms and will strive to double it by 2020, while maintaining Omani values and traditions. Secondly, the importance of this plan is attributable to the inevitable changes in the role of government in Oman's economy, from a dominant role necessitated by the requirements of the previous stage, to the role of strategic guidance of an economy that depends on a dynamic private sector.

Oman's economy will be able to shift from an economy that depends on government initiative and spending, oil resources and expatriate labor as the main engines of economic activity, to an economy that depends on private initiatives, national labor, and renewable resources that lead to achievement of sustainable development, and an improvement in the living standard of the Omani citizen. The Investment Program of the Fifth Five-Year Plan is characterized by being largely dependent on the private sector's investments. The share of the private sector's investments (Omani and Non-Omani) in the total investments targeted in the plan to reach (53.3%), while the share of the private sector in the investments of the Fourth Plan did not exceed (38.1%).

1-3. Electricity Supply

1-3-1. Ministry of Electricity and Water

In the late 70s the growing nationwide demand for electricity and water was such that the Ministry of Electricity and Water (MEW) was established in 1978. MEW is entrusted with the generation, transmission and distribution of electricity to all the Governorates and regions of the Sultanate as well as the provision of drinking water. The Ministry's Electricity department has adopted main policies as follows, ① Provision of electricity to the whole country, ②Replace diesel generators with gas turbines, ③Encourage participation of private sector in the electricity business.

The first large project to provide electricity was the construction of the Ghubrah power station and desalination plant in 1976, with an initial capacity of 25.5MW. The first major extension to the power plant was completed in 1983 increasing the capacity to 287 MW. At the same time of MEW' establishment the gas pipeline to the coast was extended to Sohar where a power station was constructed close to the copper mining and smelting project. Along the gas pipeline, provision was made for spur lines to meet industrial and domestic demand for electric power. One of the most important connections was at Rusayl, the site of Oman's first industrial complex, where a power station was constructed in 1984 with a capacity of 250 MW. After expansion projects, this capacity has now been doubled to 500MW. There are currently 31 power stations with a total installed capacity of 1,794MW in Oman.

The electricity grid system has some 220 main sub-stations and about 11,000 distribution transformers. Electricity now reaches all the populated areas of the

Sultanate except for some remote mountain villages, which means that about 87% of the country is fully supplied electricity. It is expected to extend this coverage to 93% of the total populated areas by the end of the current Five-Year Plan.

1-3-2. Privatization

The Investment Program of the Fifth Five-Year Plan is characterized by being largely dependent on the private sector's investments. The share of private sector's investments in the electric sector targeted in the plan to reach 70%, while in the Fourth Plan the share of public investment was 100%. The Ministry of Electricity and Water has always encouraged the involvement of the private sector since its establishment as the Government body responsible for planning and supervising the development of these utilities.

The Manah Power Project was the most important achievement of the Government's privatization policy at the start of the current Five-year Plan. It is not only the first independent power project in the Sultanate, but also the first in the Gulf Countries. It has been established on the build-own-operate-and-transfer (BOOT) scheme. In the case of the Manah power station it was agreed that the United Power Company would operate the power station, while the Ministry will be responsible for operating the transmission facilities for twenty years. The new plant replaced the old diesel power stations at Nizwa, Bahla and Izki.

Chapter 2

Power Demand Forecast and Present State of Power Demand and Supply

2. Power Demand Forecast and Present State of Power Demand and Supply

2-1. Power Demand Forecast

2-1-1. Present Power Consumption

(1) Power Consumption Levels and Demand Structure

This report and following discussions are mainly focused on the energy usage of both the Muscat and Wadi Jizzi systems. Together, they account for 80% of the total electrical energy consumption in Oman. As a whole, the Sultanate of Oman consumed a total of 5,623GWh in 1997. Of this total, the Muscat system consumed 3,589GWH or 64% of the total. The Wadi Jizzi system accounted for 845GWH, or, roughly, 15% of the total energy output.

From 1990 to 1997, power demand of the Muscat system grew 1.49 times, and the mean annual growth rate was 5.9 %. The annual growth in demand varied significantly from year to year. For example, the electricity demand in 1993 marked a high growth rate of 13.9 %, while the growth rate in 1991 was as low as 1.2 %.

In contrast, the electricity demands of the Wadi Jizzi system grew 2 times for the same eight-year period. This growth rate is noticeably greater than that of the Muscat system. In particular, from 1992 to 1994, annual growth rates were as high as 13~17%. At present, electricity demands continue to grow at high rates. (Table 2-1-1)

Table 2-1-1 Actual Energy Consumption (GWh)

Year	Muscat	Growth Rate	Wadi Jizzi	Growth Rate	Muscat + Wadi Jizzi	Growth Rate	Other Regions	Oman Total	Growth Rate
1990	2397.4	-	414.7	-	2812.1	-	662.9	3475.0	-
1991	2426.4	1.2%	436.9	5.4%	2863.3	1.8%	705.0	3568.3	2.7%
1992	2666.6	9.9%	512.3	17.3%	3178.9	11.0%	1083.8	3947.1	10.6%
1993	3038.5	13.9%	599.4	17.0%	3637.9	14.4%	882.2	4520.1	14.5%
1994	3179.3	4.6%	675.7	12.7%	3855.0	6.0%	964.3	4819.3	6.6%
1995	3314.4	4.2%	727.1	7.6%	4041.5	4.8%	1045.2	5086.7	5.5%
1996		3.5%	791.5	8.9%	4221.4	4.5%	1081.0	5302.4	4.2%
1997	3588.6	4.6%	845.4	6.8%	4434.0	5.0%	1189.0	5623.0	6.0%
Aver. Growth Rate		5.9%		10.7%		6.7%			7.1%

The maximum power demand for the Muscat system in 1996, including peak-time load shedding of 55 MW, was 986 MW or 6.8 % above the previous year's level. The maximum power demand of 1997 increased significantly to 1,080MW as a result of the interconnection between the Muscat and Manah systems at the end of 1996. The maximum power demand for the Wadi Jizzi system, including load shedding of 16 MW, were 265 MW in 1996, and 293 MW in 1997. The maximum power demand of 1997 marked a large growth of 10.6 % from the previous year. Maximum power demands of the two power systems are increasing significantly and power source development is lagging behind. Hence, both systems have to use peak-time load shedding during the summer season. (Table 2-1-2)

Table 2-1-2 Actual Peak Demand (MW)

Year	Muscat	Growth Rate	Wadi Jizzi	Growth Rate
1990	658	-	172	-
1991	679	3.2%	177	2.9%
1992	725	6.8%	192	8.5%
1993	817	12.7%	218	13.5%
1994	878	7.5%	234	7.3%
1995	923	5.1%	247	5.6%
1996	* 986	6.8%	265	7.3%
1997	**1080	9.5%	*** 293	10.6%
Average		7.3%		7.9%

* 931+55(Load shedding)
**After Interconnection with Manah System
*** 277+16(Load shedding)

Electricity demands in Oman are classified by application: households, governmental agencies, commerce and industry, and others (agriculture, fishery, tourism, etc.). Table 2-1-3 shows the actual records of demand for both the Muscat and Wadi Jizzi systems, by application, over the last six years. According to the 1997 records of the Muscat system, household usage accounted for 54 % of the total demand. Demands by governmental agencies were 25 % and demands by commerce and industry have been growing year after year, but percentages remain only 20 %.

As for the Wadi Jizzi system, household demand accounted for 69 % and governmental agencies accounted for 15 %. Together, these applications accounted for 84 % of the total. The ratio of demand for commerce, industry and others is as low as 17%. On the basis of these findings, the features of electricity demand in Oman are summarized as follows:

- Air conditioning accounts for the greatest part of household electricity demands.
- Demands by governmental agencies are relatively large.
  (Demands of this kind account for 23 % of the total demand from both systems.)
- Power for the drilling and refining of oil and natural gas is supplied separately.
- No other large-scale industries can be included in the base demands for electricity. Moreover, demands by commerce and industry remain relatively low.

Table 2-1-3 Actual Demands by Application

Muscat System (MWh)

Year	Household	Commerce & Industry	Governmental Agency	Others	Industrial Estates	Total	Growth Rate (%)
1992	1621.1	222.8	799.2	23.6	0	2666.7	-
1993	1856.8	253.3	884.5	43.9	0	3038.5	13.9%
1994	1960.1	293.8	899.9	25.9	0	3179.7	4.6%
1995	1949.4	403.4	920.4	41.3	0	3314.5	4.2%
1996	1846.0	635.7	889.1	59.1	0	3429.9	3.5%
1997	1935.7	711.7	882.3	58.8	0	3588.6	4.6%

Wadi Jizzi System

Year	Household	Commerce & Industry	Governmental Agency	Others	Industrial Estates	Total	Growth Rate (%)
1992	394.6	37.9	77.5	2.4	0	512.4	-
1993	453.0	44.1	90.5	11.8	0	599.4	17.0%
1994	502.3	46.5	111.2	15.7	0	675.7	12.7%
1995	524.6	68.4	118.1	16.1	0	727.2	7.6%
1996	544.3	103.9	126.6	16.7	0	791.5	8.8%
1997	579.4	124.2	122.6	19.1	0	845.4	6.8%

(2)Annual and Daily Load Variations

As described above, the main demand for electricity in Oman comes from household air conditioning. During hot summer days, when maximum air temperatures can exceed 40℃, combined with a high humidity, air conditioners operate fully, not only during the day, but until midnight. The electrical consumption of air conditioners is said to account for 70 % of the peak demand.

Regarding annual load fluctuations, the maximum power demand for the Muscat system in 1997, 1,080 MW, took place on August 2, and the minimum power demand, 206 MW, was on January 2. The ratio of the minimum power demand to the maximum power demand is 19 %. This ratio is half as large as the ratio, 38%, of the Shikoku Electric Power Company in 1997. This annual load fluctuation in Oman is very large. The actual record of the annual load factor is about 50 %, and this value is about 10 % lower than that of the Shikoku Electric Power. This is due to the difference in base loads. The insufficient base load makes it difficult to achieve an efficient demand and supply operation (See Annex 2-1-a,b). As for the daily load fluctuations, the load curves of the days of maximum power demand for the Muscat and Wadi Jizzi systems in 1996 and 1997 are shown in Figure 2-1-1.

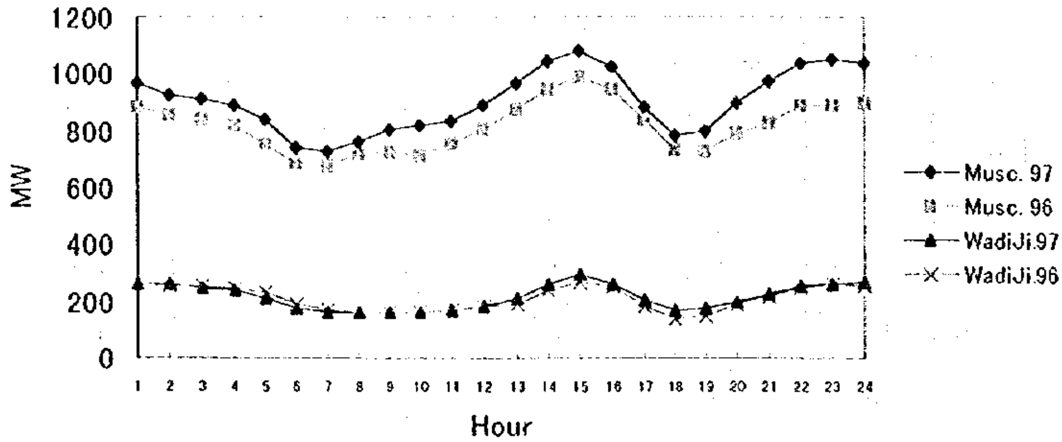


Figure 2-1-1 Daily Load Curve in Peak Demand (1996,1997)

During days of maximum power demand, the Muscat system's load fluctuation ratios, of minimum to maximum power demand, were 730/1080=0.62 in 1997 and 681/986 =0.69 in 1996. The 1996 load fluctuation ratio of Shikoku Electric Power was 0.49. The ratios of the Muscat system are low, relative to Shikoku. In the Muscat system, peak demands were generated, mainly, by air conditioning at 15:00 during the day and 23:00 at night. Daily load factors for the Muscat system are 83% to 84 % in the peak season. This is fairly high, compared to 75.5 % of Shikoku. As mentioned above, in Oman, the daily load fluctuation is rather small relative to that of the Japanese electric power companies, but in contrast, the annual load fluctuation is large. Because of this, the utilization factors of the power generation facilities and of the transmission and distribution facilities are low, causing higher total power supplying costs.

2-1-2. Prospects of Power Demand

The current basic approach to the power demand forecasting in Oman is based on the master plan, a method proposed by the German consulting firm, Fichtner. Similarly, the plans for electric power equipment, including the generation expansion plan, were established on the basis of this projection. This master plan has been examined and reviewed.

(1) Method for Projecting Power Demands

①Forecast of Electric Energy Consumption

Detailed power demand forecasts are made by area and by application. These approaches are as follows.

a. Estimate by Area

The country is divided into eight areas according to population concentration, ratio of unelectrified areas and other classifiers. Then, estimation is made based on actual records from these areas.

b. Estimate by Application

Electric energy consumption, in MWh, is estimated by application for households, commerce and industry, governmental agencies, etc., using past trends, correlation with social and economic indicators and other factors. Electric energy consumption for new industrial development projects is estimated separately.

Household estimates are derived from the increase of households (population growth); the growth in power consumption per household (considering saturation levels of electric energy consumption) and from previously electrified and newly electrified areas.

②Forecasting Maximum Power Demands

Maximum power demands are estimated for each power system using records of annual load and loss factors and the above-mentioned estimates. The electric energy consumption and maximum power demand growth rates for the Muscat and Wadi Jizzi systems, which also have been estimated in the above-mentioned manner, are shown in Table 2-1-4.

Table 2-1-4 Growth Rate of Energy Consumption & Power Demand (%)

		95～2000	2000～05	2005～10	1995～10
Muscat	MWh	5.5	5.1	3.2	4.6
	M W	9.0	5.0	3.1	5.7
Wadi Jizzi	MWh	7.9	4.7	3.5	5.4
	M W	7.2	3.8	3.3	4.8

The Muscat system's saturation levels for household electric energy expenditures are estimated to be 12,000 kWh/year per household. Actual consumption has almost reached this level. Unelectrified areas remain in the periphery of this power system; hence, the growth rate is estimated to be about 5 % in and after the year 2000 and about 3 % beyond 2005.

As for the Wadi Jizzi system, based on records up to now, electric energy consumption is estimated to continue growing at a high rate. And, just like the Muscat system, saturation levels will be reached beyond the year 2005, when the growth rate is estimated to be about 3.5 %. With regards to maximum power demand, the annual load factor of the Muscat system was 0.5 in 1995, and 0.42 for the Wadi Jizzi system. In coming years, load factors are estimated to improve by 0.01 to 0.02 due to increases in base loads, such as industrial development.

(2) Prospects of Long-term Power Demand

In this study, on the basis of the long-term power demand estimates of the Fichtner master plan, we made the following modifications to reflect actual records and estimated the power demands up to the year 2010.

①Forecasts of Energy Consumption

The recorded growth rate for the electric energy consumption of 1997 was 4.6% for Muscat System and 6.8% for Wadi Jizzi System. The growth rate of electric energy consumption after 1998 is based on Fichtner's master plan.

Table 2-1-5 Forecasts of Energy Consumption (MWh)

Year	Fichtner Forecast		After Modification			
	Muscat	Wadi Jizzi	Muscat	Growth. Rate	Wadi Jizzi	Growth. Rate
1997	3767.7	882.3	3588.6	4.6%	845.4	6.8%
1998	4006.9	957.1	3887.7	6.3%	938.1	8.5%
1999	4248.1	1031.7	4121.7	6.0%	1011.3	7.8%
2000	4540	1110.1	4404.9	6.9%	1088.1	7.6%
2001	4831.6	1185.5	4687.8	6.4%	1162.0	6.8%
2002	5122.1	1237.2	4969.7	6.0%	1212.7	4.4%
2003	5412.5	1289.8	5251.4	5.7%	1264.2	4.3%
2004	5620.1	1342.5	5452.9	3.8%	1315.9	4.1%
2005	5826	1397.1	5652.6	3.7%	1369.4	4.1%
2006	6029.2	1449.3	5849.8	3.5%	1420.6	3.7%
2007	6229.1	1501	6043.7	3.3%	1471.3	3.6%
2008	6424.9	1552	6233.7	3.1%	1521.2	3.4%
2009	6624.5	1604.5	6427.4	3.1%	1572.7	3.4%
2010	6828.1	1660.5	6624.9	3.1%	1627.6	3.5%

②Forecasts of Power Demand

Table2-1-6 Forecasts of Power Demand (MW)

Year	Fichtner Forecast		After Modification			
	Muscat	Wadi Jizzi	Muscat	Growth. Rate	Wadi Jizzi	Growth. Rate
1997	1129	295	1080	-	293	-
1998	1185	317	1210	12.0%	310	5.8%
1999	1242	335	1268	4.8%	328	5.7%
2000	1393	358	1423	12.2%	350	6.9%
2001	1482	375	1514	6.4%	367	4.7%
2002	1571	390	1605	6.0%	381	4.0%
2003	1658	404	1693	5.5%	395	3.6%
2004	1720	418	1756	3.7%	409	3.5%
2005	1782	432	1820	3.6%	422	3.3%
2006	1842	447	1880	3.4%	437	3.5%
2007	1901	462	1940	3.2%	452	3.4%
2008	1958	476	2000	3.0%	465	3.0%
2009	2016	491	2060	3.0%	480	3.2%
2010	2075	507	2120	2.9%	496	3.3%

The load growth in 2000 is high because Mudaiybi and Mudairib in the Sharqiya Region will be interconnected to the Muscat system.

Estimates of the 1998 maximum power demand have been predicted by considering the growth-rate of the last five years (8.3% in the Muscat System and 8.8% in the Wadi Jizzi System) and figures for the first half of this year.

2-2. Present State and Problems of Power Demand and Supply

2-2-1. Generation Expansion Plan

(1) Basic Approach to the Generation Expansion Plan

The generation expansion plan, like other electric power facility plans, is based on the (N-1) criterion. This approach can be defined as follows:

a. To prevent a supply shortage, in case of a large drop in the power source output, each power system is developed to have a capacity equivalent to the maximum power demand plus the capacity of the largest generator.

b. The capacity of each developed unit is limited from 15% to 20% of the total capacity of the power system.

In recent years, this approach to the generation expansion plan has caused supply shortages due to delays in power source development. Shortages occur because the spinning reserve, equivalent to the capacity of the largest unit, cannot be secured during the summer peak. Operation is quite tight and troubles on small-capacity units force the system to do load shedding.

(Actual load shedding of 1997)

Muscat system:	50 MW	one time.
Wadi Jizzi system:	Max. 35 MW	12 times.

The supply-capacity shortage became harder in 1998, from May to June, when load shedding took place almost everyday. Supply power needs to be secured immediately in preparation for next summer. Moreover, a method of reviewing long-term plans, based on actual records of demand, needs to be established and implemented, such as the master plan.

(2)Review of Generation Expansion Plan

After modifying the long-term forecasts of the maximum power demands, the generation expansion plan, from 1998 to 2010, was re-evaluated

①Muscat System

As a result of modification, the maximum power demand was revised upward by 2.0 %. To compensate for the recent power supply shortage, new generation units need to be installed, GT7 in Rusail PS and GT4 in Manah PS, and existing generation units in Rusail and Ghubrah PS should be augmented by water injection for next summer. The expanded generation capacity from 1998 to 2010 will be 1167MW, including a retirement of 460MW of old units. (Generation expansion plan, see Annex:2-2-a)

②Wadi Jizzi System

Like the Muscat system, Wadi Jizzi requires about 90 MW of improved power development before next summer, GT12 and GT13, including water injection. The expanded generation capacity from 1998 to 2010 will be 248MW including a retirement of 81MW of old units. (Generation expansion plan, see Annex:2-2-b)

(3) Examination of System Interconnection

Wadi Jizzi is a small capacity system and the power demand growth rate is relatively high. To secure the specified level of reliability, an increase in capacity must be developed. However, the following restraints must also be considered.

- System size prohibits the development of a large capacity unit (95 MW class).
- When a relatively large capacity unit (60 MW class) is developed, operation requires a spinning reserve equivalent to the largest generator.

These conditions require frequent development of small capacity units (30 MW class) and have caused a supply capacity shortage in recent years.

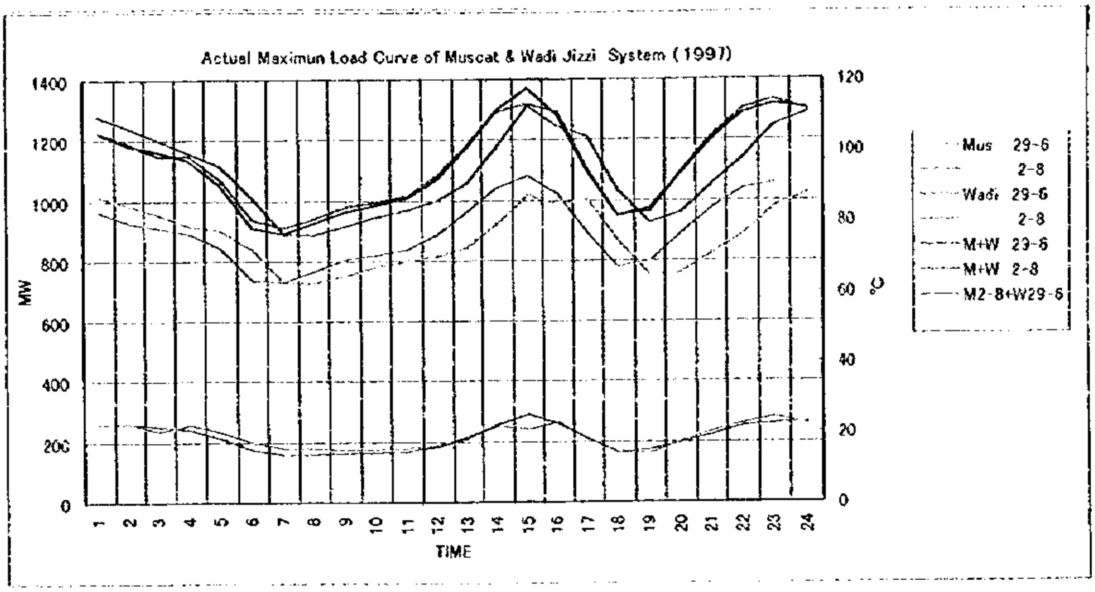
After calculation, the diversity of maximum demand between the Muscat system and the Wadi Jizzi system is about 4%. This figure was 2% in 1996. (See Annex: 2-2-c) Furthermore, a 2% maximum-demand diversity factor between the Muscat and Wadi Jizzi systems can be expected. Accordingly, the system interconnection should allow for a power source reduction equal to 2% of the total capacity.

(Table 2-2-1 Actual Maximum Load Curve of Muscat &Wadi Jizzi System (1997)

	Muscat		Wadi Jizzi		Muscat +Wadi Jizzi		
	Mus 29-6	2-8	Wadi 29-6	2-8	M+W 29-6	M+W 2-8	M2-8+W29-6
1	1014	964	264	262	1278	1226	1228
2	981	924	260	263	1241	1187	1184
3	952	912	250	235	1202	1147	1162
4	914	892	242	255	1156	1147	1134
5	903	841	212	232	1115	1073	1053
6	837	738	173	199	1010	937	911
7	731	730	161	181	892	911	891
8	727	763	160	177	887	940	923
9	751	803	163	176	914	979	966
10	780	819	165	174	945	993	984
11	797	836	171	178	968	1014	1007
12	815	888	183	191	998	1079	1071
13	845	964	213	216	1058	1180	1177
14	921	1042	258	251	1179	1293	1300
15	1018	1080	293	240	1311	1320	1373
16	986	1024	261	268	1247	1292	1285
17	1004	889	208	210	1212	1099	1097
18	867	782	166	166	1033	948	948
19	751	801	175	164	926	965	976
20	762	893	197	203	959	1096	1090
21	825	976	225	234	1050	1210	1201
22	888	1039	251	263	1139	1302	1290
23	979	1054	264	280	1243	1334	1318
24	1020	1037	268	263	1288	1300	1305

Diversity Factor; (1080+293)/1320=1.04

Coincidence Factor ; 1/1.04=0.962



The results of examining the possible interconnection between the Wadi Jizzi and Muscat systems are summarized hereafter.

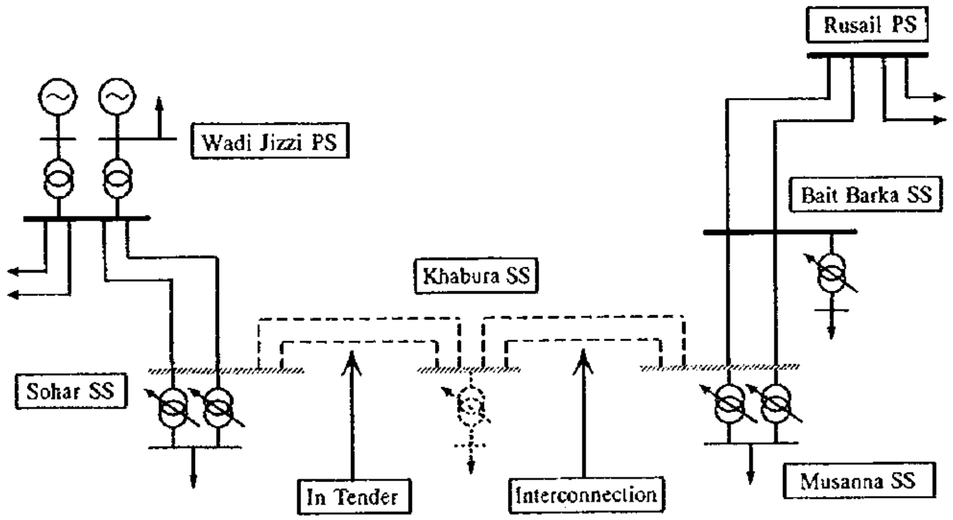


Figure 2-2-1 Interconnection line between Wadi Jizzi and Muscat System

① Financial Evaluation

a. Reduction of Spinning Reserve

- With this interconnection, the Wadi Jizzi system can share its spinning reserve with the Muscat system and reduce its present spinning reserve (maximum capacity: 30 MW) to zero.

Calculating the generation expansion capacity of the interconnected and isolated cases, the interconnected case proved that from 2001 to 2018, new generation capacity can be reduced by 176MW with the elimination of spinning reserves and the peak-time diversity of both systems. This will significantly lower investment costs.

b. Construction Costs of 132 kV Interconnection Line

- Interconnection line (Musanna Grid SS ~ Khabura Grid SS)
  400 mm^2 × 2 cct × 70 kM: 5,830,000 RO

- Difference in 132 kV bus configurations of the interconnected grid SS
  (Musanna & Khabura Grid SS)
  Increment due to interconnection: 1,700,000 RO

Total construction costs of Interconnection: 7,530,000 RO

Overall reduction in investment costs (present value) 15,285,000 RO
(See Annex 3-3-i)

c. Operation of the Wadi Jizzi Power Station at Higher Efficiency

The gas turbines of the Wadi Jizzi PS are operated below full power so a spinning reserve (30 MW) is always secured. As a result, the average operating load factor is about 53 % (based on the records of 1997). If the Wadi Jizzi system is interconnected with the Muscat system, the gas turbines can be operated at a higher load factor corresponding to the elimination of this spinning reserve with a fuel expense reduction of about 13.9 %.

Reduction of annual fuel expenses of the Wadi Jizzi PS:
7,988,000 RO (fuel expenses of 1997)*0.139= 1,110,000RO

Reduction of fuel expenses 2001 to 2018 : 15,537,000 RO
(Conditions: Interconnection at 2001) (See Annex 2-2-e and Annex 3-3-i)

Net Present Value of Interconnection 30,822,000 RO
(See Annex 3-3-i)

②Benefits in Daily System Operation

After the initial interconnection, but before the full installation of monitoring and control functions, such as central control and remote communications:

- Under normal conditions, both systems will balance demand and supply, as before, keeping the interconnection tie flow to a minimum.
- If a fault occurs in the Wadi Jizzi system, the system can receive relief power.

③Necessity of a Central Load Dispatching Center

Interconnection will increase the scale of the systems and their complexity. This, in turn, will require improvement in supply reliability and more economical system operations. In the near future, introducing a central load-dispatching center that includes, but is not limited to, the following functions, will be necessary.

- Monitoring and control of power flow
- Frequency control of systems
- Automatic control of system voltage
- Economical demand and supply adjustment
- Early recovery from system fault

④Other Related Issues

Even now, the voltage drops of Saham, Dank, and Ibri SS in the Wadi Jizzi system, and Khabura and Musanna SS in the Muscat system, are serious problems. They must be solved quickly, and solved independently of the issue of interconnection. However, this is being examined as a problem of system interconnection. (See Chapter 4)

⑤Conclusion

The economic merits of interconnection are so significant that the system interconnection should be materialized as soon as possible. For the time being, there is no emergency relief power because both systems lack enough supply power and should only be interconnected after supply power is deemed sufficient. The central load dispatching functions should be developed and expanded within the range of these merits. Detailed investigation is required to determine the necessary level of central load dispatching functions, steps for expanding functions, and required investments.

2-2-2. Plan for Power Demand and Supply

(1) Present State of Power Demand and Supply

- Presently, Oman has no system to examine the state of demand and supply or operations of the national or primary systems. Thus, there are no plans for demand and supply.

- Demand and supply adjustments help to control the economics and reliability of the power output for each power station; no one currently bears these adjustment duties. MEW owns these facilities and is responsible for their operation and maintenance. If a problem occurs, such as a tripped unit, these power stations compensate by increasing the number of units operated in parallel. This is a very inefficient operation.

- In the future, when the system interconnection is implemented, system capacities will increase further, meaning higher supply reliability and more economical operations will be required.

(2)Necessity of Economical Demand and Supply Operations

A demand and supply operation program has been developed that is easy to understand and offers simple, economical techniques for daily control center operations members and the planners in MEW. After discussions with control center operators, the program was revised by considering operational restraints and connecting actual data files. This program is practical for daily operation planning and evaluation.

The economical demand and supply operations of this program are summarized below.

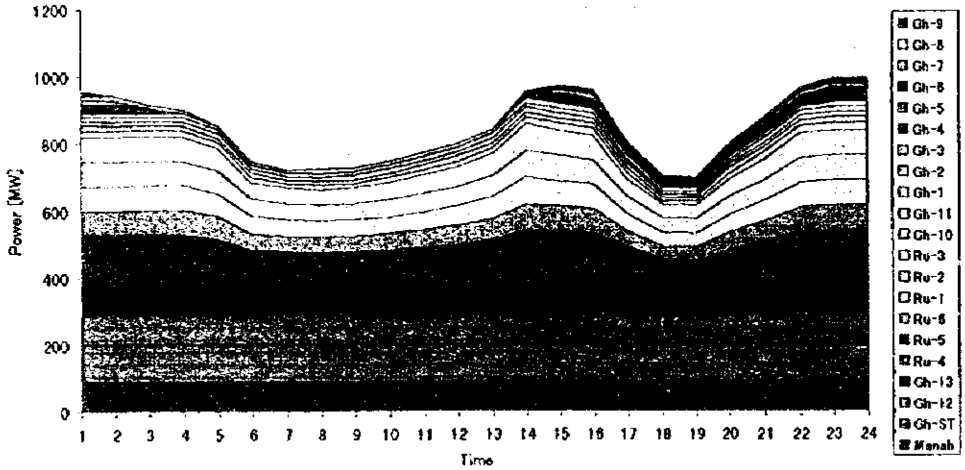
- The steam turbine units at Ghubrah PS for desalination and the units at Manah PS are used prior to other units. The operation of Manah units is determined by contract. (This item can be changed to make the Manah units work with other units in parallel.)

- More efficient base units (Ghubrah PS 12, 13 & Rusail PS 4~6, 1~3) continually supply full output to meet hourly demands.
- Less efficient peak units (Ghubrah PS 10, 11, 1~9) deliver output and keep the spinning reserve, which is equal to the capacity of the largest unit.

①Comparison of Actual versus Economical Operation

A typical summer day (1-August-1997) was selected to compare actual operations with the economical operations in the Muscat system. (Figure 2-2-2)

Actual Operation



Economical Operation

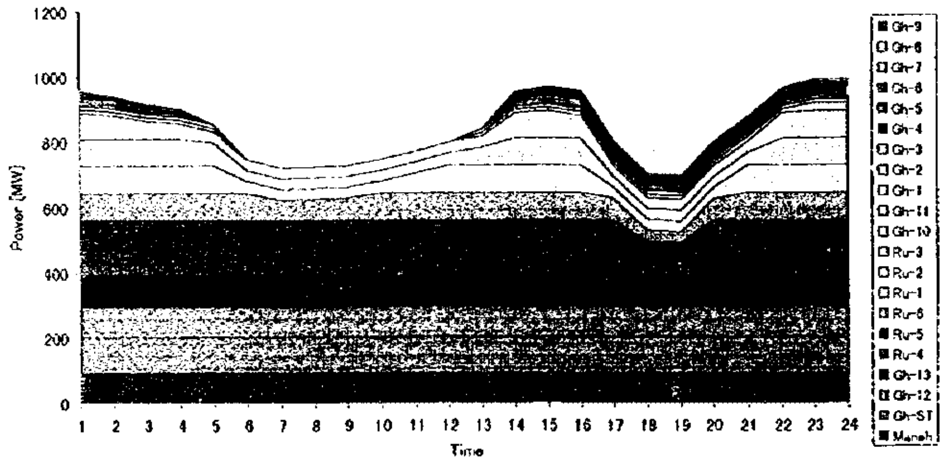


Figure 2-2-2 Difference of Actual Operation and Economical Operation (1-8-1997)

Table 2-2-2 Comparison actual operation with economical operation (1-8-1997)

		Actual Operation	Economical Operation
Base Units Average Output (MW)	Ghubrah PS(12,13)	90 MW	94 MW
	Rusail PS (1~6)	62	69
	Average	69	75
Average Spinning Reserve		201	159
Gas Fuel Cost / Day (1000 OR)		107.4	103.6

Compared with the actual operation, the economical operation is as follows

- The number of units in parallel can be reduced, saving 42MW of hourly spinning reserves.
- Economical operation can reduce gas fuel costs by 3.5% with a 6MW increase in the average outputs of efficient base units instead of peak units.

②Fuel Cost Saving by Economical Operation and Necessity of a Central Load Dispatching Center

Estimates of yearly gas fuel costs were made by examining the load-curve through typical days, such as peak season, off-peak season and days in between. With the introduction of an economical load dispatching function, the results are as follows.

During the peak season, there is no room to operate economically. Almost all units operate at full output in order to meet the high loads and the merit is about 3.5%. In off peak or middle season when the load is fairly light or load fluctuation is large, economical operation results in merits of 6~14% because more efficient units can be selected to work in parallel.

Table 2-2-3 Fuel cost saving in different seasons

	Typical Day	Merits of Gas Fuel Cost/Day	MWh/Day
Peak Season (June~August)	1-8	3.5 %	20,300
Off Peak Season (Nov.~Apr.)	14-1	6.0%	7,500
Middle Season (May, Sep., Oct.)	1-5	14.2%	14,000

Yearly Merits of Fuel Cost; 20,300/12,330*3/12*3.5% + 7,500/12,330*6/12*6.0% + 14,000/12,330*3/12*14.2% = 7.3%

The Muscat system's yearly gas fuel costs (Ghubrah PS & Rusail PS) are approximately 24,250,000 RO in 1997. The merits amount to about 1,800,000 RO.

Economical, computer-based demand and supply coordination functions, which are part of the proposed central load dispatching center, will offset required investment costs. Introducing a central load dispatching center is recommended, when the interconnection between the Muscat and Wadi Jizzi systems is completed, and system capacity increase further requiring improved supply reliability and more economical operations.

Chapter 3

Financial and Economic Evaluation

3. Financial and Economic Evaluation

3-1. Objectives and Methodology of Financial and Economic Evaluation

3-1-1. Objectives of Financial and Economic Evaluation

Objectives of Financial and Economic Evaluation are, in general, to show criteria of decision making of whether a certain project should be adopted or not, or which out of more than one alternatives should be selected, by making numerically clear their profitability. Though the words of "Financial and Economic Evaluation" are used in this report, the words of "Economic Evaluation" seem to be used more often in the same meaning. "Economic Evaluation" in a broad sense is divided in "Financial Evaluation" and "Economic Evaluation" .

"Financial Evaluation" is going to show a criterion of judging whether they should invest their money in a certain project or not, from an owner, investor or banker's point of view. "Economic Evaluation" is, on the other hand, going to show a criterion, in numerals, of judging whether an investment should be made or not in a certain project for a public benefit or in a similar nature. In this case, not only the profitability of the project, but also its significance and consequences to the national economy should be taken into consideration from the public benefit's point of view. It is common that "Financial Evaluation" is practiced prior to "Economic Evaluation," and the factors of the former are modified and developed into those of the latter.

3-1-2. Methodology of Financial and Economic Evaluation

(1)Cash Flow Analysis

In both "Financial Evaluation" and "Economic Evaluation," method of calculation is equally based on general accounting rules. Methodology of analysis should be provided with objectiveness, consistency and continuity so that the result of analysis can be compared among different projects or ones of different time, and accepted among the persons of even different advantages. "Cash Flow Analysis" is often adopted as a suitable method of analysis to meet such a requirement.

Input and output will take place in any kind of projects and there must be outflows and inflows of cash, accordingly. It is what we call "Cash Flow Analysis" to classify these cash outflows and inflows on a certain basis, calculate Net Cash Flow and analyze the results.

(2)Calculation of Net Cash Flow

When revenue is expected in a project, it should be listed in an item of Cash Inflow, while Cash Outflow consists of fixed capital, operating capital, operation cost, interest, tax and so on. Depreciation and Deferred assets in usual income statements should be excluded from operation cost, because they do not cause Cash Outflow. Then, Net Cash Flow in every year of project life can be calculated.

The following four methods of evaluation analysis can be possible, based on the above information.

①Net Present Value Method
②Internal Rate of Return Method
③Pay Back Period Method

④Least Cost Method

(3)Present Value

Money does not change its face value even after many years, as far as it is put in a safety box. Once it is, however, utilized as one part of management resources, it is possible to get distribution of added value, which has been created as a result of using such resources. When money is deposited to a bank, some amount of interest can be earned as a result of its use in creating value.

When the interest rate of bank deposit is 8% per annum, the present Riyal Omani 100 will get RO 8 as an interest after one year. Namely, the present RO 100 has the same value as RO 108 after a year. In other words, RO 108 after a year is equal in value to the present RO 100.

In a country or in a society, an increase rate for a year in the value of money is generally acknowledged to be the rate "i", then, "i" is called "Social Discount Rate." And money at the different time can be compared in terms of present value, by using such equations as follow:

Price of RO X after n years $= X(1 + i)^n$
Present Value of RO Y after n years $= Y/(1 + i)^n$

Since cash outflow and inflow will take place for a long time of more than 10 years or, sometimes, more than 20 years, the concept of present value is essential in Economic Evaluation,

(4)Net Present Value (NPV) Method

One of the most popular methods for analysis, used in Economic Evaluation is Net Present Value Method.

NPV = Present Value of Cash Inflow − Present Value of Cash Outflow

In actual calculation, Net Cash Flow in every year in a project life is counted first, and then NPV is computed at once. When NPV of a project is positive, the project is worth investing. The larger its NPV, the higher its profitability. However, NPV varies significantly due to the change of discount rate or project period, the absolute value of NPV does not have much meaning in itself. When more than one project on the same premises are compared, the absolute value of NPV can be a good criterion of selection. When a single project is evaluated, however, once its NPV is turned out to be positive, then the project can be selected regardless of its absolute value.

3-2. Prerequisites and Parameters of Economic Analysis

3-2-1. Prerequisites

(1) Accounting Standard

Accounting Standard is based on "International Accounting Standards," which has been adopted by MEW as "Commercial Accounting Basis." Titles of accounts in cost accounting will follow suit with those of MEW as much as possible. However, it is also acceptable to sum up a few accounts in "Operation & Maintenance," if breakdown is not necessary.

MEW's items of cost accounting

Within Power Station	Fuel, Manpower, Spare Parts, Depreciation, Financing Cost, Insurance and Others
Out of Power Station	Depreciation, Financing Cost, Spare Parts, Maintenance, Insurance, MEW Administration Expenses, Billing Charges and Power Purchases

MEW Administration Expenses are allocated to each accounting unit at the end of a year, according to the book value of assets.

Next, a definition of fixed costs and variable costs in a cost analysis is as follows:

Fixed costs	Manpower, Maintenance, Depreciation, Financing Cost, Insurance, MEW Administration Expenses, and Billing Charges
Variable costs	Fuel, Spare Parts, Other consumables, and Power Purchases

(2) Base Year

The base year of current price is to be 1998, that is taken as Year 0. Investment is to be conducted in Year 0 except a special case, and the amount of investment is put in Assets at the end of Year 0. Business operation is to start from Year 1.

(3) Project Life

Project Life is to be 20 years at the longest in this report, though 5 to 10 years are appropriate for a usual project life, because the term of depreciation of assets in power station was 20 years. However, it was revised in 1997 from 20 years to 25 years and the term of depreciation of assets out of power station was revised from 30 years to 40 years. As a consequence, the project life will remain to be 20 years, while the residual book value will be listed in Year 21 and revenue and expenses after Year 21 will be excluded from accounting.

3-2-2. Parameters

(1)Construction Cost of Gas Turbine

In this report, the following prices (current price in 1998) will be used as construction costs of gas turbines:

①Gas Turbine	Frame 9-E	94.1MW	RO13,850,000
②Gas Turbine	Frame 6-B	30.0	RO 6,660,000

However, when a construction cost of a substitute gas turbine in an economic evaluation of a new technology is computed, the following price (current price in 1998) will be used:

RO 160,000 per MW, or RO160 per kW

In the price, an incremental factor for the planned Barka power station is added onto the price mentioned at above ①.

(2)Interest of Project Finance

It is considered that all existing assets of MEW are raised by loans from the Ministry of

National Economy under the following conditions:

Interest rate　4% per six months (compounded annual rate: 8.16%)
Repayment　Equal installment per half year from capital and interest
However, repayment is made once at the end of a year, so the actual rate of interest, 8.16% is applied.
Reference: $(1+0.08/2)^2 - 1 = 0.0816$

Term of loan　All assets　20 years

(Reference) Interest rate of loans except MNE

①Project Finance of Ministry of Commerce and Industry (MCI)
(Fixed capital for more than RO200,000)　3%
Maximum amount　1.5 times of paid up capital or RO 5,000,000 (2 times in the districts out of Muscat)
Term of loan　15 years (equal repayment of capital once a year, including 5 year grace period in the beginning)

②Project Finance of Omani Bank of Development
(Fixed capital for up to RO200,000)　3%
Term of loan　5 years (equal repayment of capital once a year)

③Project Finance of commercial banks　9%
(Fixed capital)
Term of loan　4-10 years (equal repayment of capital quarterly a year, including 1 to 2 year grace period in the beginning)

④Project Finance of commercial banks　8-10.75%
(Operating capital)　Term of loan　4 years

⑤Consumer loan of commercial banks, British Bank as of Jun. 24, 1998
Term of loan: Within 1 year　12%
Term of loan: 1 to 5 years　13%

⑥Interest rate of deposit in commercial banks, British Bank as of Jun. 24, 1998
Fixed deposit for 1 month　6.5%
Fixed deposit for 1 year　8.0%

(3) Discount Rate

A discount rate, at which the current prices listed in after Year 1 are converted to the present value in 1998, is to be 8%. A discount rate is often mixed up with an interest rate. However, a discount rate is considered to be an increase rate of the value in the long run, which will be created as a result of utilization of money as one of management resources, as described before. Therefore, it is a basic, long-term and fixed index, while an interest rate fluctuates from time to time according to a short-term demand and supply of money or inflation, though it keeps co-relation with a discount rate.

On the other hand, a discount rate compares with profitability in investment. It is considered in general that a discount rate stays at a lower level than profitability in investment and is ranked at the marginal profit among the order of preferable investments.

It is internationally accepted that a discount rate falls in the range of 6% to 12%. Thus, a discount rate of 8% is considered to be reasonable for Oman, taking the stability of its economy in the long run into account.

(4) Depreciation

Rules of Depreciation in this report are as follows, in accordance with MEW standards, which were revised in 1997:

Term	Gas turbine	25 years
	Transmission and distribution	average 40 years
Method	Straight line method	
	Residual value	0 (Book value: RO 1)

(Reference) General standard of depreciation in Oman

Terms of depreciation adopted in the private sector are as follows:

Solid first-class buildings	25 years
Second-class buildings	6.6
Bridges, pipelines, railway lines	10
Cars, transportation equipment, heavy equipment	3
Equipment and implements	6.6
Aircraft and ships	6.6
Hospital buildings, educational establishments	1

(5) Insurance

Insurance is assured at the following rate with the Ministry of National Economy as assuror. MNE assures it again with reliable insurance companies in the world. The current premium rate has been revised in 1997.

Premium rate 0.02% per annum (against book value of assets)

(6) Corporate Tax

Since MEW's projects are national undertakings, corporate tax is not applicable to them. However, Independent Power Producer (IPP) must pay the corporate tax, described in the following:

Corporate tax in Oman should have been levied since 1995. However, Omani companies except 100% foreign companies are exempted from corporate tax for 5 years from the start of their operation (substantially 10 years with another 5 year extension.)

Tax rates for Omani companies are as follows:

①Omani capital is equal to or more than 51%

Profit	Tax rate
Up to RO 30,000	0
RO 30,000 - 200,000	5.0%
Above RO 200,000	7.5%

②Omani capital is less than 51%

Profit	Tax rate
Up to RO 30,000	0

RO 30,000 - 130,000	15%
RO 130,000 - 280,000	20%
Above RO 280,000	25%

(7) Inflation

A factor of inflation is not to be taken into consideration. The reasons are:

①Prices of Input and Output in a project will change as time passes. However, if the changes affect both Input and Output almost at the same rate, these affects will offset with each other and give no impact on the result of economic evaluation.

②The consumer price indices in Oman had been kept at a very stable level of not more than 1% from 1992 to 1995, except 1.1% in 1993, according to the official release. The inflation rate through 1996 to 2000 is targeted to be less than 1% per annum in "The Fifth Five Year Development Plan."

(8) Exchange Rate

Exchange rate of Rial Omani (RO) against US Dollar has been kept at the following fix rate for a long time.

Rial Omani (RO) 1 = US$ 2.58
US$ 1 = RO 0.388

(9) Custom Duties

Custom duties in Oman are classified in the following 4 categories:

Items	Rate
①Alcoholic	100%
②Pork	100%
③Tobacco	70%
④Others	5%

However, even in category ④, there are 21 items of food and other daily necessities and so on, which are exempted from custom duties. In this report, custom duties are not to be taken into account, because "Commodities which Government organizations directly import" are included in such exemption.

3-3. Financial Analysis of Power Supply Business

The total balance of revenue and expenses of Power Supply Business, which MEW had achieved in 1997 is shown in Annex 3-3-a "Production Cost at Consumer End," Annex 3-3-b "Unit Cost at Consumer End" and Annex 3-3-c " Unit Cost at Exported from Power Station." (Sources: MEW's Annual Report, 1997)

Analysis will be made in the following categories according to the Annual Report:

(1)Muscat	Total of Ghubrah PS and Rusayl PS
(2)Manah	Manah PS
(3)Wadi Jizzi	Wadi Jizzi PS
(4)Rural	Total of 27 PSs with diesel turbines in rural districts

Though the Manah PS is owned and operated by an IPP (Independent Power

Producer,) it is included in MEW, as far as statistics are concerned.

3-3-1. Generation and Consumption of Electricity

Installed capacities of power stations by category are as follows:

Table 3-3-1 Installed Capacity

Category	No of PS	Turbine	Capacity MW	%
Muscat	2	Gas	1,037	57.8%
Manah	1	Gas	84	4.7%
Wadi Jizzi	1	Gas	278	15.5%
Rural	27	Diesel	395	22.0%
Total	31		1,794	100.0%

(1)The total generation of electricity in 1997 was 7,318 GWh. (7.6% increase against 1996)

(2)Electricity exported from power stations was 6,949 GWh, that is 95.0% of total generation. The remaining 5.0% was consumption in power stations and desalination plants.

(3)Total consumption of electricity at consumer's end was 5,623 GWh, which was 76.8% of total generation or 80.9% of electricity exported from power stations.

(4)The difference between exportation and consumption was 18.2% of generation, which has worsened by 1% from 17.2% in 1996. Its cut down must be one of the most important targets, which MEW should challenge to achieve.

Table 3-3-2 Electricity Generated

Energy	GWh	%
Generated	7,317.7	100.0%
Exported	6,948.6	95.0%
Billed	5,623.0	76.8%

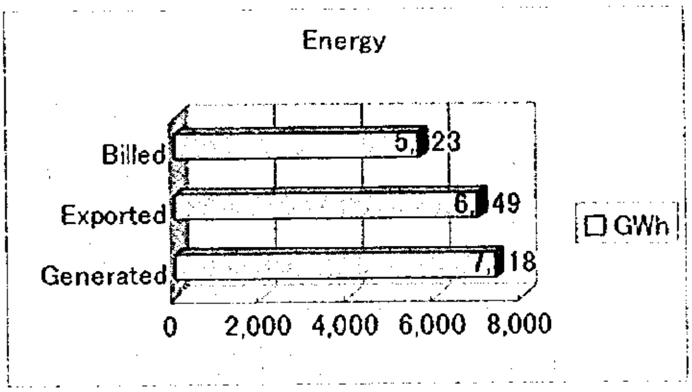


Figure 3-3-1 Electricity Generated

3-3-2. Production Cost

(1)The unit cost of electricity at consumer's end was 26.2 Bz/kWh, which has improved by 6.4% against 28.0 Bz/kWh in 1996.

(2)The average unit tariff, which consumers paid, was 15.1 Bz/kWh (57.5% of the total unit cost) and it could not reach even 18.8 Bz/kWh, which was the cost of electricity exported from power stations.

Table 3-3-3 Production Cost

Production Cost	Million RO	bz／KWh	%
Fuel	66.98	11.5	43.9%
Others within PS	42.51	7.3	27.8%
T/D Cost	30.39	5.2	19.9%
MEW Administration	8.89	1.5	5.8%
Billing Charges	3.88	0.7	2.5%
Total	152.65	26.2	100.0%

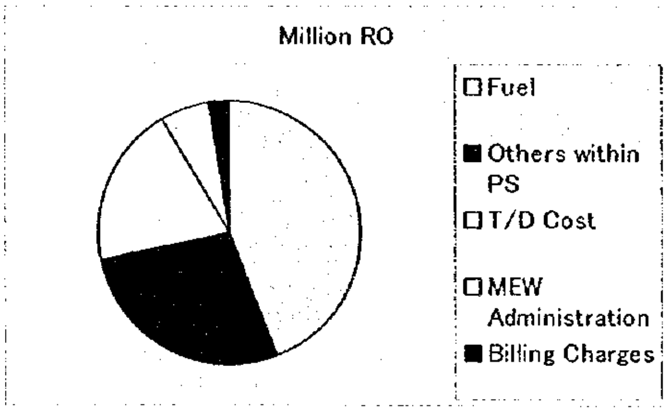


Figure 3-3-2 Production Cost

(3)Production cost by category is shown in Table 3-3-4. It is clear that the generation cost of rural power stations is as three times high as that of Muscat system. The main reason is the fuel cost, as shown in the following tables and figures.

Therefore, the conversion of rural power stations from diesel to gas turbine should be pursued as one of the most urgent tasks.

Table 3-3-4 Production Cost

Bz/kWh

Category	Muscat	Wadi Jizzi	Manah	Rural	Total
Generation Cost	12.916	15.362	27.250	38.639	18.798
Cost outside PS	4.607	9.604	17.940	9.796	7.410
Production Cost	17.523	24.966	45.190	48.435	26.208

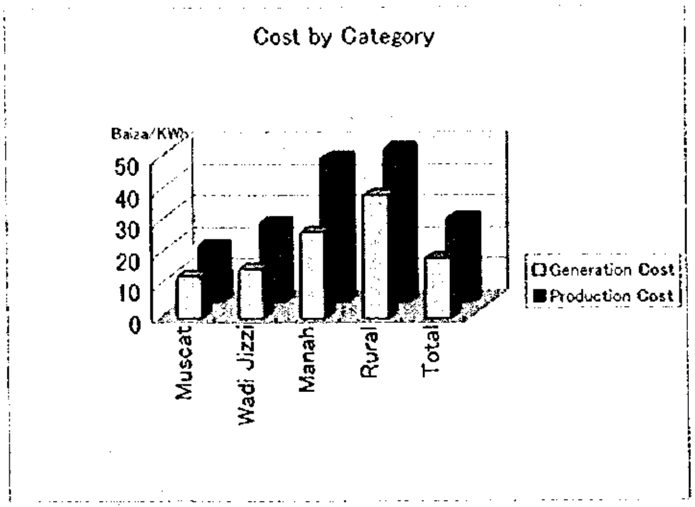


Figure 3-3-3 Production Cost by Category

Table 3-3-5 Fuel Cost

Bz/kWh

Category	Muscat	Wadi Jizzi	Manah	Rural	Total
Fuel Cost	8.155	9.456	8.242	27.411	11.499

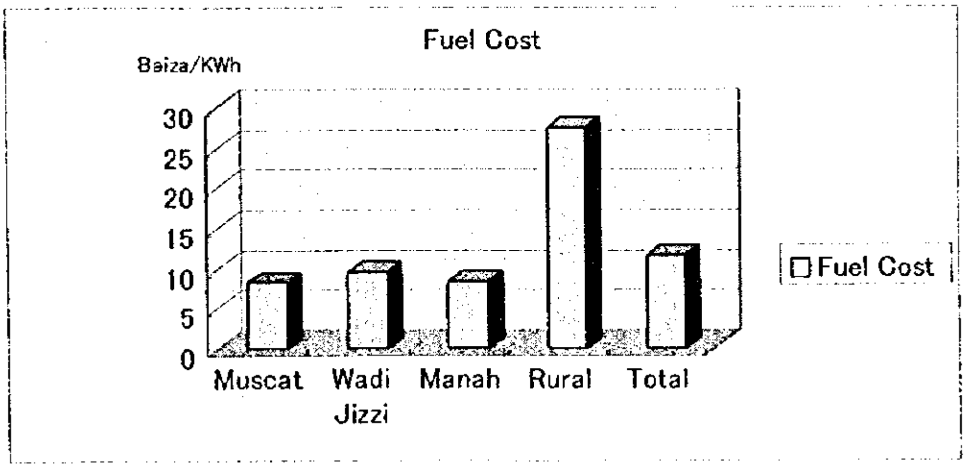


Figure 3-3-4 Fuel Cost by Category

(4)Government subsidy was 11.144 Bz/kWh (42.5% of production cost) , the total amount of which came up to RO 64.9 million in 1997, though it was reduced by RO 5 million from RO 69.9 million in 1996. In other words, the Power Supply Business is still suffering from this huge amount of deficit.

Looking in more details by category, 50% of the government subsidy was disbursed to cover up the deficit which was derived from the high cost of generation by small-scale diesel turbines in rural areas.

Table 3-3-6 Government Subsidy RO1000

Category	Muscat	Wadi Jizzi	Manah	Rural	Total
Govt. Subsidy	6,200	9,973	16,160	32,577	64,910
Billed	54,955	11,132	8,125	13,534	87,746

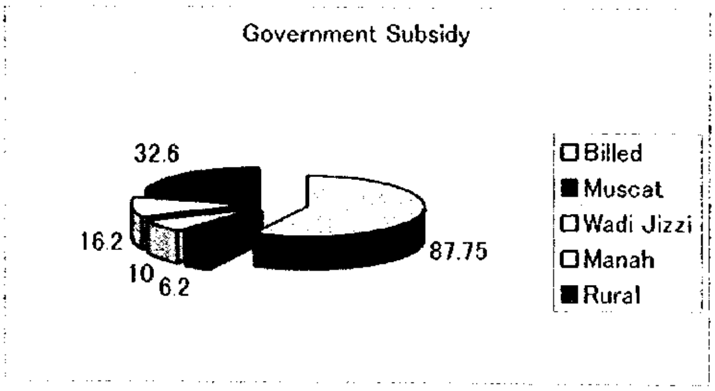


Figure 3-3-5 Government subsidy by Category

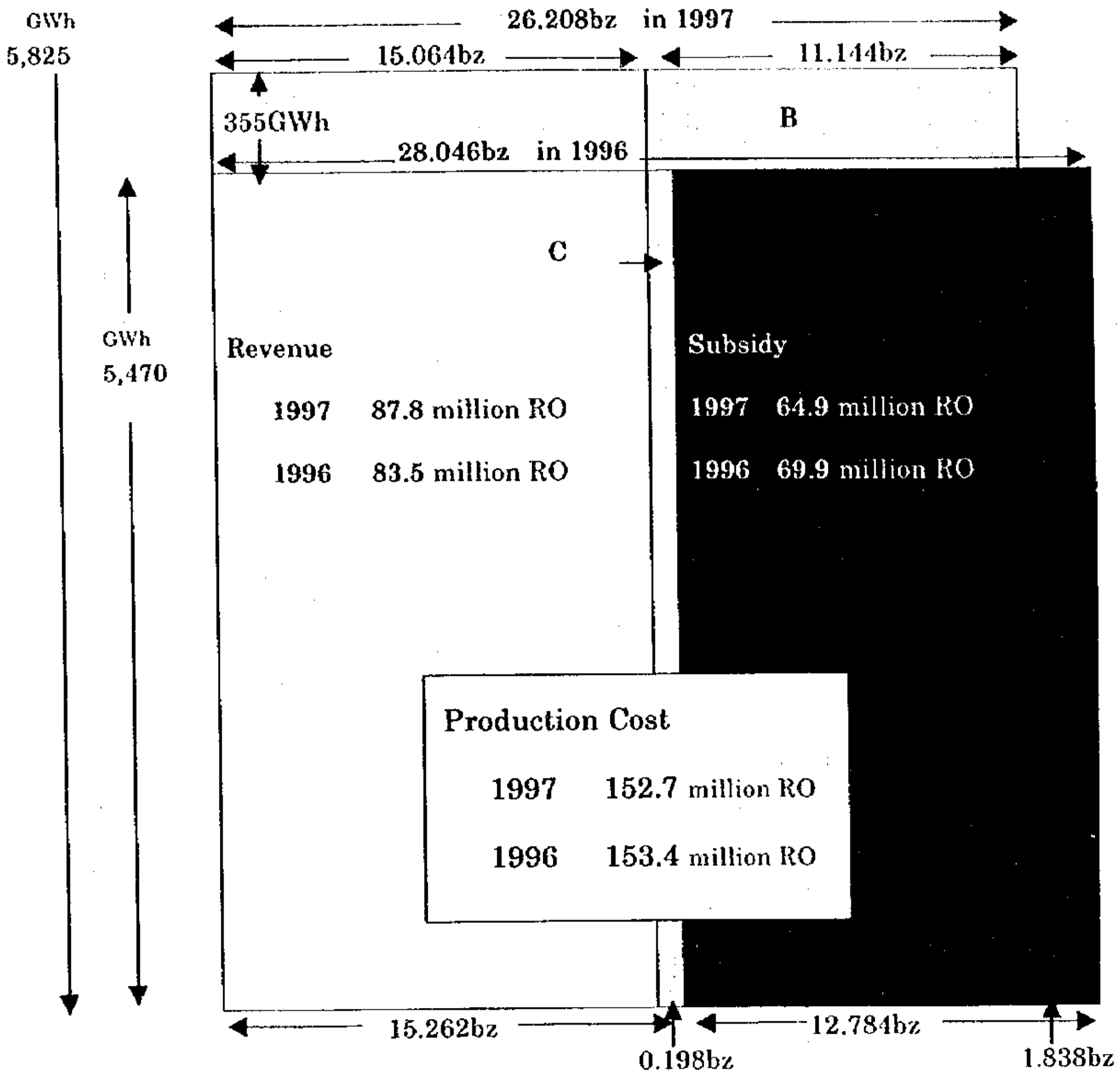
3-3-3. Analysis on Reduction of Government Subsidy

The government subsidy in 1997 was reduced by RO 5 million from RO 69.9 million in 1996. Figure 3-3-6 shows the causes of the above reduction. According to the figure, the reduction by the cost down amounts to RO 10.05 million ("A" in the figure), which was derived from the unit cost reduction from 28.046 Bz/kWh in 1996 to 26.208 Bz/kWh in 1997. However, the cost reduction itself was brought about by the reduction in capacity cost as a result of the change of depreciation standards, not by the effort of cost reduction in a real sense.

On the other hand, RO 3.96 million of the total reduction ("B" in the figure) was offset by the increase of electricity consumption by 355GWh from 5,470GWh in 1996 to 5,825GWh in 1997. Furthermore, RO 1.08 million of the total reduction ("C" in the figure) was offset by the decrease of the revenue by 0.198 Bz/kWh from 15.262 Bz/kWh in 1996 to 15.064 Bz/kWh in 1997, and eventually the effect of cost reduction was curtailed to RO 5.01 million.

It is very difficult to diminish the government subsidy only by means of cost reduction, because the deficit increases as the consumption of electricity grows. In order to eliminate the government subsidy, therefore, some drastic measures of increasing revenue will be necessary.

Cause Analysis of Reduction in Government Subsidy



A: Plus Effect by Cost Down	(28.046 - 26.208) bz x 5,470GWh = 10.05 million RO
B: Minus Effect by Increase in Production	11.144bz x (5,825 - 5,470) GWh = 3.96 million RO
C: Minus Effect by Decrease in Revenue	(15.262 - 15.064) bz x 5,470GWh = 1.08 million RO
Total	10.05 - 3.96 - 1.08 = 5.01 million RO

Figure 3-3-6 Structure of Government Subsidy

3-3-4. Proposals for Financial Soundness

The power supply business has a large amount of deficits every year, and the loss has been offset by government subsidy so far. However, such a situation is not sound. It is, therefore, an urgent task to improve the profitability of the business and balance its revenues and expenditures. MEW has revealed the policy of accelerating the privatization of the electricity business. In order to go ahead with the privatization, it is definitely necessary to improve profitability. In this regard, we would like to propose the following measures:

(1) Conversion from Diesel Oil to Natural Gas

The higher costs of diesel generation in rural areas result in a huge amount of losses. It is needless to say that replacing old diesel generators with new efficient generators, gas turbine generators for example, is extremely important. With this understanding, MEW has been tackling this problem and planning the construction of gas turbine power stations in the Dhofar and Sharquiya regions with the initiative of the private sector.

(2) Improvement of Load Factor

The heavy electricity demand for air conditioning has caused a fundamental problem of low load factor in Oman. The gap between the summer season and the winter season is very large. Because of this problem, the power plants only operate at only 50% of their capacity. It is very difficult to deal with this discrepancy in demand. However, the best effort must be made to improve efficiency of operation by reducing the peak demand and increasing the base load during low load operation. The methodology of DSM is useful to reduce peak demand.

(3) Improvement of Thermal Efficiency

The thermal efficiency of power plants is not good because the present operation method is not systematized. It is possible to improve the thermal efficiency through an integral planning and operation of turbines. For that purpose, we would like to propose the following measures:

① Interconnection between the Muscat system and the Wadi Jizzi system
② Construction of a central load dispatching center and operation of turbines with an economical load distribution program

In addition, operation and maintenance of all the main power stations in the northern grid have been consigned to private companies by contract for 3 to 4 years. According to the contracts, fuel, spare parts, electricity and water for home use are supplied by MEW. The biggest concern of operators is how to avoid accidents and power failures, and how to keep the stable operation of the power station. They usually do not pay much attention to improvement of thermal efficiency. Therefore, we would like to propose that MEW plan some incentive schemes for paying back a certain portion of reduced costs to operators, so that they will make efforts in reducing fuel costs.

(4)Reduction of Losses

According to the Annual Report 1997, the net system loss, excluding plant in-house use and desalination, amounts to 16.9% (1,234 GWh). That is an increased of 0.8% (141 GWh) from 16.1% (1,093 GWh) in 1996. The loss rates (loss at transmission and distribution) in advanced countries are less than 8% (1995). In Japan, the Unite States and Germany the losses are around 5%. Since the reduction of loss leads directly to an increase of revenue, more and more emphasis should be put on this point. Regarding loss management, MEW has already launched measures for improvement, and as the first step, it is going to measure the amount of losses by replacing meters at power stations.

In addition, according to the recent operation records at power stations, there are significant differences of between 2-10% in the volume of natural gas purchased from PDO. Fuel consumption is the largest portion, 44%, in the production cost. Keeping accurate records is extremely important in cost management. It is necessary to calibrate meters as soon as possible and also at regular intervals.

(5)Reduction and Deferral of New Investment

According to the Annual Report 1997, the depreciation and financing costs of fixed capital came to 36.2% of the total production costs. We would like to propose the following two measures in order to reduce new investments, which will eventually contribute to lower fixed costs.

①Interconnection between the Muscat system and the Wadi Jizzi system
②Increasing the outputs of existing gas turbines by water injection
③Promotion of DSM

(6)Restructuring of Tariff System

As already mentioned, it will take a long time to eliminate the deficits through cost reduction alone. It seems inevitable to also pursue restructuring of the tariff system to increase revenue. This matter is discussed in Chapter 6.

3-3-5. Integral Investment Plan and Economic Analysis

(1) Integral Investment plan

An integral investment plan for the proposed measures from 1999 to 2010, which are considered to contribute to the improvement of profitability, is shown in Annex 3-3-d. The plan only addresses the Northern Oman Electricity Grid, which includes the Muscat system and the Wadi Jizzi system including the Barka power station that is to be constructed in the future. The Manah system is excluded, because it is operated by an independent power producer. The recommended projects during the 10 year master plan period, from 1999 to 2010, and their investment costs are listed in Table 3-3-7. The details of each project is discussed in other chapters.

Table 3-3-7 Integral Investment Program (1999 to 2010)

No	Project	Investment RO 1,000
1	Interconnection between the Muscat and Wadi Jizzi system	7,530
2	Water injection system to gas turbines	7,330
3	Central load dispatching center	4,000
4	Battery energy storage system (BESS)	(2,500)
5	Replacement of old meters	1,000
	Proposed project total (BESS not included)	19,860
	Investment to new gas turbines	251,280

This investment plan does not include the investment to transmission and distribution facilities, as well as the investment for maintenance under the ordinary yearly budget, which is out of this study's scope. As a result, the total amount of investment from 1999 to 2010 came to about 270 million RO at 1998 price.

(2) Income Statement

With this project list, impacts on the profitability were estimated under different preconditions. The results are shown in the form of preliminary income statement of the Northern Oman Electricity Grid which covers the Muscat and Wadi Jizzi systems. (See Annex 3-3-e and Annex 3-3-f)

The Case 1 was estimated under the precondition that all the proposed measures in this report will be carried out. It is called " Income Statement with Project." The Case 2 was estimated under the precondition that none of the proposals will be carried out and called " Income Statement without Project." The preconditions of accounting are described as notes at the last lines of each table. In an accounting income statement, the factors of depreciation, financing cost and insurance, which are called "Capacity Cost," are naturally included. A summary is shown in Table 3-3-8.

Table 3-3-8 Comparison of Net Income

Unit : RO1,000

Year	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
	1999	2000	2001	2002	2003	2004
Case 1: With Project	-7,277	-8,479	-1,749	-1,519	-3,627	-1,899
Case 2: Without Project	-12,453	-13,119	-10,391	-9,588	-12,728	-12,740
Difference (Without - With)	5,176	4,640	8,642	8,069	9,101	10,841
Accumulation of the above	5,176	9,816	18,458	26,527	35,628	46,469

Year	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
	2005	2006	2007	2008	2009	2010
Case 1: With Project	-1,421	-535	925	2,817	3,083	3,701
Case 2: Without Project	-13,131	-10,982	-10,420	-9,398	-8,581	-8,897
Difference (Without - With)	11,710	10,447	11,345	12,215	11,664	12,598
Accumulation of the above	58,179	68,626	79,971	92,186	103,850	116,448

As a result of the above estimation, it is found that the deficit of the power supply business will be getting smaller year by year, but can not be eliminated till 2007, though it is in the case of "With Project." However, compared with the estimation in the case of "Without Project," it is very clear that "With Project" will bring about significant improvement in the bottom line. The accumulated amount of this improvement through 1999 to 2010 will reach RO 118 million at the current price in 1998. Furthermore, it is possible to make various kinds of sensitivity analysis from Annex 3-3-e. The following are two cases of sensitivity analysis as an example.

①Case 1: Reduction of Loss by 1%

Electricity at consumer's end in the Northern Oman Electricity Grid was 80% of the total generation in 1997. An income statement is shown in Annex 3-3-g, assuming that the loss is improved by 1%. As consumption of electricity does not change, generation of electricity can be reduced as much as the loss of electricity has been cut. The reduction in generation is expected to reach 100GWh / Year on average for 13 years from 1998 to 2010, and the eventual reduction in fuel cost and others will be estimated to be roughly RO 720,000 per year.

②Case 2: Revenue Increase by 5%

Another income statement is shown in Annex 3-3-h, which is based on the assumption that the revenue in the Northern Oman Electricity Grid increases by 5% on top of the increase by tariff restructuring. It is estimated that the revenue will increase by RO 5.0 million / Year on average for 13 years from 1998 to 2010 and the net income turns to be positive from 2001.

(3)Economic Evaluation

There seem to be two issues regarding the difference between the financial analysis and economic analysis. One is the transferred electricity price to desalination, mining and other public institutions such as the Royal Oman Police, to which electricity has not been charged. The other item is the difference between the marginal cost and the actual transaction price of natural gas. According to the Annual Report 1997, the total amount of the transferred price reached RO 4.4 million. This amount should have been added to the revenue of power supply business, which will change the picture of financial situation of the electricity supply.

In addition to the adjustment mentioned above, the cost of natural gas was examined in the following 2 cases:

①Case 1: Price of natural gas is $ 1.5 / 1000 CFT

The net cash flow in Case 1 was computed as the price of natural gas at $ 1.5 / 1000 CFT, which has been the actual purchase price from PDO since 1995. The total investment is shown in the following table in the next page:

The total net income amounts to RO 521 million (RO 319 million at NPV) in 1998 against the total investment. Net cash flow in a year became negative when investment amount was big enough. However, the NPV of the total net cash flow came to RO 170 million, because the residual book value of investment was also big .

Table 3-3-9 Total Amount of Investment Unit: RO 1,000

Facility	Investment at 1998 current price	NPV in 1998
Power Station	262,610	
Transmission and Distribution	115,454	
Others	8,320	
Total	379,064	149,388

After all, it is concluded that the power supply business is worth investing from the national economic point of view.

②Case 2: Price of natural gas is $ 0.75 / 1000 CFT

In Case 2, the cost of natural gas is assumed as $0.75 / 1000 CFT, as the estimated marginal cost of natural gas. The difference between the actual price and the marginal cost can be regarded as a transfer price from the national economic point of view. The result was that the NPV of the total net cash flow in 1998 came to RO 385 million and the value of investment in the power supply business became far higher.

(4)Cash Flow Analysis of Projects

Regarding the projects studied in this report, the same style of cash flow analysis of each proposal is shown in Annex 3-3-i to Annex 3-3-v Detailed explanation is given in each section.

3-4. Project Finance

(1) Source of financing

There are various kinds of investment projects which are planned for the next ten years. Although private participation is encouraged, MEW still has to undertake many development projects, which require a huge amount of initial investment. One of the biggest issues in securing a stable supply of electricity in the future is project financing. There might be no other way for MEW than to raise funds by means of loans from overseas, because sufficient domestic capital has not been accumulated yet.

There are many organizations that are capable of providing project financing. For example, the International Finance Corporation of the World Bank and the Overseas Economic Cooperation Fund of Japan specialize in providing low interest loans to developing countries. We would like here, however, to introduce the project finance scheme of the Export-Import Bank of Japan (EXIM Japan).

(2)EXIM Japan's Finance

EXIM Japan is a governmental financial institution of Japan and provides the following kinds of finance to corporations in the private sector as well as to governmental institutions in foreign countries:

①Finance to private corporations

a. Buyer's Credits
b. Import Loans
c. Overseas Investment Loans
d. Project Finance
e. Loan Guarantee

②Finance to governmental institutions in foreign countries

a. Un-tied Loans
b. Guarantees for un-tied loans
c. Equity Participation

Among the financing plans above, the following two are the most appropriate for the country to apply for.

a. Loans to foreign corporations in the private sector
b. Un-tied loans to foreign governments

Recently, foreign governments tend in general to avoid giving their guarantees for loans from overseas in the private sector in order not to increase the balance of debt in the public sector. The similar direction has been adopted even in Oman, according to Development Council Resolution No. 71 in 1994.

As stated above, EXIM Japan is ready to provide loans to foreign corporations in the private sector for infrastructure projects like power supply, communication, transportation, water supply and so on. However, this kind of financing is provided only when Japanese exporters or investors are involved in a project. Loans to foreign governments, however, are un-tied -- they are not limited to the projects in which Japanese corporations participate. Therefore, it can be regarded as the best option for Oman.

(3)Terms and conditions of loan

Terms and conditions of loans are based on "The Arrangement on Guidelines for Officially Supported Export Credits," which was established among OECD member nations. Therefore, they do not vary by type of loan. The main points are:

①Interest rate	2.1% Fixed rate
②Object of finance	Total amount of investment Excluding down payment of not less than 15%
③EXIM Japan's loan amount	60-70% of total
④Repayment term	About 10 years Extension to 12 years in case of turbines

(4) Access to EXIM Japan

In case of requesting a loan, an official letter should be sent to :

The Export-Import Bank of Japan
Loan Department II
4-1, Ohtemachi 1- chome, Chiyoda-ku, Tokyo 100-8144, Japan
Tel: +81- 3-3287-9250

It is also possible to ask the Embassy of Japan to help to make necessary arrangements.

(5) Previous EXIM Loans to Oman

It should be mentioned for reference that a provisional loan agreement for the construction of the port of Sohar was signed in June 1998 between the Government of the Sultanate of Oman and the Export-Import Bank of Japan.

Chapter 4

Measures on Supply Side

4. Measures on Supply Side

4-1. System Stabilization Technology and Load Dispatching Operation

Electricity is an infrastructure of life and industry. Electricity must be supplied in a stable way at a constant voltage and a constant frequency without service interruption, and at inexpensive rates. This task will gain in importance more and more with the further development of the society. To achieve such a supply of electricity, it is essential to promote systematic development of plants and equipment according to reliable estimate of future demands, and to operate these plants and equipment efficiently. The following report covers the present state of the electric power systems in Oman, available technical measures for system stabilization, and a load dispatching instruction system for implementing efficient load dispatching operation.

4-1-1. Present State of Power System Operation and Problems

(1) System Configuration

In Oman, there are some independent power systems. As shown in Figure 4-1-1, each of these power systems comprised of, transmission systems of 132 kV and 33 kV, and distribution systems of 11 kV and 415 V.

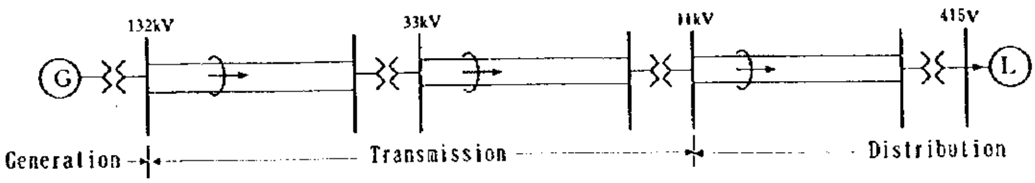


Figure 4-1-1 System Configuration

The configurations of the 132 kV systems of the primary power systems, the Muscat system and the Wadi Jizzi system, are as follows(See Figure 4-1-2 and Figure 4-1-4):

Features of the Muscat power system

The power generating facilities is comprised of three power stations, Ghubrah power station (537 MW), Rusail power station (500 MW), Manah power station (84 MW), for a total output power of 1121 MW. The 132 kV transmission line of the trunk system is comprised of two circuits of 400 $mm^2 \times 2$. In particular, Ghubrah PS, Rusail PS, Wadi Adai SS and Madinat Qaboos SS constitute powerful loop systems. The power system of Manah PS was interconnected with the Muscat system at Rusail PS in October, 1996. Other systems are load feeders. They comprise two circuits of conductors of 400 $mm^2 \times 2$, 400 $mm^2 \times 1$ or 240 $mm^2 \times 1$ depending on the demand scale and local characteristics.

As for transformers, major substations have 125 MVA × 2 transformers, and other substations have 63 MVA × 2 transformers or 40 MVA × 2 transformers. Thus all substations have double banks. As for 132 kV bus of substations, the bus is omitted for load feeding substations; transmission lines and transformers are directly connected to improve the efficiency of equipment. (Figure 4-1-2)

Features of the Wadi Jizzi power system.

The capacity of the Wadi Jizzi system is about a quarter of that of the Muscat system. The power generating facility is Wadi Jizzi PS (278 MW) alone.

As for 132 kV transmission lines, the trunk system, Wadi Jizzi PS ~ Sohar SS, is comprised of two circuits of 400 $mm^2 \times 2$. This is to prepare for interconnection with Muscat system in the future. Other systems are load feeders. Most of them comprise one circuit of thin conductors, 225 $mm^2 \times 1$, 175 $mm^2 \times 2$ or 175 $mm^2 \times 1$ depending on the demand scale and local characteristics. As for transformers, Sohar SS has 125 MVA×2 transformers. Other substations have 60 MVA×2 transformers, 63 MVA×1 transformer, or 30 MVA×1 transformer. As for 132 kV bus of substations, the bus is omitted for load feeding substations; transmission lines and transformers are directly connected to improve the efficiency of equipment. (Figure 4-1-4)

(2) Approach to Expansion of Facilities

The expansion plan of transmission and transformation facilities is based on the N— 1 criteria. The standards are applied to all transmission and transformation facilities. The facilities are expanded in such a way that a single circuit fault on a transmission line or a fault on a transformer will not result in a voltage drop below 90 % of the reference voltage or overload of the remaining facilities. The standard installation of transformers for a 33/11 kV substation is 10 MVA×2 transformers or 20 MVA×2 transformers.

(3) Approach to Supply Reliability

As for voltage fluctuation, during normal operation, the 132 kV system has a target of within ± 5 %, the 33 kV system ± 5 %, the 11 kV system ± 5 %, and the 415 V system ± 6 %, respectively. In case of fault, the target is within ± 10 %.

Regarding frequency, the target is within 50 ± 0.02 Hz. The UF relay system is provided to maintain the frequency. This system uses frequency relays to effect load shedding when the frequency drops excessively due to, for example, generator drop-out. Load control of the first stage is initiated when the frequency drops to 49.3 Hz. The control is initiated in ten stages; one stage corresponds to a drop by 0.1 Hz.

As for electric outage time, there is no special target. During the heavy load season of summer, peak cutting or load shedding is practiced. When an electric outage lasts for a long time, switchover of affected loads is made.

There are no special restraints on operation of the transmission and transformation facilities. As they are constructed according to the N—1 criteria, the failure of a single circuit of the transmission line, or a failure of a transformer does not hinder the supply of electricity.

(4) Actual Records of Power System Faults

Actual records of faults on the Muscat system were examined for a period between 1994 and 1997 (up to the survey in November). It was found that there were about 11 faults on the 132 kV system every year. They are classified by cause as follows:

Facilities (facilities, cables) ....2 faults (18 %)
Operation (control, manual disconnection, overload, etc.) ..... 2 faults (18 %)
Natural disasters (rain, tree) .... 0 fault

People (accident of vehicle, person) .... 0 fault
Unknown causes ....4 faults (37 %)
Momentary fault ....3 faults (27 %)
(For details, see Annex 4-1-a)

There were about 117 faults on the 33 kV system every year. They are classified as follows:

Facilities (facilities, cables) ....35 faults (30 %)
Operation (control, manual disconnection, overload, etc.) ..... 26 faults (22 %)
Natural disasters (rain, tree) .... 7 faults (6 %)
People (accident of vehicle, person) .... 4 faults (4 %)
Unknown causes .... 6 faults (5 %)
Momentary fault .... 38 faults (33 %)
(For details, see Annex 4-1-b)

These findings show that there are very many faults caused by facilities or by operation. This means that faults can be reduced by improving the operation and maintenance of the facilities, the facilities themselves, or system operation.

In the future, electricity will gain more in importance with the development of the society. It, therefore, is necessary to strive to reduce the number of service interruptions. To this end, it is necessary to analyze the causes of faults in more detail, and when appropriate, to take countermeasures, such as improvement of methods of operating and maintaining facilities, improvement of the facilities, and enforcement of the system operation system. In contrast, it should be noted that, in Japan, there are almost no faults caused by facilities. Faults are mainly caused by natural disasters such as typhoon, thunder, snowfall, birds and animals. And most of them are recovered momentarily.

4-1-2. Examination of Supply Stabilization Measures

(1) Examination of System Stability through Simulation Analysis

On the basis of data obtained from the control center, simulation models of 132 kV Muscat system and Wadi Jizzi system were developed. The validity of these model was checked by collating them with data at the control center. Then simulation analyses of the current systems were made to examine problems of the systems and countermeasures. A simulation analysis of the serious voltage fluctuation problem of the 33 kV system of Musanna SS was also made to examine the problem and countermeasures.

①Results of voltage flow analysis and countermeasures

a. Muscat system

The 132 kV Muscat system (Figure 4-1-2) was simulated, and data on power generation and loads supplied by the control center were inputted to make calculation. Results shown in Figure 4-1-3 were obtained. (See Annex 4-1-c)

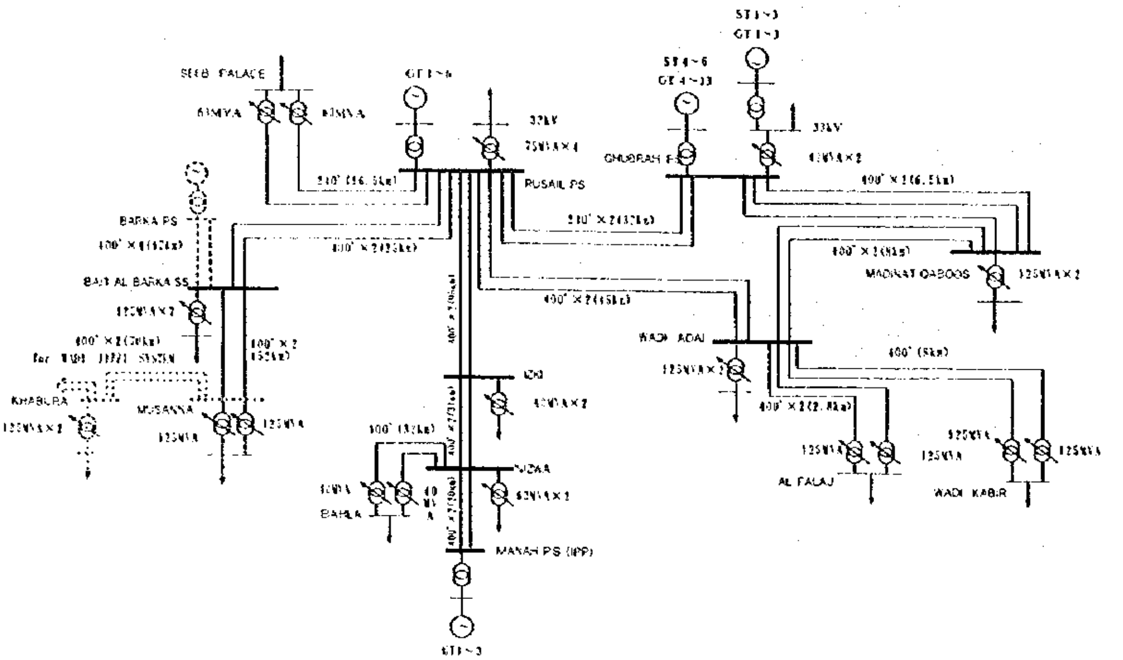


Figure 4-1-2 132kV Muscat System

This diagram shows that as the power factor of the load is bad, the voltage of the entire 132 kV system is dropping. In particular, the voltage at Musanna SS is fairly lower than the target voltage (1.05 ~ 0.95 p.u.), and with the present facilities, the target voltage can not be maintained. (The curve "Peak" of Figure 4-1-3)

One countermeasure against this is to improve the power factor of the loads of the 33 kV system. A method of installing a shunt capacitor (SC) on the 33 kV system to improve the power factor of the 33 kV system load to about 0.95 was examined. With the installation of many SCs (total capacity 255MVA, Musanna SS 10MVA, Barka SS 10MVA, Wadi Adai SS 50MVA, Madinat Qaboos SS 40MVA, etc.; See Annex 4-1-c), the power factor of the 33 kV system load was improved from 0.87 to 0.95, and all the system voltages including that at Musanna SS were improved and present in the target voltage ranges. (The curve "Peak (SC in)" of Figure 4-1-3)

With the installation of the SC, the peak voltage can be maintained. However, there is a possibility that the voltage may rise excessively in off-peak period. This possibility was examined. It was confirmed that the voltage rise was within the target voltage range. There will be no problem of overrise of voltage in off-peak period even if the SC is not opened. (The curve "Off Peak (SC in)" of Figure 4-1-3)

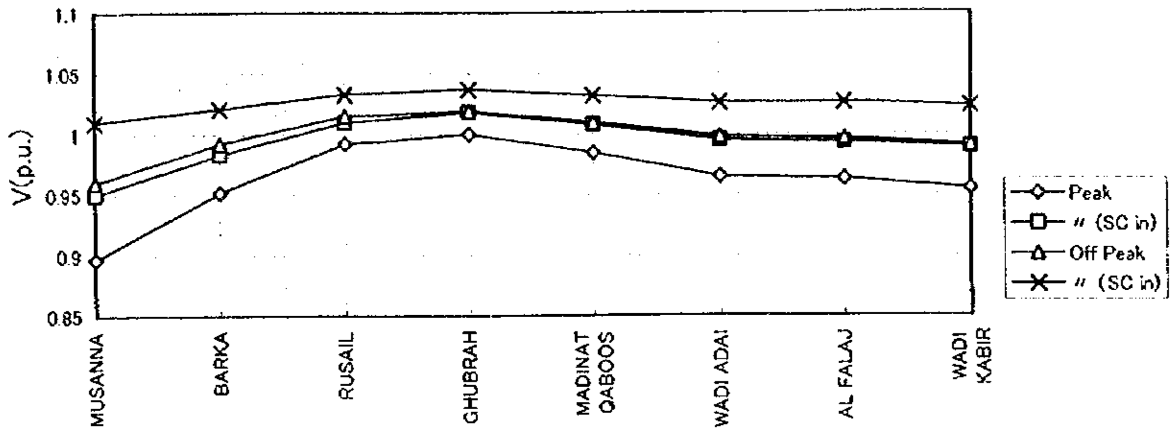


Figure 4-1-3 132kV Bus Voltage (Muscat System)

Next, the voltage problem of Rusail-Barka-Musanna line, where voltage fluctuation is posing a serious problem, was considered, including the 33 kV system.

As for the 132 kV system, to verify its voltage stability, the P-V curve that shows the relationship between received power and receiving voltage of Musanna SS was obtained. It was found that the limit of voltage stability had not been reached, and Musanna SS could secure the received power by installing an SC. (See Annex 4-1-d)

As for the 33 kV system of Musanna SS, voltage countermeasures were examined. The system was found to have some points of excessive voltage drop and points reaching the transmission limit. (See Annex 4-1-e and 4-1-f) As described above, as countermeasures for Musanna SS system for the time being, it is necessary to take countermeasures listed in Table 4-1-1 and Table 4-1-2. In future, it will be necessary to take countermeasures such as establishment of the Barka PS, and improvement of the power factor of the transmission system to 0.95 or over.

Table 4-1-1 Problems and Measures of the 132kV System

Name	Problems	Measures
Barka SS 33kV Bus	Low Voltage	Install 10MVA SC
Musanna SS 33kV Bus	Low Voltage	Install 40MVA SC

Table 4-1-2 Problems and Measures of the 33kV System(Musanna SS)

Name	Problems	Measures
Khaborah fdr-2	Limit of transmission	Introduction of 132kV transmission line
Rustaq-2 SS 11kV Bus	Low voltage	Install 5MVA SC
Sana Bani Gafir SS 11kV Bus	Low voltage	Install 3MVA SC
Suweiq-2 SS 11kV Bus	Low voltage	Install 5MVA SC
Marble Factory 11kV Bus	Low voltage	Install 3MVA SC
Wadi Jawahir SS 11kV Bus	Low voltage	Install 3MVA SC

b. **Wadi Jizzi system**

The 132 kV Wadi Jizzi system (Figure 4-1-4) was simulated, and data on power generation and loads supplied by the control center were inputted to make calculation. Results shown in Figure 4-1-5 were obtained. (See Annex 4-1-g)

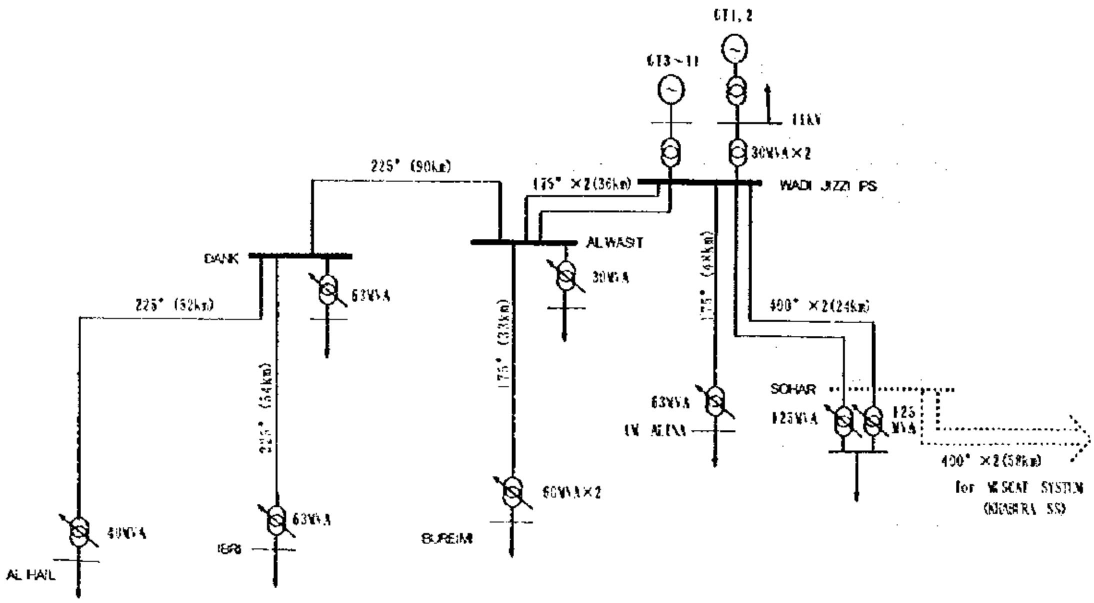


Figure 4-1-4 132kV Wadi Jizzi System

The diagram shows that, like the Muscat system, as the power factor of the load is bad, the voltage of the entire 132 kV system is dropping. In particular, the voltages at Dank SS, Ibri SS and Al Hail SS are much lower than the targets. With the present facilities, the target voltage can not be maintained. (The curve "Present" of Figure 4-1-5)

One countermeasure against this is to improve the power factor of the loads of the 33 kV system by installing an SC on the 33 kV system. Another method is to add one circuit of transmission line between Al Wasit SS and Dank SS.

First, the method of improving the power factor by installing many SCs (total capacity 83MVA, Dank SS 3MVA, Al Hail SS 5MVA, Sohar SS 40MVA, etc. ; See Annex 4-1-g) on the 33 kV system was examined. It was found that, even when the power factor of the 33 kV system load is improved from 0.83, the present value, to 0.95 by the installation of SCs, the voltages at Dank SS, Ibri SS and Al Hail SS can not be raised to within the target voltage ranges. (The curve "case 1" of Figure 4-1-5)

A line between Al Wasit SS and Dank SS can not keep the voltages at Dank SS, Ibri SS and Al Hail SS within the target ranges. It was also found that the other method or addition of one circuit of transmission. (The curve "case 2" of Figure 4-1-5)

It, therefore, is necessary to consider both the addition of one circuit of transmission line between Al Wasit SS and Dank SS and the power factor improvement with installation of SCs as the voltage countermeasures for Dank SS.

A completely different countermeasure is to newly install a 132 kV transmission line from Manah PS system and switch the loads of Ibri SS that suffer heavy voltage drops to Manah PS system. As the project is in progress in this direction, the resulting voltages of this case were examined. As a result, the voltages of Dank SS and Al Hail SS were found to almost go back to the target values. (The curve "case 3" of Figure . 4-1-5) However, in view of the increase in demand in future, the voltages at Dank SS and Al Hail SS are tight. It seems necessary to install, for the time being, SCs of about 5 MVA each.

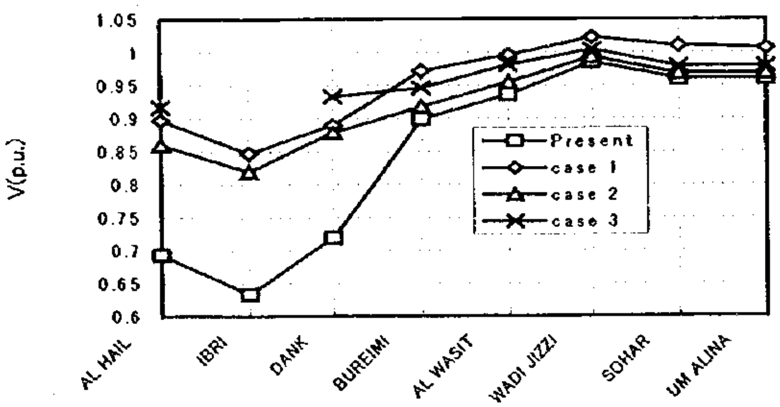


Figure 4-1-5 132kV Bus Voltage (Wadi Jizzi System)

c. Power Factor Improvement and its Effects

At present, the load power factor of Fichtner's master plan is planned at 0.85. To maintain the voltage level, Fichtner is planning to install SC's in the 11kV system. However, in the present system, the capacity of SC's is short and the voltage is in a very severe state. For this reason, we will install additional SC's in both 11kV and 33kV systems and plan to recover the voltage. In the future, we intend to install more SC's and improve the load power factor into 0.95 and over.

The effects of the power factor improvement are as follows

- Decrease in the voltage dropping
- Increase in the facility reserve
- Decrease in the transmission loss and the transformation loss

These effects will bring much stability and efficiency to the electric power system. They will also improve the efficient operation of the electric power equipment.

d. Voltage characteristic of air conditioners for household

It has been reported regarding voltage characteristics of household air conditions of the conventional type and of the inverter type as follows

- When the voltage drops, the conventional type air conditioners consume much reactive power, they will accelerate voltage instabilities.
- When the voltage drops, the inverter type air conditioners have a characteristic that reduces the reactive power, and behave more desirably than the conventional type conditioners in the aspect of voltage stability.

Hence from the viewpoint of voltage stability, the inverter type air conditioners are preferable. The voltage characteristic curves are shown in Annex 4-1-h.

e. Measures at Planning or Operation

- Measures at Planning

  As the system voltage is always changed by the load condition, we must check the voltage every year based on the demand for the next few years. We plan to install phase modifying equipment to maintain the voltage within the target voltage.

- Measures at Operation

  Power stations and substations are operated by the target voltage which is decided in every hour and every season. The power system is operated at the higher voltage within the target voltage. This will increase system stability and decrease system loss.

②Examination of Ibri-Manah interconnection

(1) 1999~2001 year

- The voltage of Ibri SS is improved by the interconnection of Ibri and Manah
- When a large generator drop out in Muscat system, transmission lines of Al Waist SS~Dank SS and Dank SS~Ibri SS get overloaded.
- Transmission line of Al Waist SS~Dank SS~is single. Therefore, if a single line fault occurs, the system will be separated two systems. In the separated system, it is necessary to control the frequency and the voltage individually and, in some circumstances, there is a possibility of shutting down the load by Under Frequency relay system.

On the basis of these findings, as the Ibri-Manah interconnection for the voltage improvement has little merit, we suggest that the interconnection line is opened at the Ibri SS and the power is supplied from the Muscat system.

(2) After 2001 year (After the Musanna-Khabura interconnection)

- After the route fault, for example shutting off Wadi Jizzi PS~Sohar SS line, as the power flow of Al Waist SS~Dank SS~Ibri SS line is about 240~270MW, this line will be burned off. (See Figure 4-1-6)
- System operation at fault is very difficult.
- There is no effect of loss reduction.

On the basis of these findings, as there is no merit of the 132kV loop system operation, we suggest that the interconnection line is opened at the Ibri SS and the power is supplied from the Muscat system.

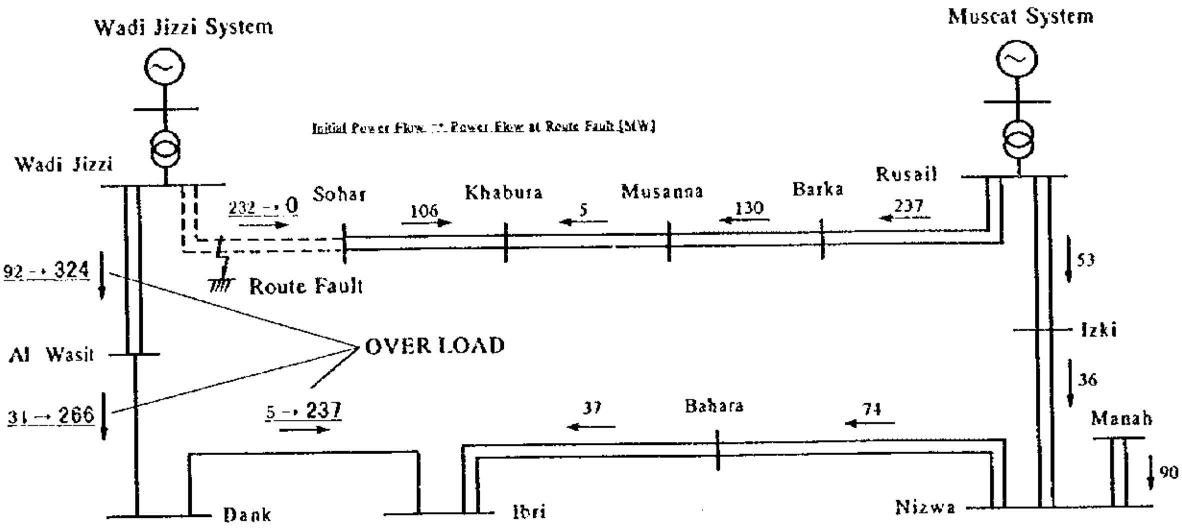


Fig.4-1-6 Power Flow of 132kV Loop System (2001 year)

③Examination of Muscat -Wadi Jizzi interconnection

A case of operating Muscat system and Wadi Jizzi system independently of each other up to the year 2000 inclusive and interconnecting both systems in 2001 was examined in terms of system voltage and system stability.

a. System voltage

Section examined : 2001 Year

(The demand and supply balance is shown in Annex 4-1-i)

Results of examination :

The voltage and power flow of the interconnection line are shown in Figure 4-1-7 and Annex 4-1-j)

The diagram shows as follows:

- When the voltage is maintained in each system, the interconnection will not generate any voltage problem.
- When the Barka power station is newly established and connected in parallel with the system at Barka SS, the voltage of the interconnection line will rise, and the system stability will be improved.
- When Wadi Jizzi PS is operated fully, the transmitted power to Muscat system will increase and the voltage of the interconnection line will drop a little. However, the voltage will be still in the target voltage range and will not pose any problem.

・In 2001 and beyond, with the increase in demand, the voltage will drop gradually. However, new establishment of Barka PS in the aspect of supply capability, and addition of an SC in Khabura SS in the aspect of voltage, will help the system to maintain the voltage.

On the basis of these findings, it is possible to maintain the voltage of the interconnection line after interconnection of both systems.

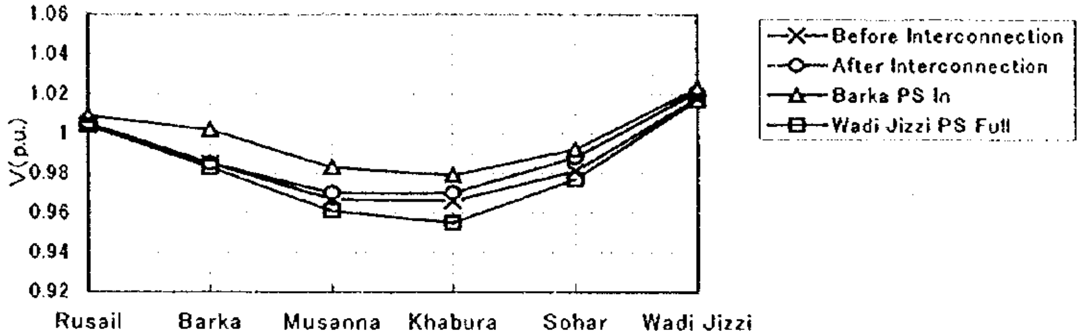


Figure 4-1-7 132kV Bus Voltage (2001)

b. Stability

Section examined : 2001 Year (Annex:4-1-j)

・Muscat system and Wadi Jizzi system are simulated in contraction.
・Characteristics and voltage regulator of generators are on standard model in Japan.
・Transmission lines, transformers, loads and capacitors situated between Rusail PS and Wadi Jizzi PS are simulated in detail.

Fault condition :

・Single phase ground fault.
・Fault point is the most severe fault point between Rusail PS and Wadi Jizzi PS. (Figure 4-1-8)
・Sequence of breaking an electric circuit is shown in Figure 4-1-9.

Results of examination :

The disturbance waveforms calculated by simulation are shown in Annex 4-1-k and Annex 4-1-l.

The diagram shows as follows :

i)If the opening time of fault point side CB is 0.12 sec [6 cycle] or less, power system is stable.
ii)If the opening time of other side CB is 0.5 sec or less, power system is stable.
iii)The limit of transmission power flow from Musanna SS to Khabura SS is about 170MW from the point of view of the system stability.
iv)When the Barka PS is connected, the limit will increase by about 40 MW.

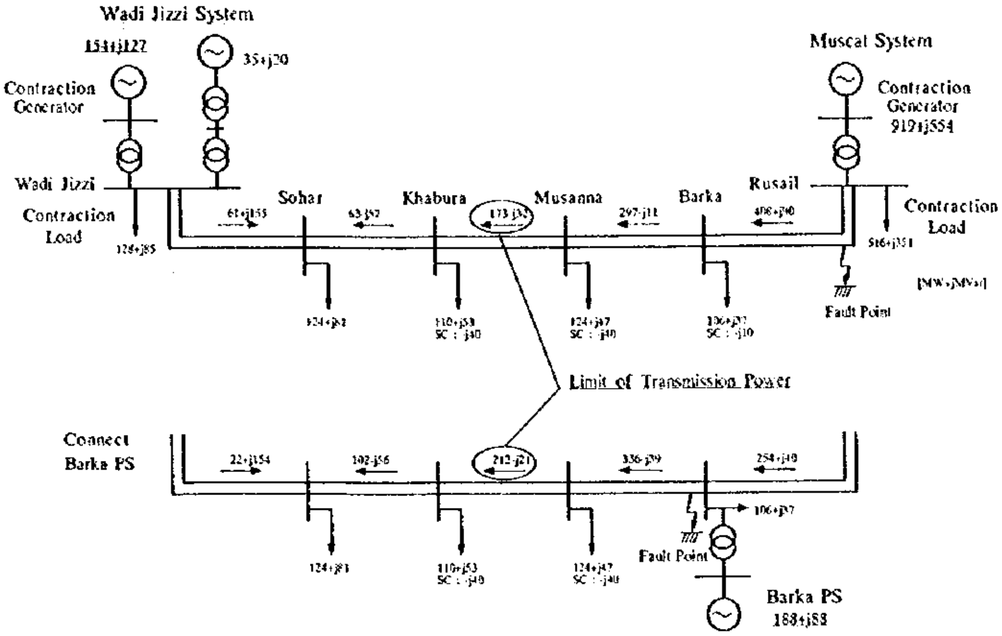


Figure 4-1-8 System model for the stability analysis

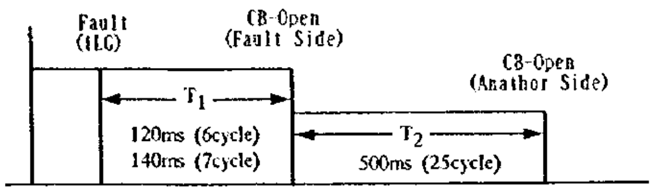


Figure 4-1-9 Sequence of breaking an electric circuit

④Technology transfer of analytical programs

Technology transfer of the voltage flow analysis program, system fault calculation program and demand and supply operation program, that are based on a personal computer and can make calculations with ease, were made to the control center, etc. For more details, please refer to Chapter 9.

(2) Examination of Load Dispatching Instruction System

The load dispatching instruction system is an organization that is indispensable in controlling the power system in an integral manner and supplying electricity stably and efficiently. In the following, we will examine the present state of the load dispatching system in Oman and what it should be in future.

①Present Load Dispatching Instruction System and Its Problems

The present load dispatching instruction system, as shown in Figure 4-1-10, is comprised of a main control center, local control centers, etc. The system mainly controls the power systems and collects the actual operation data. It does not do any tasks related to demand and supply (such as demand forecast, generation planning, etc.).

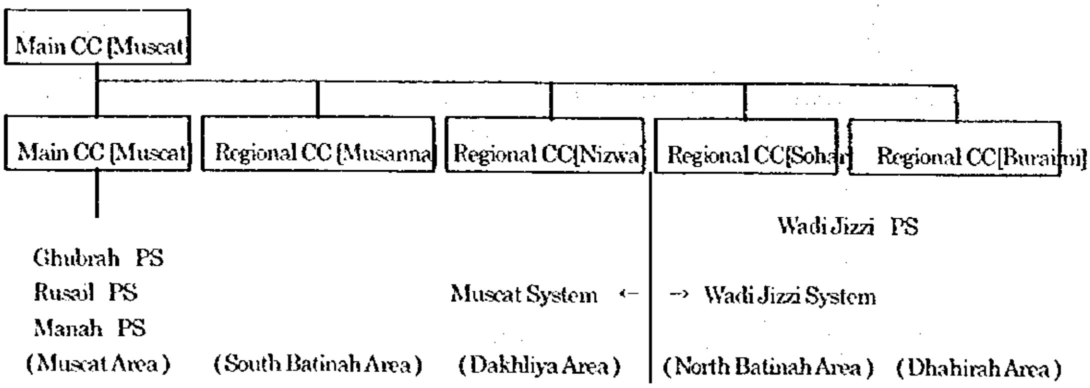


Figure 4-1-10 Present load dispatching system

In the survey, we examined the main control center, and power facilities such as the respective power stations, primary 132 kV substations, and distribution substations, and load dispatching information, load dispatching facilities, and load dispatching organization. Our findings are as follows:

- As there is no organization that makes the demand and supply operation plan of the entire power system, the power stations are not coordinated for efficient operation.
- The respective power stations are operated independently of each other by different contractors. There is no organization that seeks an efficient operation of the power system as a whole. Hence each contractor is controlling operation so that a local fault at its power station will not cause hindrance. The operation of each power station has very many losses.
- At the main control center, the states of the trunk systems can be displayed on CRTs. However, there are no system panel display. Telephone communication is not with direct telephone line but by pushing buttons. Hence they lack promptness in grasping the overall status of the power system at the time of a fault.
- System operation is provided by dedicated operation engineers. This causes a delay in recovering the power system at the time of a fault. (Members of the shift of the 132 kV substation should control the power system.)
- The system information of unattended distribution substations (33/11 kV) is not conveyed to anywhere. Even if a fault occurs, it is difficult to detect the fault. (It may be necessary to collect information on 11 kV distribution lines.)
- Load dispatching information is generally scarce.

In short, the system and facilities are not adequate to respond to the expansion of the systems and the increase in reliance of electricity.

②Necessity of Central Load Dispatching Center

In case of a small power system with a single power station, it is sufficient to control the generators at the power station according to the conditions of demand to achieve efficient operation. When the power system expands, and the number power stations increases, an organization is needed that controls in advance the allocation of power outputs to the respective generators according to the demands. In allocating power outputs, it is necessary to consider efficiencies of generators, and the conditions of the power system (power flow, voltage, system loss, etc.) so as to achieve the most economical operation.

With the development of the society, needs of higher reliability of electricity, supply of quality electricity, and early recovery from fault increase. As a result, enforcement of monitoring and control of the power system is required. Hence with the expansion of the power system and the development of the society, it will become necessary to have a central load dispatching center having these two functions.

③Duties and Organization of Central Load Dispatching Center

The duties of the central load dispatching center are shown in Table 4-1-3:

Table 4-1-3 Central Load Dispatching Center Duties

Item	Contents
Demand and supply control	· Development of demand and supply operation plan for the next day. · Continuous demand and supply operation of the day.
System control	· Power flow control. · Voltage control. · Frequency control. · System switching (work outage, system modification, switching in case of fault) · System monitoring.
System protection and operation	· Setting of relays, etc.
Record keeping	· Power flow charts, generation records, meteorological records, etc.
Information and communication	· General conditions of load dispatching, system operation status, information on faults, etc.

When the instruction system of the present control center is utilized to establish a central load dispatching center, its organization is shown in Figure 4-1-11:

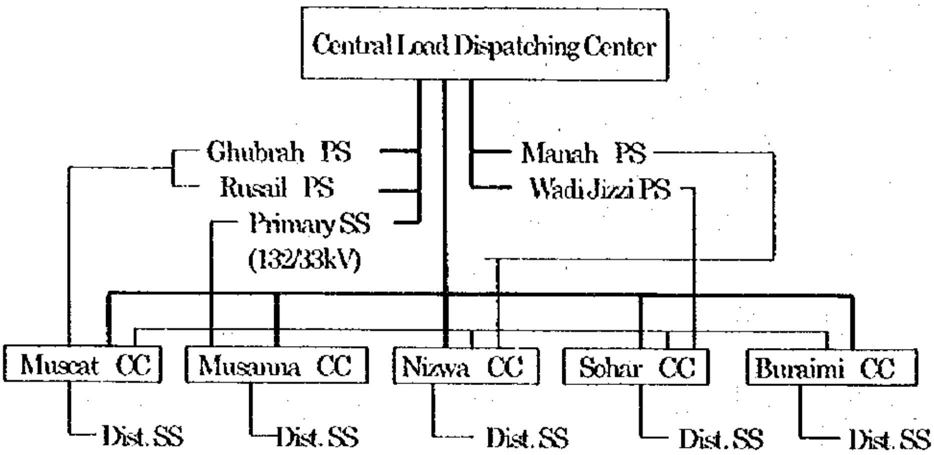


Figure 4-1-11 Instruction system of a central load dispatching center

Specific assignment of duties is compared with that of the present system in Annex 4-1-m. In outline, the central load dispatching center performs demand and supply operation of the entire power system, and system operation of the 132 kV systems. The system control centers perform system operation of systems of 33 kV or under and system control of 132 kV systems.

④Control and Load Dispatching Information

As for control method, load dispatching information, etc., the present SCADA system is to be utilized. However, in the introductory stage, more details should be clarified. We think at least on-line information from substations through which the interconnection line passes, such as Wadi Jizzi PS, Sohar SS and Musanna SS, is needed. At present, it is not planned to introduce the SCADA system to these substations. It is necessary to establish a system where each new control center can collect information on its area so that the control center can operate the systems within its own area of responsibility.

Table 4-1-4 Object PS, SS and Content of information of present SCADA system

Object PS and SS	Item	Content of information
Rusail PS, Ghubrah PS, Wadi Adai SS, Madinat Qaboos SS, Bait Barka SS, (Within one year: Manah PS, Nizwa SS, Izki SS, Bahla SS, Nizwa TawnSS(dist. SS). Future: Seeb Palace SS, Jahloot SS.)	Generator	P, Q, CB
	132kV Line	P, Q, A, CB, LS, E, Relay
	132/33kV Tr.	〃
	132kV Bus	V, CB, LS, E, Relay
	33kV Line	A, CB, LS, E, Relay
	33kV Bus	V

⑤Introduction steps

Introduction steps are shown in Table 4-1-5.

Table 4-1-5 Introduction steps of the function of the Central Load Dispatching Center

	First Step	Second Step
Time of introduction	At the time interconnected Muscat system and Wadi Jizzi system	Future
Central Load Dispatching Center	· Introduction of demand and supply operation program · Economic load dispatching · Power flow monitoring · Introduction of system monitoring panel (132kV system) · Introduction of automatic record keeping program.	· Introduction of the system control program · Automatic frequency control · Control of voltage and reactive power · Emergency control
Regional Control Center	· Reinforcement of regional control center	· Introduction of system monitoring panel (33kV system) · Introduction of automatic record keeping program. · Introduction of remote switching system · Introduction of automatic recovery operation system
Others	· Organization preparation · Operator training	

⑥Location

As for the location, in view of the issues of security, it will be appropriate to establish the central load dispatching center in Ghubrah PS where the present main control center is located. The new Muscat control center is established in Wadi Adai SS or Madinat Qaboos SS. Other new local control centers are the present local control centers or key substations of service areas.

4-2. Performance Improvement of Gas Turbine Power Generation System

4-2-1. Gas Turbine Performance Improvement

In this study, improvement of gas turbine performance means improvement of thermal efficiency and augmentation of output. Currently, the power generation system in the Sultanate of Oman has following four basic problems, as follows;

1) In the summer peak load time, there is a shortage of power supply in some areas and load shedding is necessary.
2) Gas turbines, which accounts for a major portion of the power generation system, experience a considerable decrease of output, according to their ambient temperature-output characteristics, during the summer peak load time when higher output is required.
3) Air conditioners are the major loads of the system and, therefore, the system load falls sharply in the winter time.
4) The average running load factor of gas turbines is very low, so the thermal efficiencies of turbines are low accordingly.

Seasonal load fluctuation is difficult to technically deal with. Therefore, in this study, we place an emphasis on gas turbine power augmentation, and thermal efficiency improvement by raising running load factors. The results of investigation and analysis so far highly recommend that a water injection operation of gas turbines be applied in the summer peak load time due to the reasons mentioned in 4-2-1,(2), 1) and 4-2-2,(2).

(1) Improvement of Thermal Efficiency

①Modification to Combined Cycle

In existing power stations, a simple cycle is adopted for all gas turbine power generation systems. However, in a simple cycle system, only 30-35% of heat input is converted into electric power, and the remaining energy is exhausted as waste heat. In a combined cycle, this waste heat of gas turbine is also utilized for power generation in a steam cycle. Therefore, the thermal efficiency of a combined cycle is substantially higher than that of a simple cycle by approximately 50%. However, a combined cycle, unfortunately, cannot be applied to any existing unit in Oman due to the reasons mentioned below.

- A steam cycle requires huge amount of cooling water(usually sea water) for the condenser, however, sea water is available only in the Ghubrah power station.
- The GT12 and GT13, large capacity gas turbines, at the Ghubrah power station, which are suitable for modification to a combined cycle, are already equipped with heat recovery boilers to supply steam to a desalination plant.
- The GT1-11 gas turbines of Ghubrah power station are all small machines with low load factors for peak load use, and it is not economical to apply combined cycle for these units.

② Uprating of Gas Turbines

For most of the existing units, more than ten years have passed since the start of operation. If major internal parts of the gas turbines are replaced with those of the newest model, thermal efficiency can be improved by some percent. Technically, it is possible to apply this uprating to all of the existing old model machines, however, it is not recommended because of the following reasons.

- Frame 5 and Frame 6 gas turbines are small capacity machines with low plant factors and load factors, and it is not economical to apply uprating to these units.
- Large capacity Frame 9 machines are adopted for GT12 and GT13 of the Ghubrah power station and GT1-6 of the Rusail power station. However, GT12 and GT13 are already equipped with heat recovery boilers. Furthermore, the average running load factor of GT1-6 is as low as approximately 50%, because of their duty to control the frequency of the Muscat system and to secure spinning reserve during operation. At the 50% load, the thermal efficiency of gas turbine will fall by approximately 19% comparing with that at rated point. It is not economical to apply uprating to those units which are forced to operate at partial loads to fulfill their duties.

③Operation at Higher Loads

Gas turbines have output-efficiency characteristics as shown in Annex 4-2-a. Namely, thermal efficiency is lower by approximately 14% at 60% output and 19% at 50% output than that at rated output. Lower thermal efficiency leads to higher fuel consumption. Therefore, gas turbines should always be operated at high outputs, which are close to the rated point, to maintain high efficiency.

On the other hand, gas turbines have ambient temperature-output, efficiency characteristics as shown in Annex 4-2-b. Output and efficiency fall when ambient temperature rises. This is an inherent characteristic of gas turbine and the efficiency drop caused by high ambient temperature cannot be controlled. Weighted average of monthly ambient temperature with distributed weight in proportion to total power generation in a month is 32.8°C for the Ghubrah power station and the Rusail power station, and 33.8°C for the Wadi Jizzi power station. Decrease of output and efficiency at those ambient temperatures, average running load factors of gas turbines in those power stations in 1996/1997, and efficiency decrease at those power factors are shown in Table 4-2-1.

As is clear from the table, the efficiency of gas turbines in those power stations is lower than that at the rated point by 10-20% due to very low running load factors, though the efficiency drop based on ambient temperature-efficiency characteristic is only a few percent lower. The major causes of low running load factors are a very low grid load in the winter time, which is only one third to one fourth of the summer peak load, and also the partial load operation of gas turbines to keep the spinning reserve.

Table 4-2-1 Average Running Load Factors and Efficiency Drop

Power Station, Unit	Gas Turbine Temperature Characteristics			1996/1997 Operation Data	
	Weighted Mean Temp. °C	Output Drop %	Efficiency Drop %	Aver. Load Factor %	Efficiency Drop %
Ghubrah	32.8	12.3	2.6		
GT1-GT11				46.4	20.9
GT12,GT13				61.9	12.0
Rusail	32.8	12.3	2.6		
GT1-GT6				52.7	17.1
Wadi Jizzi	33.8	12.9	2.8		
GT1-GT11				54.2	16.3

Regarding the low load in the winter time, it will be very difficult to improve the situation because air conditioners, which are used only in the summer time, accounts for 70% to 80% of total load demand in Oman. Regarding the spinning reserve, it will be possible to minimize the amount of reserve and to improve the gas turbine efficiency by several measures. One measure is the interconnection of the Muscat system with the Wadi Jizzi system, and another measure is the provision of power battery for spinning reserve.

In the Wadi Jizzi power station, three units of Frame 5 gas turbines and eight units of frame 6 gas turbines are installed. The average running load factor of those units in the past two years is only 54.2%. If Wadi Jizzi system is connected with Muscat system, it is no longer necessary to keep the spinning reserve in the Wadi Jizzi system. The gas turbines in the Wadi Jizzi power station can be operated at an average output of 87% which corresponds to 33.8°C ambient temperature. The efficiency improvement by this operation at 87% load will be approximately 14% and fuel cost can be saved by OR 1,400,000 in a year.

If a power storage battery is installed as a spinning reserve in the Muscat system, gas turbines in the system can be operated at higher load. This would lead to significant fuel saving. Detailed study for the interconnection and the installation of power battery is performed in other sections.

④Measurement of Fuel Consumption

According to the recent operation records of power stations, 2-10% difference is observed between the fuel flow measurement by the power station and that by the supplier. Fuel flow and power generation measurements are the most important ones to determine the performance of a power generation system. It is very difficult to control the performance of generation units correctly under this situation. It is necessary to calibrate the fuel flow measuring device urgently.

(2) Power Augmentation

①Water Injection

Injecting water into the head end of the combustor for NOx abatement increases mass flow, and therefore, output. Water or steam injection for power augmentation has been an available option on GE gas turbines over 30 years and this is a well proven technique. (See Figure 4-2-1)

<u>a. Objective Gas Turbines</u>

As water injection is very effective for power augmentation, it is recommended to apply water injection to all gas turbines with the exception of the GT12 and GT13 of Ghubrah power station, to which the heat recovery boiler for desalination plant is connected, and the GT1 and GT2 of Wadi Jizzi power station, which are owned by another company. Namely, water injection shall be applied to the following units.

- Ghubrah power station : GT1-GT11; Frame 5 and Frame 6
- Rusail power station : GT1-GT6; Frame 9
- Wadi Jizzi power station : GT3-GT11; Frame 5 and Frame 6

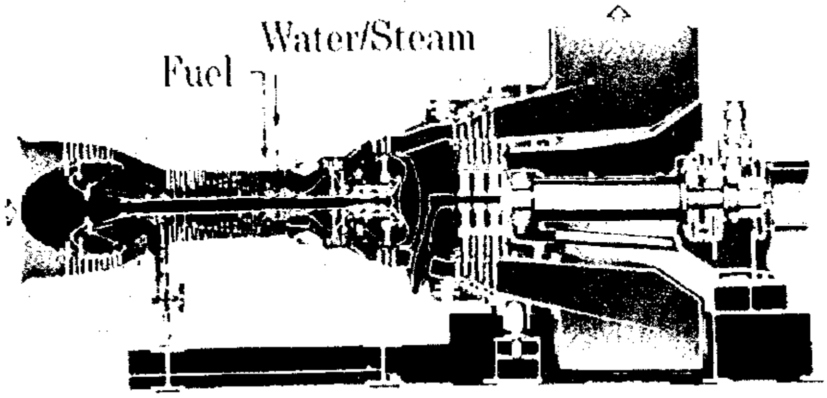


Figure 4-2-1 Water Injection

b. Preconditions

Gas Turbine Rated Performance

The study has been conducted based on the condition that each Frame 5,6 and 9 gas turbine has the performance shown in Table 4-2-2. Gas turbine performance at 50°C is calculated using Annex 4-2-b which shows the relationship between ambient temperature and several performance. As is clear from the figure, at 50°C ambient temperature, output decreases by 24% and heat rate increases by 7.5% compared with ISO conditions.

Performance Correction for Water Injection

Corrections for gas turbine performance shown in Annex 4-2-c are necessary when water injection is applied. When water is injected to gas turbine at the flow rate of 150% fuel flow(ca. 2.5% of air flow), output increases by 13% and thermal efficiency falls by 4.4%.

Table 4-2-2 Gas Turbine Performance

At ISO conditions, LHV base

Model	Output MW	Inlet Temp. °C	Exhaust Temp. °C	Heat Rate Btu/kWh	Exhaust Flow kg/sec
Frame 5	26.3	957	483	11,190	124
Frame 6	38.3	1,104	539	10,860	139
Frame 9	123.4	1,124	537	10,110	410

At 50°C

Model	Output MW	Heat Rate LHV Base		Fuel Rate kg/sec	Exhaust Flow kg/sec
		Btu/kWh	kJ/kWh		
Frame 5	20.0	12,890	13,600	1.51	107
Frame 6	29.1	11,670	12,320	1.99	120
Frame 9	93.8	10,870	11,470	5.97	355

Gas Turbine Partial Load Performance

Gas turbine has a partial load performance as shown in Annex 4-2-a.

c. Conditions in Water Injection

Water injection will be performed under the following conditions.

- Water will be injected so that the power augmentation by water injection at the Ghubrah, Rusail and Wadi Jizzi power stations equals to the output of one Frame 6, one Frame 9 and one Frame 6 gas turbine respectively.
- Water injection period : 100 days in the summer time
- Time period : 3 hours per day, from 13:00 to 16:00
- Injection flow rate : 130-190% of fuel flow
- Ambient temperature when water injection is applied : 50°C

Relevant data about water injection under the conditions mentioned above are shown in Table 4-2-3.

Table 4-2-3 Relevant Data for Water Injection

50°C ambient temp., LHV base heat rate

Model	Flow Rate		Output MW		Heat Rate kJ/kWh	
	kg/sec	ton/day	Without Injection	With Injection	Without Injection	With Injection
Ghubrah						
Frame 5	2.13	23.0	20.0	22.5	13,600	14,180
Frame 6	2.80	30.2	29.1	32.6	12,320	12,840
Rusail						
Frame 9	11.47	123.9	93.8	109.4	11,470	12,150
Wadi Jizzi						
Frame 5	2.00	21.6	20.0	22.2	13,600	14,130
Frame 6	2.63	28.4	29.1	32.5	12,320	12,800

The injection water flow rate is 2-3% of air flow rate and is far below the maximum flow rate of 5% which is usually applied to GE gas turbines. However, final confirmation from the gas turbine supplier on injection flow rate is necessary.

d. Water Injection

Quality of Injection Water

Injection water becomes superheated steam when heated by combustion gas. Steam flows through the gas turbine and comes in contact with hot gas path parts. Therefore, water quality shall satisfy the requirements of the gas turbine supplier to avoid the deposition of impurities in hot gas path, which could result in efficiency deterioration or corrosion of hot gas path parts. Usually, the following requirements shall be satisfied. Regarding water quality, a final confirmation from gas turbine supplier is necessary.

Water Quality

- Conductivity(μS/cm at 25°C) : less than 0.5
- Contents of impurities
  - Sodium(ppm as Na) : less than 0.01
  - Calcium(ppm as Ca) : less than 0.1
  - Silica(ppb) : less than 20
  - Total residuals(ppm) : less than 10

Water Consumption

Water consumption in water injection operation under the conditions mentioned in section 4-2-1,(2),①, b is shown in Table 4-2-4.

Table 4-2-4 Water Consumption

Power Station	Flow kg/sec	Consumption ton/day	Gas Turbines
Ghubrah	24.8	268	Frame 5 : GT1-9, Frame 6 : GT10, 11
Rusail	68.8	743	Frame 9 : GT1-6
Wadi Jizzi	23.0	249	Frame 5 : GT3, Frame6 : GT4-11

e. Gas Turbine Efficiency

When water injection of 130-190% flow rate is applied, efficiency will fall by approximately 4.0-5.5%

f. Additional Equipment

According to the site investigation, no gas turbines are designed to perform water injection operation. Therefore, gas turbine modification work, such as installation of water injection nozzles, modification of control system etc. shall be carried out during a shutdown period for regular maintenance before the start of water injection operation. This modification work can be performed easily. In addition to the modification work of gas turbines, additional equipment such as raw water tank, demineralizer, demineralized water tank, injection water piping, injection control system etc. shall be installed. The basic specifications of that equipment are shown below. See Figure 4-2-2 " Water Injection Flow Diagram ".

Raw Water Tank

A tank, to be used to store the raw water before treatment, shall be installed in each power station. Raw water tank capacity will be as shown in Table 4-2-5. Distillate water from the Ghubrah plant or city water will be used as raw water.

Table 4-2-5 Raw Water Tank Capacity

Power Station	Ghubrah	Rusail	Wadi Jizzi
Tank Capacity ton	800	2,200	800

Demineralizer

Demineralizer is used to treat raw water and to make water quality acceptable to gas turbines.

Table 4-2-6 Demineralizer Capacity

Power Station	Ghubrah	Rusail	Wadi Jizzi
Capacity tons/day	268	743	249

Demineralized Water Tank

Demineralized water is temporarily stored in this tank before injection. One common tank will be installed in each power station. Storage capacity is for one day consumption. Each tank capacity is shown in Table 4-2-7.

Table 4-2-7 Demineralized water Tank Capacity

Power Station	Ghubrah	Rusail	Wadi Jizzi
Tank Capacity tons	270	750	270

Injection Water Piping

The piping is used to transfer injection water from demineralized water tank to each gas turbine via injection water pump. Piping material shall be stainless steel.

Water Injection Control System

The system controls injection water flow in proportion to fuel flow. Injection water pumps, filters, flow control valves, shut off valves, control system etc. are included in the system. This is a part of integrated gas turbine control system, therefore, the system shall be supplied by gas turbine manufacturer and shall be installed during a turbine shutdown period for regular maintenance. Selection of water injection operation will be done for individual gas turbines, therefore, the control system shall be added to each gas turbine.

Cost of Additional Equipment

Budgetary cost of additional equipment is shown in Table 4-2-8. The cost is estimated based on the condition that sufficient water for injection is available in the vicinity of power station. Cost for the modification of gas turbine to install water injection nozzles is not clear. This information shall be obtained from each gas turbine supplier. If we assume this modification work cost to be RO 100,000 per unit, the total investment for water injection will be as shown in Table 4-2-9.

Table 4-2-8 Estimated Cost of Additional Equipment

Unit : RO 1000

Power Station	Raw W. Tank	Deminealizer	Demine. Tank	Injection Piping	Control System	Total
Ghubrah	250	300	100	200	680	1,530
Rusail	480	590	200	180	370	1,820
Wadi Jizzi	250	280	100	190	560	1,380

Table 4-2-9 Total Investment for Water Injection

Unit : RO 1000

Power Station	Ghubrah	Rusail	Wadi Jizzi	Total
Investment	2,630	2,420	2,280	7,330

② Inlet Air Cooling

a. Objective Gas Turbines

Technically, it is possible to apply inlet air cooling to any existing gas turbine unit; however, it is not economical to apply to small gas turbines such as Frame 5 or Frame 6. Therefore, the study has been focused on the application of inlet air cooling to six Frame 9 units in the Rusail power station.

b. Preconditions

Gas Turbine Rated Performance

Similar to the conditions in clause 4-2-1,(2),①,b, the study has been conducted on the condition that Frame 9 gas turbine has the performance shown in Table 4-2-10.

Table 4-2-10 Frame 9 Gas Turbine Performance

At ISO condition, LHV base

Model	Output MW	Inlet Gas Temp. °C	Exhaust Gas Temp. °C	Heat Rate Btu/kWh	Exhaust Flow kg/sec
Frame 9	123.4	1,124	537	10,110	410

Performance Correction for Ambient Temperature

Gas turbine performance shall be corrected for ambient temperature as shown in Annex 4-2-b. Performance at typical temperature is shown in Table 4-2-11.

Table 4-2-11 Gas Turbine Performance at Different Temperature

LHV base

Ambient Temp. °C	Output MW	Exhaust Temp. °C	Heat Rate kJ/kWh	Exhaust Flow kg/sec
15(ISO)	123.4	537	10,670	410
20	119.1	540	10,750	401
30	110.4	546	10,960	385
40	102.1	552	11,200	369

Gas Turbine Partial Load Performance

Gas turbine has partial load performance as shown in Annex 4-2-a.

Daily Load Curve

Load curve on July 1, 1997 is adopted as typical daily load curve in the summer peak load time and this study has been conducted based on this load curve. On this day, maximum daily load of 490 MW is recorded at 3 p.m.(39°C ambient temperature, average unit load of 81.7 MW) and minimum load of 233 MW recorded at 6 p.m.(36°C ambient temperature, average unit load of 38.8 MW).

Design Ambient Condition

The average ambient condition in the summer daytime at the Rusail power station is 37.4°C dry bulb temperature and 55% relative humidity. It is rare that maximum temperature exceeds 40°C at Rusail. Therefore, in this study, 40°C dry bulb temperature and 55% relative humidity is selected as the design ambient condition in summer daytime at Rusail. Because of high relative humidity, enthalpy of the air is as high as 122.1 kJ/kg and cooling load also becomes high. If relative humidity goes down to 40%, cooling load will be reduced by 35%.

c. Conditions in Inlet Air Cooling

The study has been carried out assuming the following operation conditions.

- Operation period : 100 days in the summer time
- Operation time period : 3 hours per day, from 13:00 to 16:00
- Ambient condition : 40°C dry bulb temperature, 55% relative humidity
- Cooled air temperature : 20°C
- Operation of chiller system : 10 hours per day, 5:00 to 11:00 and 17:00 to 21:00

d. Inlet Air Cooling

Cooling System

There are several cooling systems such as evaporative cooler, chiller cooling system, ice thermal storage cooling system, and a combination of the above. Among them, the ice thermal storage cooling system is selected in this study because of its proven experiences and its large contribution to load balance.

Performance Improvement

Performance of Frame 9 gas turbine with inlet air cooling and without cooling is shown in Table 4-2-12. When inlet air is cooled by 20°C, output increases by 17 MW(17%) and heat consumption rate is improved by 4%. Total output increase at Rusail power station is 102 MW, which is equivalent to the increase of adding another Frame 9 unit.

Table 4-2-12 Performance Improvement by Inlet Air Cooling

Frame 9, LHV base

Inlet Air Cooling	Air Temp. °C	Output MW	Heat Rate kJ/kWh
Without	40	102.1	11,200
With	20	119.1	10,750

Cooling Load

Under the operation condition mentioned in clause 4-2-1,(2),②,c, the cooling load of air cooler will be 65.0 GJ/hr or 195 GJ/day per unit.

e. Additional Equipment

Following additional equipment is necessary for inlet air cooling. Air cooler shall be installed for each unit in the inlet air duct during gas turbine shutdown period for regular maintenance. Two sets of chiller systems will be provided and each system serves for three gas turbine units.

Chiller System

The system consists of compressor, evaporator etc. Following numbers of equipment is for six gas turbine units.

Compressor	Number: 8
	Type : Screw type
	Capacity : 1,160 USRT / unit
	Motor capacity : 1,140 kW
Evaporator	Number : 24
	Capacity : 390 USRT/ unit

Ice Storage Tank

The 50/50 ice/water mixture necessary for a three-hour cooling operation will be stored in the tank. The tank is cast-in-place concrete and is installed partially below-ground to utilize the insulating effect of the earth.

Ice storage tank	Number : 2 (each one for 3 units)
	Capacity : 4,300 m^3 per each

Air Cooler

The cooler is installed in the inlet air duct of each unit. It cools the compressor inlet air by cold water which is supplied from the ice storage tank.

Air cooler	Type : Fin tube type
	Heat load : 65.0 GJ/hr

Circulating Water Pump

The pump circulates the cold water of ice storage tank through the air coolers. Two 50% capacity pumps will be installed for each storage tank.

Circulating Water Pump	Number : Two 50% pumps per each storage tank
	Capacity : 8,000 m^3 / hr

Piping System

Each storage tank will be provided with a cold water supply and return main piping. At the inlet of each branch piping air cooler, a control valve for outlet air temperature control will be installed.

Control System

The control system serves for gas turbine inlet air monitoring and control.

Electrical Equipment

The system is composed of a power source, a control source etc.

Cost of Additional Equipment

The budgetary cost of additional equipment for gas turbine inlet air cooling is shown in Table 4-2-13.

Table 4-2-13 Budgetary Cost

Unit : RO 1000

Item	Number	Cost
1. Chiller		5,090
Compressor	8	
Evaporator	24	
Condenser etc.	8	
2. Ice storage tank	2	550
3. Air cooler	6	570
4. C.W. pump	4	180
5. Piping system	6	1,230
6. Control system	6	990
7. Elec. Equipment	6	270
8. Others	6 set	800
9. Engineering	-	480
Total	-	10,160

4-2-2. Cost Estimation and Financial Study

(1) Operation at Higher Load

To be studied in other sections.

(2) Water Injection

The total output increase of three power stations under water injection operation is almost equivalent to the output increase when one Frame 6 unit, one Frame 9 unit and one Frame 6 unit are additionally installed to the Ghubrah, Rusail and Wadi Jizzi power stations respectively. Therefore, a financial study has been conducted by comparing costs and benefits of water injection operation with those of operation by additional three gas turbines.

①Conditions in Financial Study

- Asset life : 20 years
- Discount rate : 8.0% per annum
- Water injection operation : in summer time only, 100 days / year, 3 hours / day
- Output : Output at 50°C ambient temperature
- Fuel cost : 20.407 Bz / scm(standard cubic meter)
- Fuel calorific value(low) : 8,900 kcal / scm
- Energy cost : 0.5104 Bz / MJ
- Injection water cost : 0.82 Bz / kg
- Miscellaneous costs excluding fuel cost and injection water cost are same in both cases

②Power Increase

Power increase at each power station in water injection operation is shown in Table 4-2-14.

Table 4-2-14 Power Increase by Water Injection

Power Station	Ghubrah	Rusail	Wadi Jizzi	Total
Increase MW	29.1	93.8	29.1	152.0

③Investment

A comparison of investment amount in both cases is made in Table 4-2-15.

Table 4-2-15 Comparison of Investment

Unit : RO 1000

Power Station	Total Investment Amount		
	GT Addition	Water Injection	Difference
Ghubrah	6,660	2,630	- 4,030
Rusail	13,850	2,420	- 11,430
Wadi Jizzi	6,660	2,280	- 4,380
Total	27,170	7,330	- 19,840

④Power Generation Cost

A comparison of the output of each power station at 50°C ambient temperature is shown on Table 4-2-16. The outputs in both cases is the same at each power station.

Table 4-2-16 Comparison of Output

Power Station	Ghubrah	Rusail	Wadi Jizzi	Total
GT Addition MW	267.3	656.6	281.9	1,205.8
Water Injection MW	267.3	656.6	281.9	1,205.8

In water injection operation, power can be augmented, however, additional operation costs such as more fuel cost due to lower gas turbine efficiency and injection water cost are necessary. The additional costs in a year are shown on Tables 4-2-17.

Table 4-2-17 Additional Power Generation Costs

Unit : RO 1000

Power Station	Additional Cost		
	Fuel Cost	Water Cost	Total
Ghubrah	+ 28.4	+ 21.9	+ 50.3
Rusail	+ 68.0	+ 61.0	+ 129.0
Wadi Jizzi	+ 21.9	+ 20.4	+ 42.3
Total	+ 118.3	+ 103.3	+ 221.6

⑤Overall Evaluation

The net present value of the associated cash flow over 20 year period is calculated. The result is shown in Table 4-2-18. (Also see Annex 3-3-k,l,m) In conclusion, it is clear that the water injection operation is far more profitable than adding new gas turbines by present value of RO15,400,000. It is, therefore, highly recommended to apply water injection to existing gas turbines as a means of power augmentation in the summer peak load time.

Table 4-2-18 Total Evaluation of Water Injection vs New Gas Turbines

Unit : RO 1000

Power Station.	Cost difference		NPV of Water Injection
	Investment	Generation Cost	
Ghubrah	- 4,030	+ 50	+ 3,078
Rusail	- 11,430	+ 129	+ 8,863
Wadi Jizzi	- 4,380	+ 42	+ 3,466
Total	- 19,840	+ 221	+15,407

(3) Inlet Air Cooling

The total output increase of the Rusail power station with an inlet air cooling operation is almost equivalent to the output increase when one Frame 9 unit is additionally installed in the power station. Therefore, a financial study has been conducted by comparing the cash flow of inlet air cooling operation with that of operation by additional one Frame 9 gas turbine.

①Conditions in Financial Study

- Asset life : 20 years
- Discount rate : 8.0% per annum
- Air cooling operation : in summer time only, 100 days / year, 3 hours / day
- Chiller operation : 10 hours per day
- Output : Output at 40°C ambient temperature
- Fuel cost : 20.407 Bz / scm(standard cubic meter)
- Fuel calorific value(low) : 8,900 kcal / scm
- Energy cost : 0.5104 Bz / MJ
- Chiller power cost : 10.42 Bz / kWh
- Miscellaneous costs excluding fuel cost and chiller operation cost are same in both cases

②Power Increase

The total output of the Rusail power station when inlet air cooling is applied, and the output when one Frame 9 gas turbine is additionally installed are shown in Table 4-2-19.

Table 4-2-19 Comparison of Output

Ambient temp. : 40°C

Addition of One Frame 9 Unit			Inlet Air Cooling		
Unit Output MW	Number of GT's	Total Output MW	Unit Output MW	Number of GT's	Total Output MW
102.1	7	714.7	119.1	6	714.6

③Investment

Comparison of investment amount is shown in Table 4-2-20. Investment in an inlet air cooling system is approximately 70% of the cost of additional installation of a new gas turbine.

Table 4-2-20 Comparison of Investment

Unit : RO 1000

Power Station	Total Investment Amount		
	GT Addition	Inlet Cooling	Difference
Rusail	13,850	10,160	- 3,690

④Power Generation Cost

In an inlet air cooling operation, power can be augmented and fuel cost decreases due to higher gas turbine efficiency. However, at the same time, additional cost for chiller operation arises. The difference in power generation cost in a year is shown in Table 4-2-21.

Table 4-2-21 Difference in Power Generation Cost (per year)

Unit : RO 1000

Fuel Cost Saving	Chiller Power Cost	Net
- 49	+ 106	+ 57

⑤Overall Evaluation

The net present value of the associated cash flow over 20 year period is calculated. The result is shown in Table 4-2-22. (Also see Annex 3-3-n) In conclusion, it is clear that an inlet air cooling operation is also profitable than adding a new Frame 9 gas turbine. The NPV of inlet air cooling is positive; RO 2,710,000. But, if both a water injection and an air cooling operation are applied at the same time, the output of gas turbine will exceed the capability of electrical equipment such as generator, main transformer etc. Therefore, the water injection operation, which has larger NPV than the inlet air cooling, should be applied preferentially.

Table 4-2-22 Overall Evaluation of Inlet Air Cooling vs Adding New Gas Turbine

Unit : RO 1000

Rusail Power Station.	Cost difference		NPV of Inlet Air Cooling
	Investment	Generation Cost	
	- 3,690	+ 57	2,710

Water Injection System

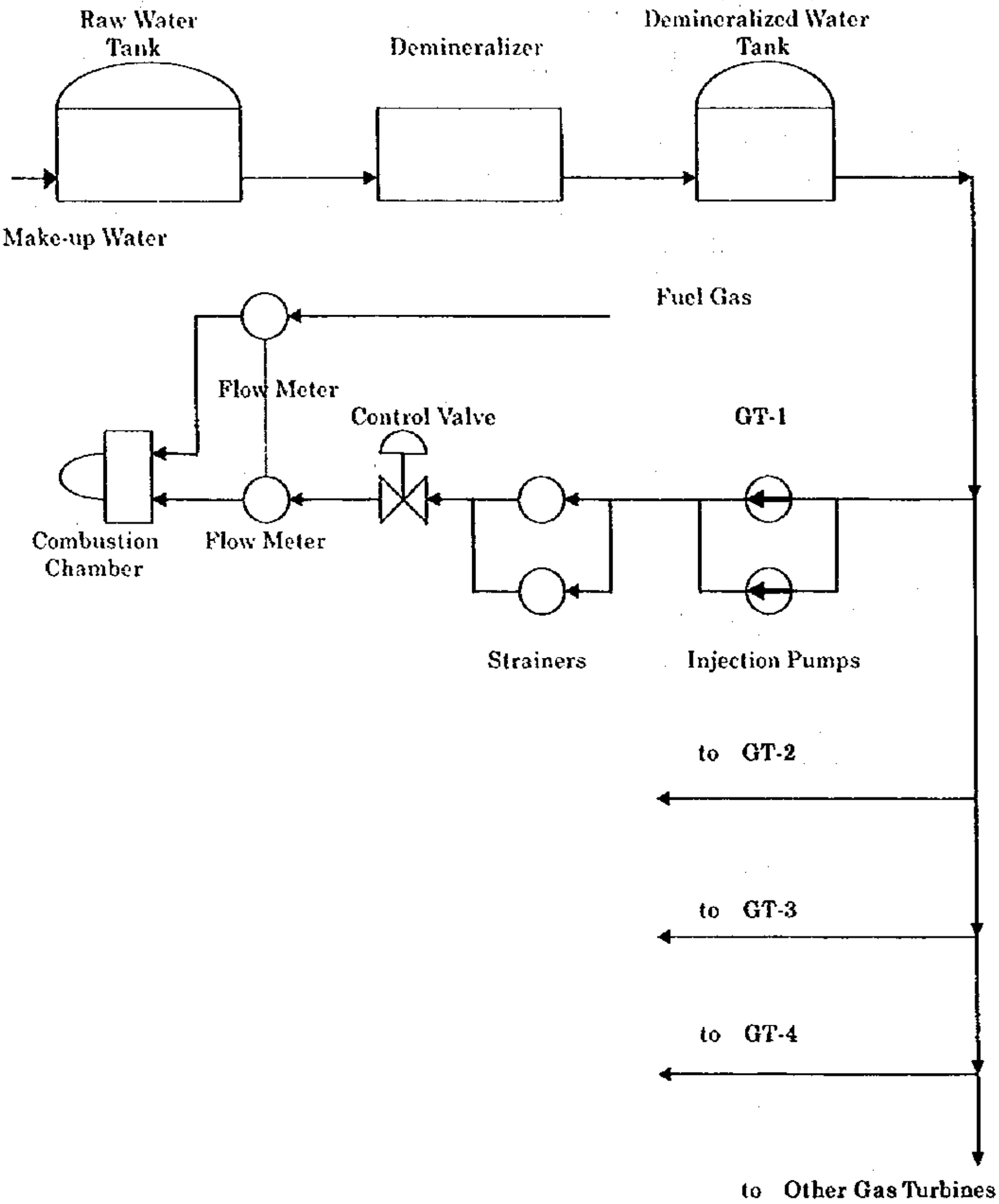


Figure 4 -2-2 Water Injection Flow Diagram