Hydro-electric Power Technical and Economical Features

By

Mawahib Elrahman Osman Elamin

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Electrical Engineering Department

Faculty of Engineering and Architecture

University of Khartoum

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بسم الله الرحمن الرحيم

}وقل ربّ زدنى علماً{

صدق الله العظيم

Dedication

To

My Parents

Whose affection is always appreciated

Acknowledgment

My sincere thanks and gratitude are due to his Almighty, ALLAH, who helped and blessed me during the course of my studies throughout.

I would like to express my deep gratitude and appreciation to my supervisor Dr. Mohammed Elamin Abu Goukh, for his sincere encouragement, his help and advice at the early stages of the project and patient guidance throughout.

My thanks extend to all friends whose help and moral support encouraged me to finalize this project.

Abstract

Hydro-electric power is the cheapest type of electric power generation in all world, if the cost of dam is not included in the capital cost. (Sometimes dams is constructed for irrigation then hydro-electric power). Hydro-electric power is also considered to be also the easiest in installation and operation with almost negligible operation and maintenance cost.

In this dissertation, because of the above advantages, an investigation to all technical features of hydro-electric power (Types of turbines, generators..etc) and also economical features (taking Roseires hydro-electric power station, as one of the major hydro-electic power station in Sudan, as a model).

Also Comfar software, computer model of feasibility studies analysis and reporting, is introduced in this dissertation and an attempt was done so as to make economic analysis for three hydro-electric power projects in Sudan using this software (Roseires, Jebl Aulia and Merawi).

بسم الله الرحمن الرحيم

ملخص البحث

تعتبر الطاقة الكهرومائية من أرخص مصادر الطاقة الكهربائية فى العالم وذلك اذا لم تحسب فى قيمتها تكلفة انشاء الخزان نفسه، (أحياناً ينشأ الخزان للرى ثم يستخدم للتوليد الكهرومائى) وكذلك تتميز بسهولة وبساطة تشغيلها وتركيبها مع قلة تكلفتها التشغيلية مقارنة مع كل مصادر الطاقة الأخرى.

على ضوء هذا السرد ونسبة لهذه المميزات، فقد ركزت هذه الاطروحة على عمل دراسة كاملة للتوليد المائى من النواحى الفنية له من ماكينات ومولدات وغيرها، وكذلك النواحىالإقتصادية (اخذين محطة توليد الوصيرص كمثال باعتبار أنها من المحطات الرئيسية للتوليد الكهرومائى بالسودان).

تضمنت هذه الاطروحة توضيح مفصل عن البرنامج الخاص بالتحليل المالى والاقتصادى للمشروعات الصناعية (كومفار)، كما تمت محاولات تطبيق هذا البرنامج لايجاد تحليل اقتصادى لثلاثة من مشاريع توليد الطاقة الكهرومائية بالسودان (الروصيرص ، جبل أولياء ومروى).

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CHAPTER 1

ELECTRICITY IN SUDAN

1.1 Introduction:

Sudan is Africa's largest country, with an area of 2.5 million square kilometers, and its geography ranges from desert in the north to grasslands in the centre and tropical bush in the south, straddling the Nile Rivers. The Blue and White Nile join in Khartoum to form the Main Nile (Figure 1.1).

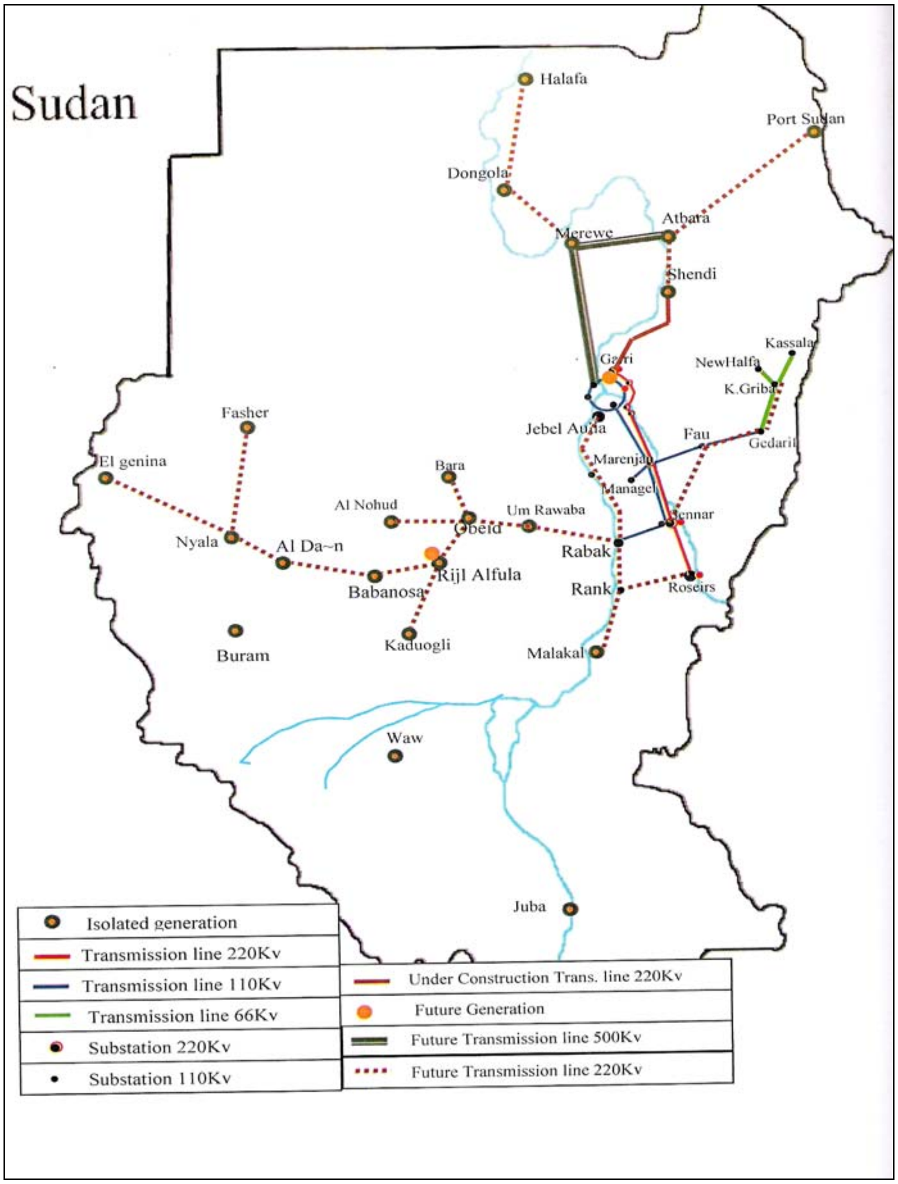


Figure 1.1 : The Sudan Map Showing the Existing and Future System

Power Generation and Transmission

A census is carried out every ten years, the last being in 1993 which is 26.46 million, although the civil war prevented full collection of data in the south in that census. The population was estimated to be 31.9 million in 2001,of which 26.8 million were in the northern states (84%)[(1)] . The overall annual growth rate between 1998 and 2003 was estimated as 2.63%, with a rate of 2.83% in the North and 1.6% in the south. A growth rate of 2.6% p.a. is high, particularly when the mortality rate of 1.15% p.a. is considered, but fairly typical for developing countries. Two thirds of the population lives in rural areas (65% in 2001). The capital is Khartoum, comprising Khartoum, Khartoum North and Omdurman and the urban population of Khartoum state was estimated to be 4.3 million in 2001, although the total urban population may be between 6 and 7 million if persons displaced due to the civil war are included. The number of the unsettled (nomadic) population is declining, the areas with the highest percentages being the Western Regions of the Sudan and the Western Kordofan region. In 1983 the nomadic population was 11% of the total.

1.2 Electricity:

The electrification ratio of the Sudan (percentage of the population with electricity supply) is one of the lowest in the world, estimated at about 17%[(2)]. (Table (1.1) gives an estimated breakdown of legal connections). Electricity is supplied mainly by NEC, but there are also small private generators and some small government generators in main towns that are not supplied by NEC. Many industrial and large commercial operations have standby generation, and some industries have their own continuous generation.

Most of NEC's customers are supplied by the NEC grid system, comprising three interconnected parts: the Khartoum grid, the Central grid to the south of Khartoum supplying parts of the Al Gezira, White Nile, Sennar and Blue Nile states, and the Eastern grid supplying parts of Gadarif and Kassala states.

[(1)] Source Long Term Power System Planning Study, Interim Report No.2 Sep2002
[(2)]Source National ElectricityCorporation, planning directorate annual report 2003

NEC's off-grid systems supplied a lot of main towns lying in the states without a grid supply, these systems comprise diesel generators and small distribution networks predominantly supplying urban consumers. The quality of supply in the grid system is much superior to that of the off-grid systems, which suffer from insufficient installed capacity, lack of spare parts, inadequate maintenance, and fuel shortages. The grid system is, however, used to be subjected to regular load-shedding at peak times, mainly residential consumers, but also including industrial and other customers.

State	**No of Houses**			**No of Houses with electrical connection**			**Electrification**
	Total	**Urban**	**%**	**Grid**	**off –Grid**	**Total**	**%**
Kartoum	761,333	640,940	85.5	348,000		348,000	45,7
AlGezira	538,333	115,742	21.5	60,086		60,086	11.3
Sinnar	190,833	51,907	27.2	29,877		29,877	15.7
Blue Nile	103,000	25,184	24.5	2,505		2,505	2.4
Whie Nile	240,167	90,303	37.6	17,473		17,473	7.3
Kassala	239,167	76,643	33.3	21,287		21,287	8.9
Gadarif	236,667	65,557	27.7	14,110		14,110	6
Northern	95,000	13,752	14.4		19,779	19,779	20.7
Nile	147,167	47,976	32.6		34,183	34,183	23.2
Red Sea	119,500	70,386	58.9		17,865	17,865	14.9
Kordofan	243,500	70,859	29.1		15,952	15,952	6.6
Darfur North	235,333	43,537	18.5		11450	11450	4.9
Darfur South	445,500	83,754	18.8		6,043	6,043	1.4
Darfur west	256,833	30,306	11.8		2,670	2,670	1
Bahr ElGazal	378,167	53,322	14.1		2,014	2,014	0.5
Equatoria	208,000	51,792	24.9		6,300	6,300	3
Upper nile	240,000	48,960	20.4		4,350	4,350	1.8
Kordofan South	182,667	41,100	22.5		2,100	2,100	1.1
Kordofan west	184,333	35,853	19.5		2,791	2,791	1.5
Total Grid areas	2,309,500	1079,276	46.7	494,187		494,187	21.4
Total Off-Grid areas	2,736,500	591,597	21.6		125,497	125,497	4.6
Overall	**5,046,000**	**1,670,87**	**333.1**			**691,684**	14

Table 1.1 : Status of Electrification

1.3 Grid Electricity Supplies:

1.3.1 Description:

NEC's grid system is divided into the Khartoum, Central and Eastern systems, with the following supply areas:

The Khartoum transmission ring supplies most of the urban areas of Khartoum state, and also feeds south about 90 km along the east bank of the White Nile via a 33 kV distribution line to Al Geteina in the White Nile state.

The Central Grid supplies areas near the Blue Nile south of Khartoum as far as Singa, including Giad industrial city. A 33 kV distribution line also feeds villages west from Wadi Medani as far as Elmanagil and Elgurashi. The grid also supplies Kosti and Rabak from Sennar on the White Nile, and then north along the White Nile as far as Al Duem. Damazen Town (Roseires) is fed by the Roseires Hydropower station, which is connected to the 220 kV grid by 220 kV lines. The Eastern grid is connected to the Central grid by a 110 kV line running east from Wadi Medani to Al Gadarif, and then north-east (66kV) to New Halfa and Kassala vis Khasham el Girbah Hydropower station.

1.3.2. Historic Supply and Demand:

The demand for electricity of the connected consumers is greater than the available generation i.e. the energy generated is constrained by the amount of generating plant available. Overall the energy generated increased from 1515 GWh in 1990 to 2704 GWh in 2001 and to 3238 GWh in 2003[(3)], an annual compound growth of 6% per year. The generated maximum demand has also increased at 6% per year; The corresponding annual load factor (average power / maximum power) is about 0.65, which is high for a system whose largest component of load is residential demand. The effects of the generation constraints are more at times of peak power demand, which means there is a greater effect on peak demand than total energy supplied, and hence this leads to higher load factors.

Grid energy sales, on the other hand, have only increased at an average of 1.5% per annum since 1990. This is due to a large increase in non-technical losses (e.g. un-

[(3)] National Electricity Corporation Sales and Generation Reports metered/illegal connections and meter tampering), with the number of legal connections only increasing at 2.8% per year over the period.

The non-technical losses are such that overall losses reached 40% of energy generated in 2001, with sales only amounting to 1604 GWh as compared to 2704 GWh generated and sales only amounting to 1928 GWh as compared to 3238 GWh generated in 2003 . Assuming technical losses of 14%, non-technical losses amounted to over 26% of energy generated.

1.3.3 Suppressed Demand

The load forecast for Long term power system planning study (LTPSP) is for unsuppressed demand i.e. the load of the existing legal and un-metered/illegal connections if there were no generation, transmission and distribution limitations. In the Sudan the limitations are predominantly due to generation shortage, though distribution voltages will also be low in some parts of the networks, reducing energy supplied. The suppressed demand is that which would be taken if electricity was available at all times with a high reliability (i.e. a low loss of load probability - LOLP). At present many large consumers (and some small) have standby generation, which is used when grid supplies are not available, and some large consumers do have continuous self-generation.

An estimate is made of the unsuppressed demand. A suppressed demand of about 15% of the total of generation plus load-shedding has been assumed, smoothed to give a reasonably consistent growth of overall demand at the generation level year on year. Thus, the energy demand at the generation level in 2001 is estimated as about 3110 GWh, as compared to the 2704 GWh actually generated. The assessment of the suppressed demand is necessarily approximate, but 15% appears a reasonable estimation based on the level of standby generation available. Figure 1.2 illustrates the growth of energy generated and the total un-suppressed demand. This yields a system generated load factor of about 50%, which is typical of an urban–rural system dominated by residential sales.

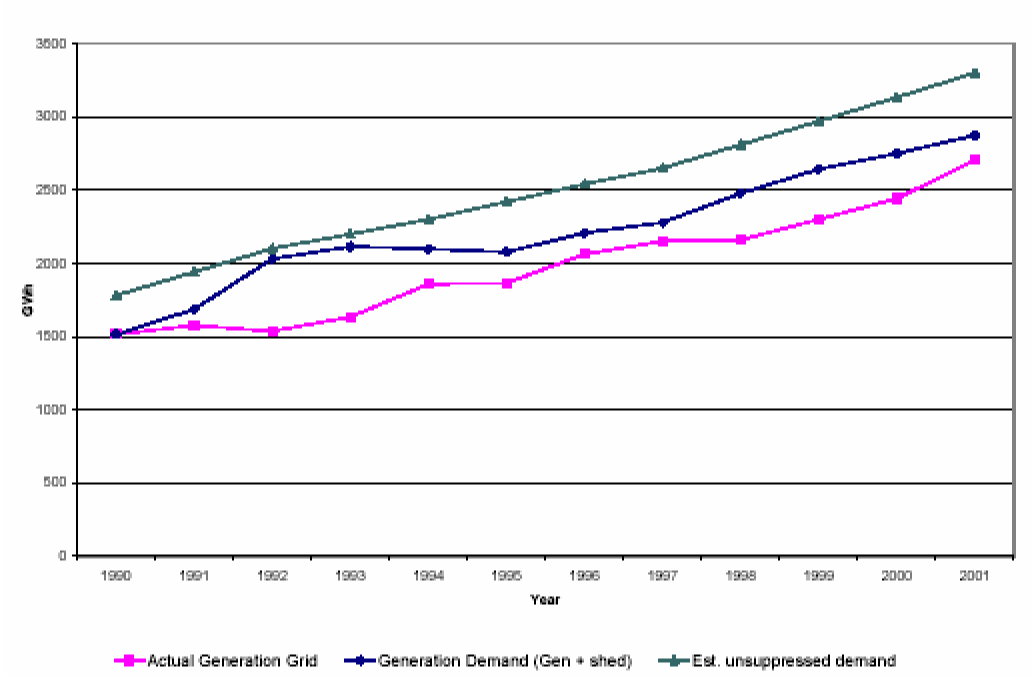


Figure 1.2 : Grid - Energy Generation

1.3.4 Sales by Category:

The sales are broken down by category, based on a combination of the Tariff Categories. The Small Commercial and Industrial Category (Flat-rate tariff T-2) applies to declared capacities up to 100 kVA, and includes light industry, offices, medical and religious customers etc. The Industry and Bulk Demand category (Tariff T-4) covers consumers with over 100 kVA declared capacity and includes large industry, large agriculture (irrigation) and other bulk supplies e.g. hotels, bakeries, institutes). The Small Agriculture category (T-3) applies to water pumping load below 100 kVA.

The largest sector is the Domestic sector, with about half of the billed consumption, followed by Large Industry and Bulk Supplies with just over one quarter of the total. Government and Street Lighting load is about 15% of sales, and Small Commercial and Industrial load just under 9%. The Small Agricultural sales are less than

2%. The Small Commercial and Industrial sector has shown a high growth rate of 12% p.a. over the last six years, exceeded only by the Government sector.

1.3.5 Unsuppressed Sales by Category:

An estimate of the overall un-suppressed consumption of electricity is done. This has been further broken down to give an estimate of unsuppressed demand by consumer category for the grid. The total number of connections including unmetered/ illegal connections are also estimated, and from the two sets of numbers the estimated consumption per connection for different categories is calculated. The latter are checked to ensure they appear realistic, and the un-suppressed demand and number of connections adjusted accordingly.

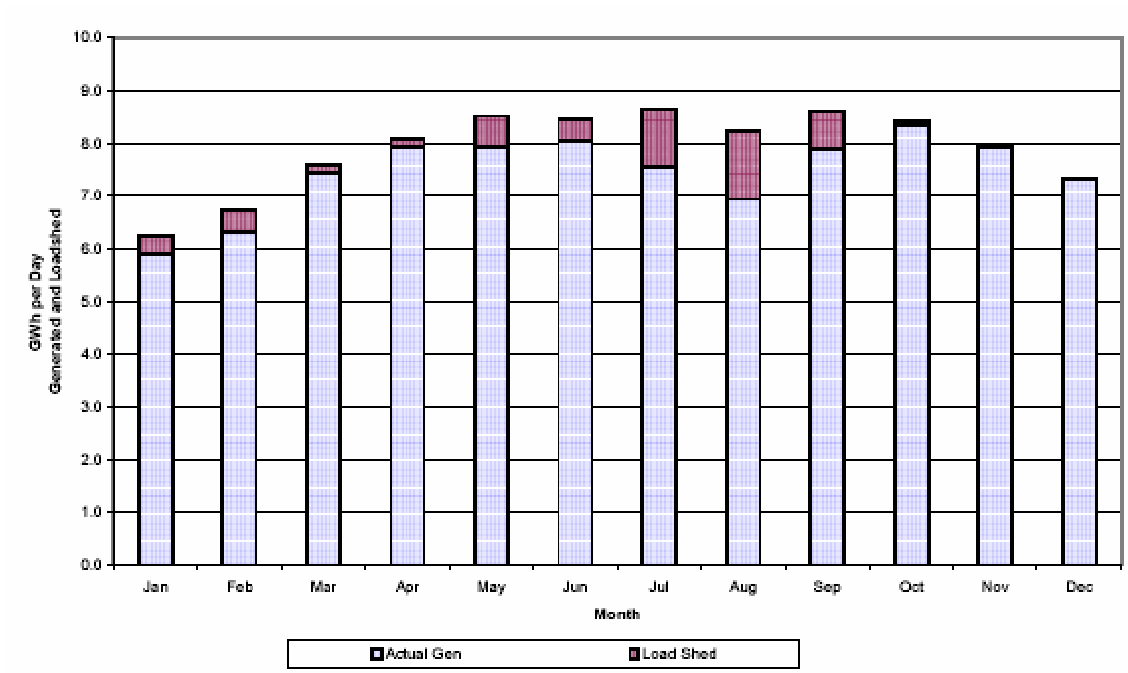


Figure 1.3 : Monthly Grid Generation plus load shedding

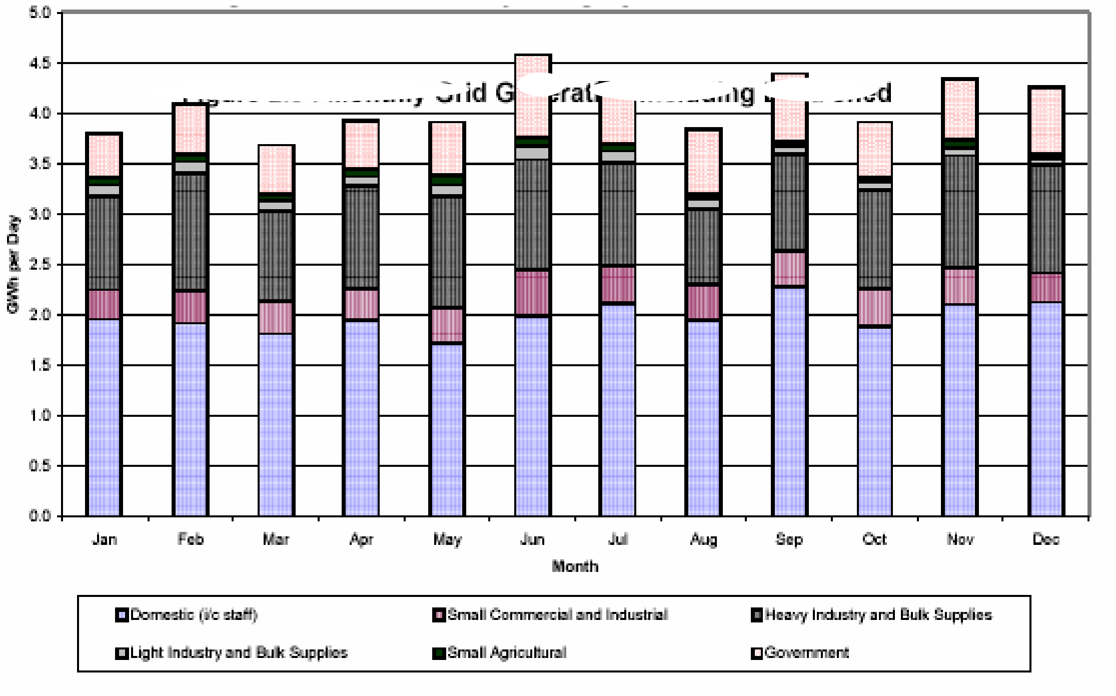


Figure 1.4 : Grid Sales by Category and Month

1.4. Off-Grid Electricity Supplies:

1.4.1 Description

Table 1.2 below lists NEC's fourteen off-grid power stations.

Town	State	Avail Capacity in 2000 MW
Atbara	Nile	9.0
Shendi	Nile	3.7
Karima	Northern	2.4
Dongola	Northern	1.9
Wadi Halfa	Northern	1.2
Obeid	North Kordofan	8.7
Um Rawaba	North Kordofan	1.0
Port Sudan	Red Sea	7.7
El Fashir	North Darfour	2.9
Nyala	South Darfour	2.4
Al Ginaina	West Darfour	1.05
Juba	Bahr Al Jabal	0.5
Wau	West Bahr Al Gazal	0.6
Malakal	Upper Nile	0.4
Overall		**43.5**

Table 1.2 : Off-Grid Power Stations

1.4.2 Supply and Demand:

The consumption of electricity in the off-grid areas is severely constrained by the available generation, and in all areas there is considerable load-shedding. Thus the maximum power demand can be assumed to be equal to the available capacity, which in 2003 amounted to 43.5 MW. Total off-grid energy generated (assumed to be the sent-out figure) that year was 193 GWh, which gives a load factor of about 50%. This is undoubtedly much higher than it would be if there were no constraints on supply. The overall sales in 2003 were 154 GWh, which gives an overall loss of 20% of energy sent out.

1.4.3 Unsuppressed Consumption:

The un-suppressed consumption and number of consumers (legal plus un-metered/illegal) by category at each load centre have been estimated. The base data used comprised the number of legal connections in 1983, 1990, 1995 and 2000 (partial data only available for 2000), and the sales in 1990 and 2001 (again partial in 2001).

1.4.4 Monthly Variation:

Figure 1.5 shows the overall NEC off-grid generation by month in 2000, It is difficult to establish too much of a pattern from this data due to the influence of constraints in generation (e.g. lack of fuel, plant outages), except to say that the maximum output coincides with the hottest months of the year.

Figure 1.6, shows the variation in sales by sector for all the NEC off-grid load centers.

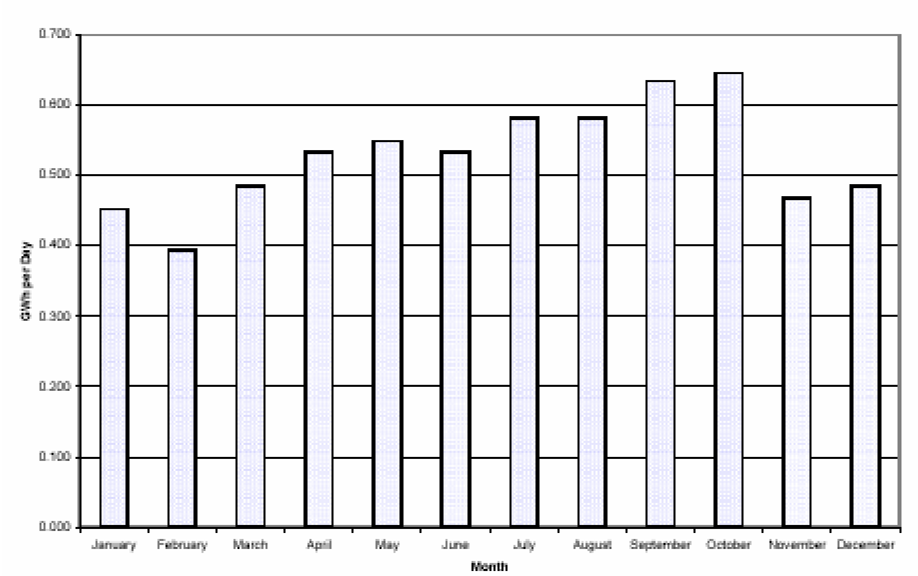


Figure 1.5 : Off-Grid Generation by Month in 2000

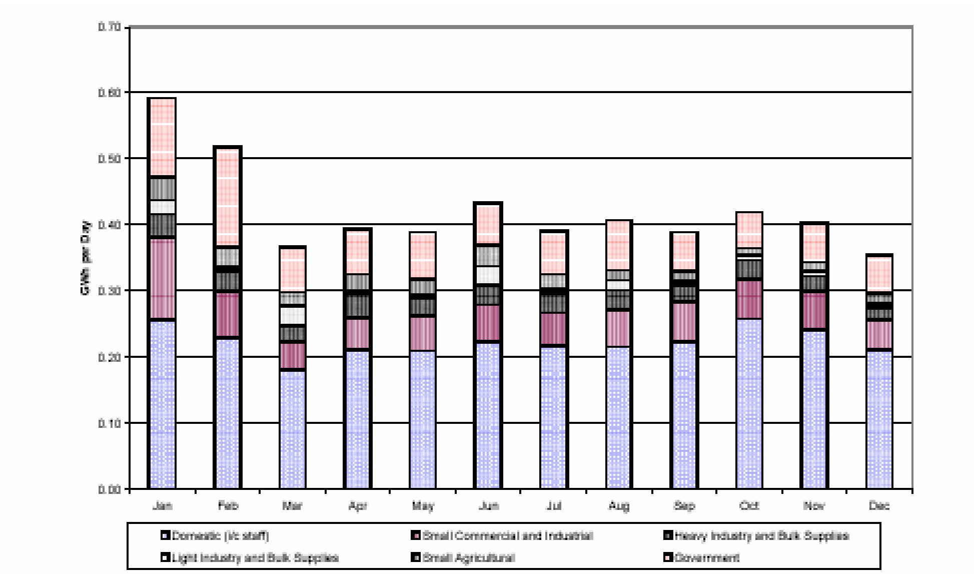


Figure 1.6 : Off-Grid Sales by Category and Month in 2000

1.5. Load Forecast Methodology:

1.5.1 Overall Description:

A load forecasting computer model has been constructed using the Excel spreadsheet program. This model comprises seven files (one for each customer category) as follows:

- Residential
- Small Commercial and Industrial
- Large Industry and Bulk Supplies (excluding Large Irrigation)
- Large Irrigation
- Agriculture (small irrigation)
- Government
- Summation

Each of the first six files forecasts the unsuppressed energy consumed by each sector. The forecasts are made by load centre for the whole country, and include a programme for providing electricity supply to all the districts of the Sudan over the twenty year period 2002 –2021. A total of 101 load centers are considered, comprising the 14 existing grid sub-stations and 87 other load centers termed “Off-Grid”, however, as the grid is extended some of these 'Off-Grid' load centers will be connected to the Grid. The 87 centers include the 14 existing “off-grid” power stations in 2001, and the 42 stations using Chinese diesel generators planned under three phases The remaining 31 load centers are termed 'Off-Grid Future'.

The customer categories have been selected based on the current classified tariff categories, except that Large Irrigation has been separated from the Large Industry and Bulk Supplies tariff category. The forecast is based on a combination of econometric and end-use techniques as described below.

The starting point for each forecast is the estimated un-suppressed energy consumption (billed plus non-technical losses plus suppressed demand due to generation constraints) in 2001 of the existing load centers, and the number of connections (metered plus un-metered). The forecast for each sector is based on a projection of the number of connections in each year at each load centre multiplied by a forecast of the specific consumption for the consumers (kWh per connection), except for Bulk Irrigation, which is based on the projected area irrigated using electric motor driven pumps. The forecasts of sales for each sector are combined using energy loss factors for each sector to give the total energy at each main supply point (either a grid sub-station or the outgoing switchgear at an isolated power station). The energy required at the generation level is calculated using loss factors to take account of transmission system (if grid connected) and power station use.

The maximum annual power demand is calculated for each load centre from the consumed energy using power loss factors, load factors and coincidence factors for each sector. The power demand at the generation level is calculated after allowing for transmission losses and power station use.

1.5.2 Price Effects:

The existing NEC tariff has been considerably increased from 1992 to 2001, and it is assumed that increases in the future will be in line with inflation i.e. no increases in real terms. It is therefore assumed that there will be no effects on electricity demand due to tariff increases.

1.5.3 Energy Substitution:

Electricity is used by residential consumers in Sudan principally for lighting, cooling (fans, and air conditioners), appliances and water heating, but is hardly used for cooking, except perhaps a hot plate. Cooking is mainly done by burning wood, charcoal, kerosene, or LPG (liquefied petroleum gas). The development of LPG at the refineries in Sudan using local oil production means that cooking by electricity is unlikely to develop in the foreseeable future, especially considering the recent tariff increases. LPG can be used for refrigeration, but electricity is almost always preferred when available. As far as we are aware, electricity is not used in significant amounts in industry for heating, so the possible increased availability of LPG is unlikely to effect electricity use significantly in industry. As regards pumped irrigation, the effects of electricity substitution for diesel driven pumps has been taken into account in the forecast.

1.5.4 Residential Sector:

The forecast for the residential sector is the key forecast, as it is the dominant sector, and will remain so for the foreseeable future.

1.5.5 Initial Connections:

For the existing Grid and Off-Grid load centre, the initial number of connections was based on the reported number of connections in 2001 plus an estimate for the number of un-metered connections. With regard to the 'Off-Grid Planned' load centers, Phase I of the installation of Chinese generators is already done. The initial number of connections is built up over three years for the planned off-grid connections such that for each 1 MW of generation 600 consumers are connected in each of the first and second years, reaching a maximum of 1500 connections per MW in the third year. The start-point for the electrification program of 'Off-Grid Future' load centers is a database of the number of urban and rural households in each district (as far as data is available in the 1993 census for the northern states). This database covers all the districts in the Sudan.

1.5.6 Derivation of Transmitted and Generated Energy and Power:

The total energy at each supply point and the total energy generation are derived from the forecasts of energy consumed. The Distribution Loss factors and Transmission and Power Station Loss / Use factors are used which have been estimated from values used in previous Sudan studies and typical values on similar systems.

The maximum power generation required for the demand of each load centre is then calculated by summing the maximum demand of each category. The power demand generated is calculated for each load centre using a further station use / loss factor.

Grid Factors

	Dist Energy Loss Factors (1)	Trans. & Power Station Losses / use (3)	Load Factor at Consumer terminals	Peak Power Losses (1)	System Coinc. Factors
Residential	10.9%		40%	15.5%	100%
Small Commercial & Industrial	10.9%		35%	15.5%	40%
Bulk Consumers (excl Irrigation)	4.6%		55%	6.5%	60%
Large Scale Irrigation	4.6%		50%	6.5%	20%
Small Irrigation	10.9%		40%	15.5%	20%
Government	7.7%		30%	11.0%	60%
Total		5%		7.1%	

Off-Grid Factors

	Dist. Energy Loss Factors (2)	Power Station Losses / use (3)	Load Factor at Consumer terminals	Peak Power Losses (2)	Coinc. Factors
Residential	10.9%		35%	15.5%	100%
Small Commercial & Industrial	10.9%		30%	15.5%	40%
Bulk Consumers (excl Irrigation)	4.6%		50%	6.5%	60%
Large Scale Irrigation	4.6%		45%	6.5%	20%
Small Irrigation	10.9%		40%	15.5%	20%
Government	7.7%		30%	11.0%	60%
Total		5%		7.1%	

(1) From Consumer Terminals to main transmission S/S level (110 kV). % energy / max demand at S/S.
(2) From Consumer Terminals to local Power Station SS. % energy / max demand at S/S.
(3) % Generated

Table 1.3 : Factors for Deriving Energy and Maximum Power Demand

1.6. Load forecast Results:

For Base Case:

Figure 1.7 below illustrate a summary of the unsuppressed power and energy demand forecast (base case) for the existing grid and for the load centers that are currently 'off-grid.

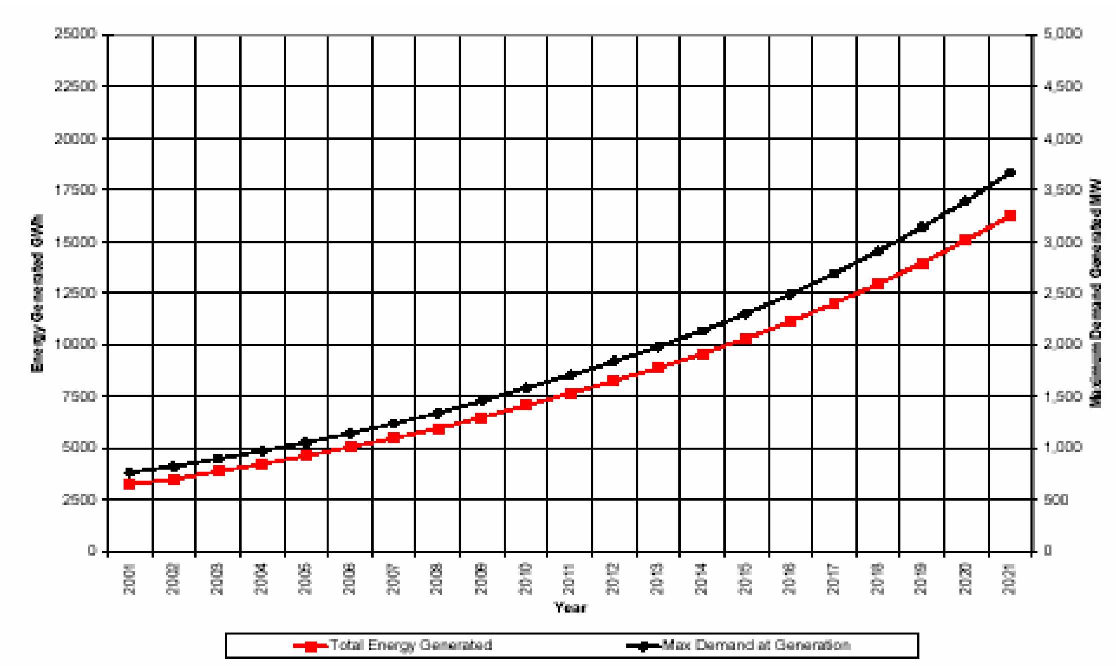


Figure 1.7 : Base Case Forecast of Generated Energy and Maximum Demand for the Grid – Unsuppressed

1.6.1 Consumption:

Overall, the unsuppressed energy consumed (i.e. taken at consumers' terminals) is projected to rise from 2,826 GWh in 2001 to 14,079 GWh by 2021, an average growth rate of 8.4 % per annum. Year– on-year percentage growth is largest in the early years, in line with the GDP forecast. Maintaining constant annual growth rates would lead to exponential growth, which would be difficult to maintain as the economy grows. High early rates of rise are also partly due to substitution for industrial self generation. The differing growth rates between sectors leads to slight changes in the sectoral breakdown.

	2001	2005	2010	2015	2020
GRID					
Residential	54.1%	51.2%	50.4%	50.3%	51.1%
Small Commercial & Industrial	8.6%	8.7%	9.2%	9.7%	10.2%
Large Industry and Bulk Supplies	18.9%	21.9%	21.7%	22.6%	23.8%
Large Irrigation	4.6%	6.1%	7.4%	7.0%	6.0%
Small Irrigation	2.4%	2.5%	2.9%	3.0%	2.3%
Government	11.3%	9.7%	8.4%	7.5%	6.7%
OFF GRID					
Residential	48.5%	45.6%	39.7%	38.3%	39.4%
Small Commercial & Industrial	7.6%	6.9%	6.1%	6.0%	6.2%
Large Industry and Bulk Supplies	28.6%	31.0%	30.0%	29.9%	32.1%
Large Irrigation	0.2%	3.0%	10.3%	11.4%	10.3%
Small Irrigation	6.9%	7.7%	10.0%	11.4%	9.5%
Government	8.1%	5.9%	3.9%	3.1%	2.5%

Table 1.4: Breakdown of Unsuppressed Energy Consumed by Sector

For the load centres of the existing grid, the Residential sector drops from 54% to 51% and the consumption of the Large Consumer category rises from 19% to 24% of the total. For the load centres that are currently off grid, the residential sector drops from 48% to 39%, due mainly to quite large increases in the consumption of large consumers and large agriculture. The forecast broken down by sector on a year-by-year basis is also done.

1.6.2 Electricity Generated and Transmitted:

The totals of the energy and maximum demand of the main supply points (the sum of the demand at the load centres, whether a transmission sub-stations or the outgoing switchgear at isolated power stations). The total energy generated is also shown, and includes transmission losses (if grid-supplied), and the losses and own-usage of the power stations. The un-suppressed maximum demand of the existing grid is projected to grow from 773 MW in 2001 to 3668 MW by 2021, an average compound increase of 8.1% p.a. The corresponding values for the off-grid load centres are 157 MW rising to 940 MW, an increase of 9.4% p.a. The higher increase is due to the connection of new load centres. The growth rates in energy are slightly higher than in maximum demand, due to the higher growth in sectors which make relatively lower contributions to the overall annual peak (high load factor/coincidence factor). This is reflected in the load factors which rise up until 2015, before slightly declining due to the growth of the residential sector demand. With regard to the off-grid load, it can be seen that energy grows relatively faster than the power demand from 2011 to 2015, due to the growth in irrigation using motor driven pumps. These should make little contribution to the peak demand as it is assumed they mainly operate outside peak hours.

1.6.3 Connections:

Total connections (legal plus currently un-metered) are projected to rise from about 850,000 (grid plus off grid) in 2001 to nearly 3 million by 2021. Considering residential connections alone, the situation is shown in Table 1.5.

	2001	2021	Ave Compound Growth p.a.
No of Residential Connections - Grid	550,000	1,663,000	5.7%
No of Residential Connections– Off-Grid	171,000	661,000	7.0%
Total	721,000	2,324,000	6.0%
Population	31,900,000	50,900,000	2.36%
Electrification Ratio (% Population with electricity supply from NEC)	12%	25%	

Table 1.5: Residential Connections and Electrification Ratio

The rate of connection has been determined by considering the number of connections made in the past and the capability within Sudan to extend the distribution networks. In the Base Case the initial rates of residential connections are about 28,000 p.a. in the existing Grid areas and 17,000 p.a. in the Off-Grid areas, giving a total of 45,000 p.a. This is assumed to increase to a total of about 120,000 p.a. by 2021. Even with this rate of connection, the electrification ratio only reaches about 25%, partly due to the high population growth rate – if there was no population growth the electrification ratio would reach 40%.

CHAPTER 2

HYDRO ELECTRIC POWER

2.1 Introduction:

Hydro-electric power is electricity produced by the movement of fresh water from rivers and lakes. Gravity causes water to flow downwards and this downward motion of water contains kinetic energy, that can be converted into mechanical energy, and then from mechanical energy into electrical energy in hydro-electric power stations. ("*Hydro*" comes from the Greek word hydra, meaning water). At a good site hydro-electricity can generate very cost effective electricity. The principal advantages of using hydropower are its large renewable domestic resource base, the absence of polluting emissions during operation, its capability in some cases to respond quickly to utility load demands, and its very low operating costs. Hydroelectric projects also include beneficial effects such as recreation in reservoirs or in tail water below dams. Disadvantages can include high initial capital cost and potential site-specific and cumulative environmental impacts.

- History and Development:

The conversion of kinetic energy into mechanical energy is not a new idea. As far back as 2000 years ago wooden waterwheels were used to convert kinetic energy into mechanical energy. The exact origin of water wheels is not known, but the earliest reference to their use comes from ancient Greece.

However, it was much later, in 1882 in the United States, that the first hydro-electric plant was built. This plant made use of a fast flowing river as its source. Some years later, dams were constructed to create artificial water storage areas at the most convenient locations. These dams also controlled the water flow rate to the power station turbines.

Originally, hydro-electric power stations were of a small size and were set up at waterfalls in the vicinity of towns because it was not possible at that time, to transmit electrical energy over great distances. The main reason why there has been large-scale use of hydro-electric power is because it can now be transmitted inexpensively over hundreds of kilometers to where it is required, making hydro-power economically viable. Transmission over long distances is carried out by means of high voltage, overhead power transmission lines. The electricity can be transmitted as either AC or DC.

Unlike conventional coal-fired power stations, which take hours to start up, hydro-electric power stations can begin generating electricity very quickly. This makes them particularly useful for responding to sudden increases in demand for electricity by customers ("peak demand"). Hydro-stations need only a small staff to operate and maintain them, and as no fuel is needed, fuel prices are not a problem. Also, a hydro-electric power scheme uses a renewable source of energy that does not pollute the environment. However, the construction of dams to enable hydro-electric generation may cause significant environmental damage.

2.2 Hydro Power Plants:

Amongst renewable energy sources, hydroelectric power seems to be the most desirable for utilities and its economic feasibility has been successfully proven. Power stations with a capacity of up to 10 GW have been built and it is estimated that there are economic resources for 3,000 GW world-wide, compared to 10,000 GW world primary energy consumption. In Europe, however, most hydroelectric potential has been realized, with Norway deriving 98% of its energy consumption from water power and the West German government concluding that there are no more sites available for exploitation. World-wide it is estimated that about 10% of resources have been realized, with most potential remaining in Africa and Asia.

Present worlds total installed hydro power capacity is about 630 000 MW. The data are uncertain because the contributions from small hydro power plants and private systems are difficult to estimate, but it is assumed that these facilities can add just a few per cent to the total figure. The annual power production world-wide is 2200 TWh* (billion

* TWh = 10^{12} watt hours

kilowatt hours), which means that the power plants are running at 40 % of its rated power.

2.2.1 Hydro power Potential:

There are two main factors that determine the generating potential at any specific site: the amount of water flow per time unit and the vertical height that water can be made to fall (head). Head may be natural due to the topographical situation or may be created artificially by means of dams. Once developed, it remains fairly constant. Water flow on the other hand is a direct result of the intensity, distribution and duration of rainfall, but is also a function of direct evaporation, transpiration, infiltration into the ground, the area of the particular drainage basin, and the field-moisture capacity of the soil. Runoff in rivers is a part of the hydrologic cycle in which -powered by the sun - water evaporates from the sea and moves through the atmosphere to land were it precipitates, and then returns back to the sea by overland and subterranean routes.

Hydro power potential can be estimated with the help of river flows around the world. The results show that this total resource potential is 50 000 TWh per year – only a quarter of the world precipitation, but still over four times the annual output of all the world present power plants. Realistic resource potential which is based on local conditions of world rivers is in range 2 - 3 TW with an annual output of 10 000 - 20 000 TWh (UN 1992).

A theoretical yearly production potential of 10.000 TWh of electrical energy means that the same amount of electrical energy produced in thermal plants with oil as fuel would require approximately 40 million barrels of oil per day. If this is compared to the world consumption of petroleum products, which amounted to around 80 million barrels per day in 1995(4). For developing countries, which together possess almost 60 % of the installable potential, the magnitude is striking. Hydro power plants are very attractive for the investors. This is due to the relative low investment costs and competitive price of electricity produced. Moreover the life span of hydro facilities is

(4) http://www.cancee.org/ren/hydro/hydro.html

considerably longer than for conventional fossil power plants. There are hydro power plants which run for almost 100 years.

2.2.2 Environmental Aspects of Hydro Power Plants :

A watercourse is an ecological system where changes within one component may create a series of spread-effects. For instance, changes in the water flow may affect the quality of the water and the production of fish downstream. Dam barriers may greatly change the living conditions for fish. In addition to the emergence of a major or completely new lake, the dam may divide upstream fish from downstream fish, and block their migration routes.

Environmental changes may be traced far downstream, at times even out into the sea. In the tropics there may be great seasonal variations as to the amount of precipitation, and in dry periods evaporation from lakes and reservoirs may be considerable. This may affect the water level of the reservoirs more dramatically than in temperate areas. The watercourse and its watershed mutually influence each other. The watercourse, for example, may affect the local climate and the ground-water level in surrounding areas. The sedimentation taking place in a reservoir can often lead to increased erosion downstream, i.e. an increase in the total erosion. Changes in water flow and water level will also lead to changes in the transportation of sediments.

During the construction phase the transport of mud and sediments will be especially large downstream from the construction area. Excavation and tunneling may lead to greatly reduced water quality and problems for those dependent on the water.

2.3 Technology(5):

In hydro power plants the kinetic energy of falling water is captured to generate electricity. A turbine and a generator convert the energy from the water to mechanical and then electrical energy. The turbines and generators are installed either in or adjacent to dams, or use pipelines (penstocks) to carry the pressured water below the dam or diversion structure to the powerhouse. The power capacity of a hydropower plant is

(5) Planning and Implementation of Hydro power Projects – Jarle Raun volume 5.1992

primarily the function of two variables: (1) flow rate expressed in cubic meters per second (m^3/s), and (2) the hydraulic head, which is the elevation difference the water falls in passing through the plant. Plant design may concentrate on either of these variables or both.

From the energy conversion point of view, hydro power is a technology with very high efficiencies, in most cases more than double that of conventional thermal power plants. This is due to the fact that a volume of water that can be made to fall a vertical distance, represents kinetic energy which can more easily be converted into the mechanical rotary power needed to generate electricity, than caloric energies. Equipment associated with hydropower is well developed, relatively simple, and very reliable. Because no heat (as e.g. in combustion) is involved, equipment has a long life and malfunctioning is rare. The service life of a hydroelectric plant is well in excess of 50 years. Many plants built in the twenties - the first heyday of hydroelectric power - are still in operation.

Since all essential operating conditions can be remotely monitored and adjusted by a central control facility, few operating personnel are required on site. Experience is considerable with the operation of hydropower plants in output ranges from less than one kW up to hundreds of MW for a single unit.

- Types of Hydro power facilities:

Hydropower technology can be categorized into two types: conventional and pumped storage. Another way of classification of hydro power plants is according to:

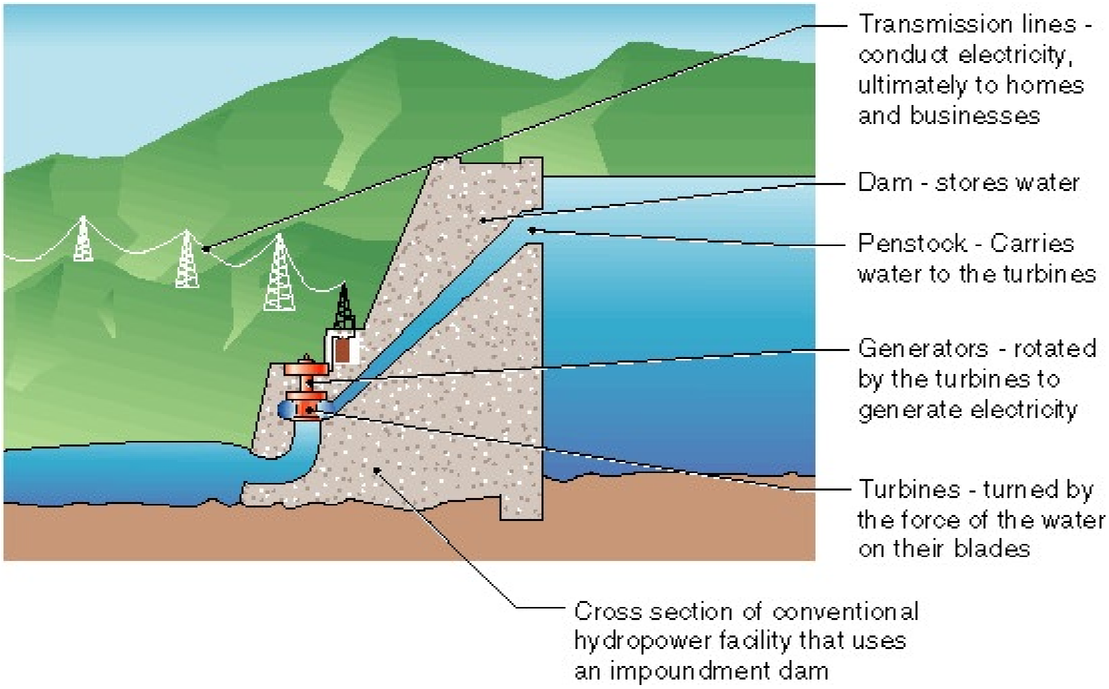
* Rated power capacity (big or small)
* Head of water (low, medium and high heads)
* The type of turbine used (Kaplan, Francis, Pelton etc.)
* The location and type of dam, reservoir.

Conventional hydropower plants use the available water energy from a river, stream, canal system, or reservoir to produce electrical energy. Conventional hydropower can be further divided between impoundment and diversion hydropower. Impoundment hydropower uses dam to store water. Water may be released either to meet changing electricity needs or to maintain a constant water level. Diversion hydropower channels a portion of the river through a canal or penstock, but may require a dam. In conventional multipurpose reservoirs and run-of-river systems, hydropower production is just one of many competing purposes for which the water resources may be used. Competing water uses include irrigation, flood control, navigation, and municipal and industrial water supply.

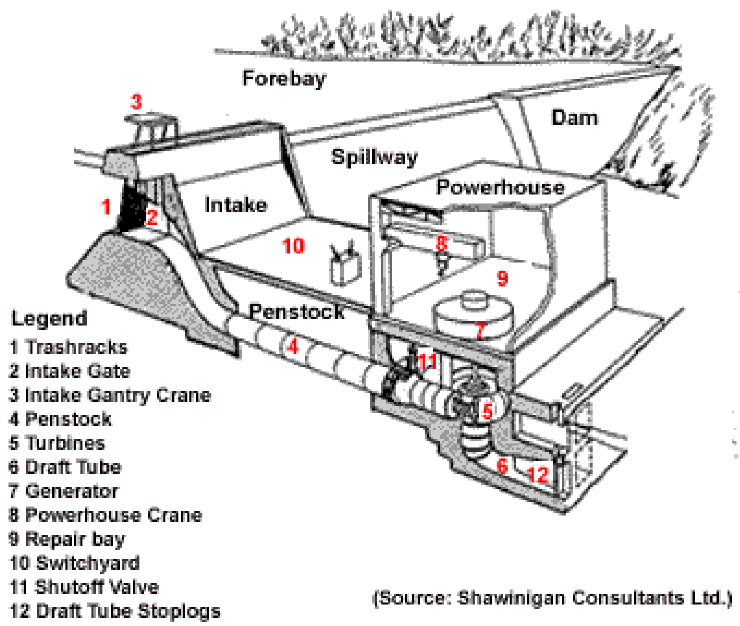
- Components of Hydro power Plants:

Most conventional hydropower plants include following major components:

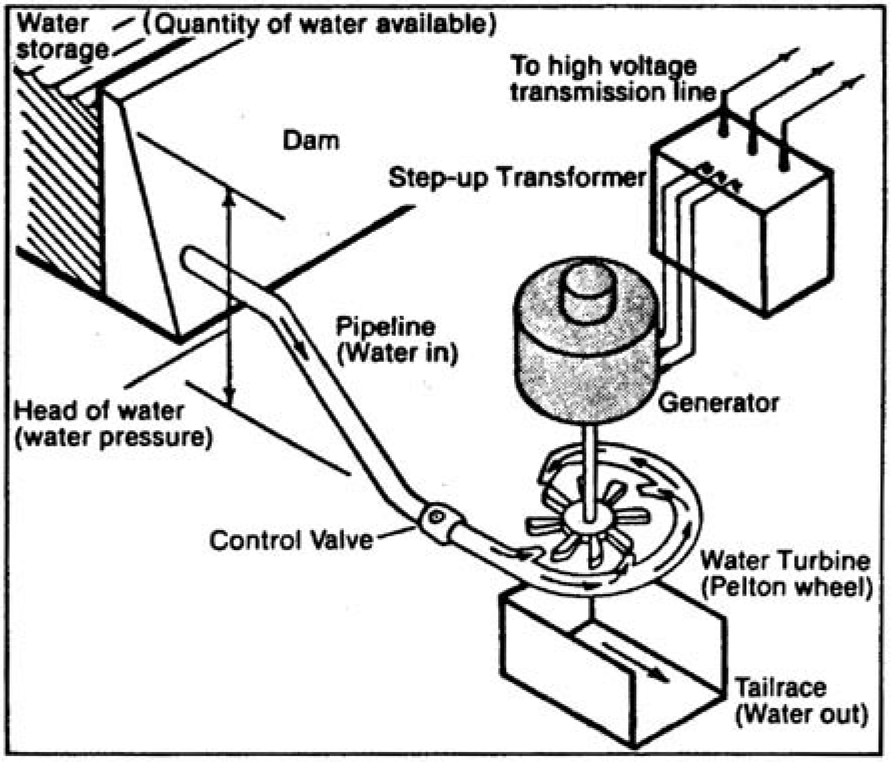
1. Dam. Controls the flow of water and increases the elevation to create the head. The reservoir that is formed is, in effect, stored energy.
2. Turbine. Turned by the force of water pushing against its blades.
3. Generator. Connects to the turbine and rotates to produce the electrical energy.
4. Transformer. Converts electricity from the generator to usable voltage levels.
5. Transmission lines. Conduct electricity from the hydropower plant to the electric distribution system.
6. In some hydro power plants also another component is present – penstock, which carries water from the water source or reservoir to the turbine in a power plant. (Figures below)


Transmission lines - conduct electricity, ultimately to homes and businesses
Dam - stores water
Penstock - Carries water to the turbines
Generators - rotated by the turbines to generate electricity
Turbines - turned by the force of the water on their blades
Cross section of conventional hydropower facility that uses an impoundment dam

(A)


Forebay
Dam
Spillway
Powerhouse
Intake
Penstock
1
2
3
4
5
6
7
8
9
10
11
12
Legend
1 Trashracks
2 Intake Gate
3 Intake Gantry Crane
4 Penstock
5 Turbines
6 Draft Tube
7 Generator
8 Powerhouse Crane
9 Repair bay
10 Switchyard
11 Shutoff Valve
12 Draft Tube Stoplogs
(Source: Shawinigan Consultants Ltd.)

(B)



(C)

Figure 2.1: Schematic diagrams of hydro-electric scheme

2.3.1 Types of Turbines:

The oldest form of "water turbine" is the water-wheel. The natural head difference in water level of a stream is utilized to drive it. In its conventional form the water-wheel is made of wood and is provided with buckets or vanes round the periphery. The water thrusts against these, causing the wheel to rotate. Traditional water wheels have been used for centuries, but these large and slow-moving wheels are not suitable for generating electricity. Water turbines used for electricity generation are made from metals, rotate at higher speeds, and are much easier to build and install. Over the years, many turbine designs have been developed to work best in different situations.

Water turbines may be classified in different ways. One way of classification is according to the method of functioning (impulse or reaction turbine); another way is according to the design (shaft arrangement and feed of water). Water turbines may operate as turbines, as pump turbines or as a combination of both. They may be of the single regulated or double regulated type. Turbines may also be classified according to their specific speed.

Impulse turbines use a nozzle at the end of the pipeline that converts the water under pressure into a fast-moving jet. This jet is then directed at the turbine wheel (also called runner), which is designed to convert as much of the jet's kinetic energy possible into shaft power. Common impulse turbines are Pelton and cross-flow. In reaction turbines the energy of the water is converted from pressure to velocity within the guide vanes and the turbine wheel itself. Spinning of the turbine is a reaction to the action of the water squirting from the nozzles in the arms of the rotor. The typical example of reaction turbine is a Francis turbine. The advantage of small hydro power reaction turbine is that it can use the full head available at a site. An impulse turbine must be mounted above tailwater level. The advantage of impulse turbine is that it is very simple and cheap and as the water flow varies , water flow to the turbine can be easily controlled by changing nozzle size. In contrast most small reaction turbines cannot be adjusted to accommodate variable water flow.

Most hydraulic turbines consist of a shaft-mounted water-wheel or "runner" located within a water-passage which conducts water from a higher location (the reservoir upstream from a dam) to a lower one (the river below a dam). Some runners look very similar to a boat propeller, others have more complex shapes. The turbine runner is installed in a water passage that lets water from the reservoir flow pass the runner blades, which makes the turbine spin.

Almost all hydraulic turbine/generator units turn at a constant speed. The constant speed one type of turbine/generator operates at may be considerably different from the speed of another. The best speed for each type of turbine is set during design, and a generator is then designed that will produce usually alternating current at that speed. A device called a governor keeps each unit operating at its proper speed by operating flow-control gates in the water-passage. There are several types of turbine designs like Pelton, Kaplan, and Francis or cross-flow turbine.

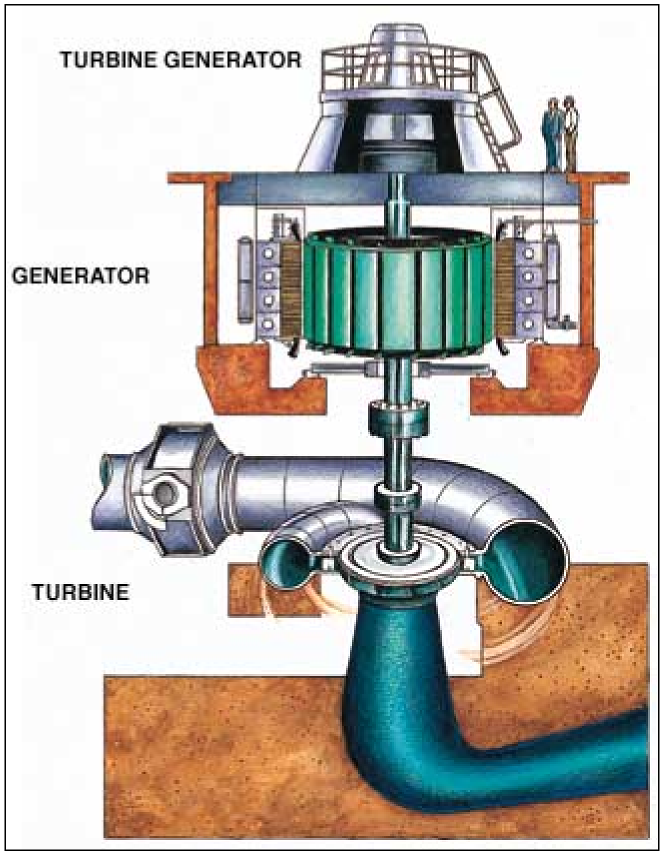


Figure 2.2: Cut-away drawing of a water-turbine generator

2.3.1.1 Pelton turbine:

The principle of the old water-wheel is embodied in the modern Pelton turbine. This turbine has a similar look and physical principle like a classic water wheel. A Pelton turbine is used in cases where large heads of water are available. The Pelton turbine is used for heads up to 2000 m. Below 250 m; mostly the Francis turbines are given preference. Today the maximum output lies at around 200 MW.

Together with crossflow turbines, Pelton turbines belong to the impulse type (or free-jet) turbines, where the available head is converted to kinetic energy at atmospheric pressure and partial admission of flow into the runner. The free jet turbine was invented around 1880 by the American Pelton, after whom it got its name. The greatest improvement that Pelton made was to introduce symmetrical double cups. This shape is basically still valid today. The splitter ridge separates the jet into two equal halves, which are diverted sideways. The largest Pelton wheels have a diameter of more than 5 m and weigh more than 40.000 kg. The wheel must be placed above the tailrace water level, which means a loss of static head, but avoids watering of the runner. In order to avoid an unacceptable raise of pressure in the penstock, caused by the regulating of the turbine, jet deflectors are sometimes installed. The deflector diverts the jet, or part of it, from the runner.

Since then the turbine has been considerably improved in all respects and the output of power has increased. Power is extracted from the high velocity jet of water when it strikes the cups of the rotor (runner). There is a maximum of 40 cup-like paddles jointed in two half-cups each water is being squirted through nozzles onto the blades where it is deflected by 180° and thus gives almost all of its energy to the turbine. By the reversal almost all the kinetic energy is transferred into force of impulse at the outer diameter of the wheel. Because of the symmetry of the flow almost no axial force is created at the runner.

From the design point of view, adaptability exists for different flow and head. Pelton turbines can be equipped with one, two, or more nozzles for higher output. In manufacture, casting is commonly used for the rotor, materials being brass or steel. This necessitates an appropriate industrial infrastructure. Pelton turbines require only very little maintenance.

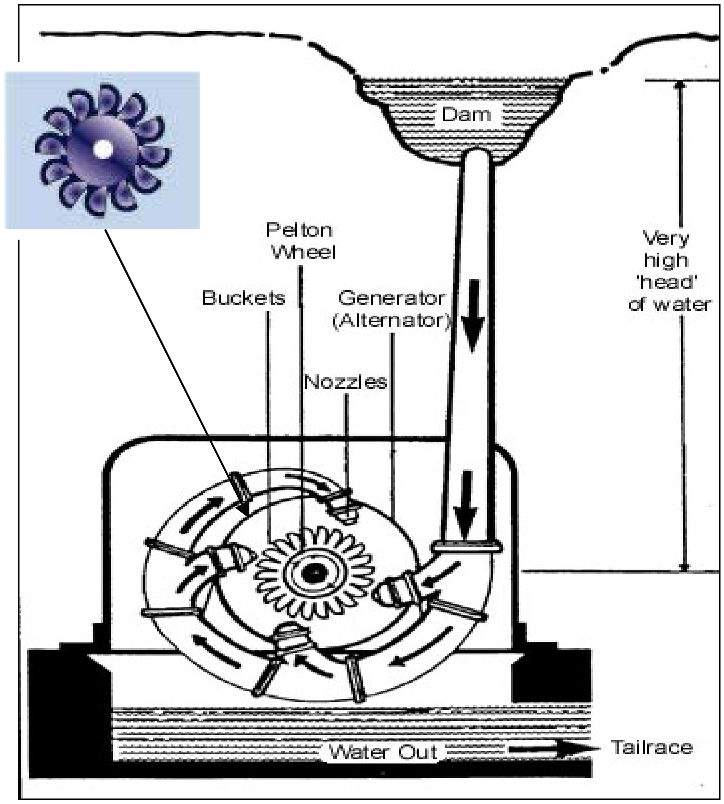


Figure 2.3: Pelton Turbine

2.3.1.2 Francis turbine :

In the great majority of cases (large and small water flow rates and heads) the type of turbine employed is the Francis or radial flow turbine. The significant difference in relation to the Pelton turbine is that Francis (and Kaplan) turbines are of the reaction type, where the runner is completely submerged in water, and both the pressure and the velocity of water decrease from inlet to outlet. The water first enters the volute, which is an annular channel surrounding the runner, and then flows between the fixed guide vanes, which give the water the optimum direction of flow. It then enters the runner, which is totally submerged, changes the momentum of the water, which produces a reaction in the turbine. Water flows radially i.e., towards the centre. The runner is provided with curved vanes upon which the water impinges. The guide vanes are so arranged that the energy of the water is largely converted into rotary motion and is not consumed by eddies and other undesirable flow phenomena causing energy losses. The guide vanes are usually adjustable so as to provide a degree of adaptability to variations in the water flow rate and in the load of the turbine.

The guide vanes in the Francis turbine are the elements that direct the flow of the water, just as the nozzle of the Pelton wheel does. The water is discharged through an outlet from the centre of the turbine. In design and manufacture, Francis turbines are much more complex than Pelton turbines, requiring a specific design for each head/flow condition to obtain optimum efficiency. Runner and housing are usually cast, on large units welded housings, or cast in concrete at site, are common.

With a Francis turbine, downstream pressure can be above zero. Precautions must be taken against water hammer with this type of turbine. Under the emergency stop, the turbine overspeeds. One would think that more water is going through the turbine than before the trip occurred since the turbine is spinning faster. However, the turbine has been designed to work efficiently at the design speed, so less water actually flows through the turbine during over speed. Pressure relief valves are added to prevent water hammer due to the abrupt change of flow. Besides limiting pressure rise, the pressure relief valve prevents the water hammer from stirring up sediment in the pipes.

With a big variety of designs, a large head range from about 40 m up to 700 m of head can be covered. The most powerful Francis turbines have an output of up to 800 MW and use huge amounts of water.

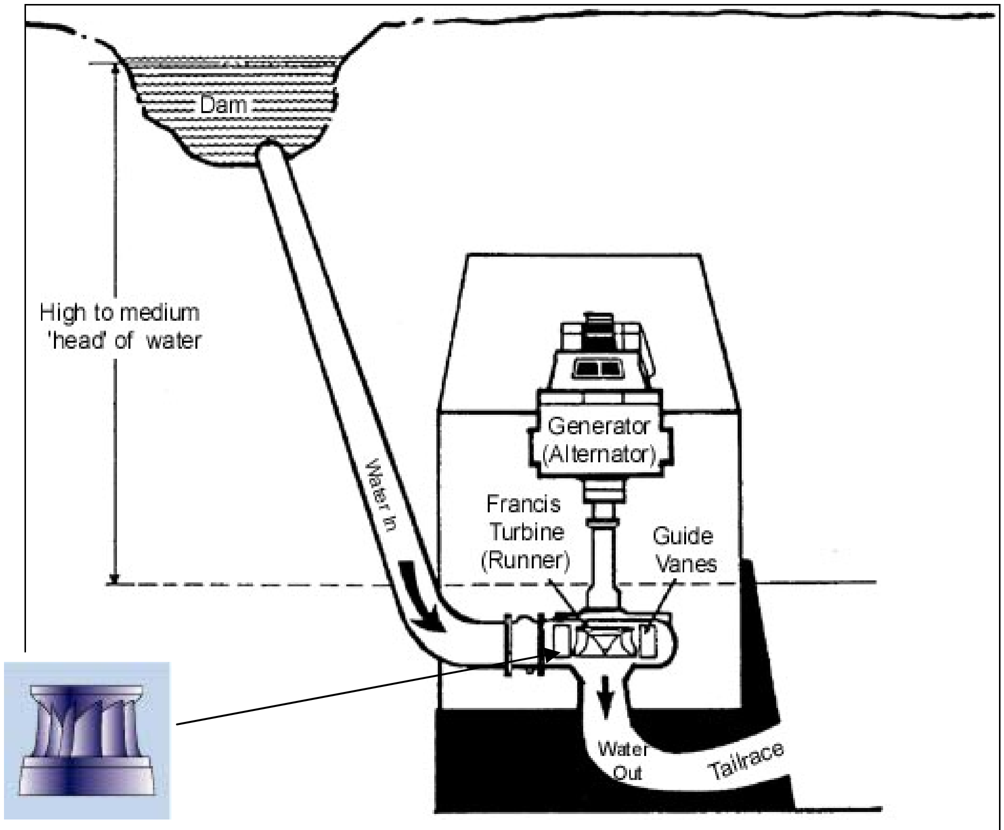


Figure 2.4: Francis Tubine

2.3.1.3 Kaplan turbine :

For very low heads and high flow rates a different type of turbine, the Kaplan or Propeller turbine is usually employed. In the Kaplan turbine the water flows through the propeller and sets the latter in rotation. In this turbine the area through the water flows is as big as it can be – the entire area swept by the blades. For this reason Kaplan turbines are suitable for very large volume flows and they have become usual where the head is only a few meters. The water enters the turbine laterally, is deflected by the guide vanes, and flows axially through the propeller. For this reason, these machines are referred to as axial-flow turbines. They have the advantage over radial-flow turbines that it is technically simpler to vary the angle of the blades when the power demand changes what improves the efficiency of power production. The flow rate of the water through the turbine can be controlled by varying the distance between the guide vanes; the pitch of the propeller blades must then also be appropriately adjusted. Each setting of the guide vanes corresponds to one particular setting of the propeller blades in order to obtain high efficiency. Important feature is that the blade speed is greater than the water speed – as much as twice as fast. This allows a rapid rate of rotation even with relatively low water speeds.

Kaplan turbines come in a variety of designs. Their application is limited to heads from 1 m to about 40 m. Under such conditions, a relatively larger flow as compared to high head turbines is required for a given output. These turbines therefore are comparatively larger.

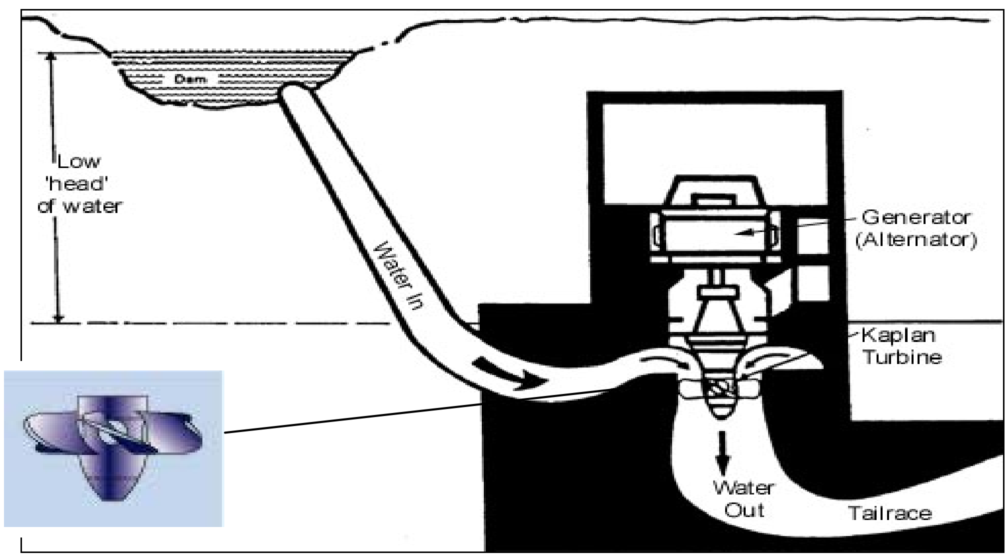


Figure 2.5: Kaplan and propeller type turbine

2.3.2Generators:

The basic configuration of a hydro power plant is determined not by the generator but by the water conditions. The turbine is designed first, for the most efficient extraction of available energy, and then the generator is made to match.

Hydro generators all operate at low speeds compared to generators in steam plants – typically between 200 and 1800 rpm. In general the highest practical generator speed should be adopted, since it reduces the size of equipment, and foundation and building requirements.

Generators like those installed in steam plants cannot be used at hydroelectric sites because they are not able to withstand the runaway speeds that can occur upon loss of load. Water turbines can accelerate quickly to as much as 260% of rated speed when load is removed while the full volume of water flows. Any sudden attempt to shut off the water will cause destructive overpressure in the penstock or supply pipe. Generators are generally designed for 185%-200% of rated speed.

Two types of generators are used in hydroelectric installations: synchronous and induction.

2.3.2.1 A synchronous generator:

Is synchronized to system voltage and frequency before the breaker device that connects the generator to the system is closed; when connected it continues to operate at synchronous speed. One advantage of synchronous generator is the ability to operate independently, supplying the required voltage, frequency and wattage at a given power factor. Disadvantages are the need for complex controls and isolated rotor windings.

2.3.2.2 Induction Generator:

Permits the simplest and low-cost control systems. The major difference between an induction and a synchronous generator is that the induction type gets the excitation from the power grid, and therefore doesn’t require an exciter or a voltage regulator.

The general method of getting a plant online with an induction generator is to start the generator as a motor, with the turbine runner spinning dry, and then open the wicket gates to load the unit, the generator then begins to function as a generator. It is practically impossible to overload an induction generator, since it will only accept as much reactive power as it requires for excitation. These units are lower in cost than synchronous generators, but are commercially available only up to 3 MW.

2.4 Big and Small Hydro Power Plant :

Hydro power plants range in capacity between few hundred watts to more than 10.000 MW. Classification between big and small is quite common where usually all power plants with capacity larger than 10 MW are considered as big and all others as small. (Small hydro power can be divided into three categories. The definitions of the categories vary, but are broadly: micro (less than 100kW), mini (100kW-1MW) and small (1MW-10MW) hydro), other than that it is a big hydro power. Terms like nano hydro with capacity less than 1 kW are also used in literature. Nevertheless it is worthwhile looking at the specific characteristics and basic differences between big and small power plants.

2.4.1 Big Hydropower :

Big hydropower stations are of a nature that requires a good infrastructure such as roads (during construction) and access to a big market, resulting in long high-tension grid systems and an extensive distribution system. It serves a great number of individual consumers and supplies power to electricity-intensive large industry.

Big plants are usually owned and operated by big companies or state enterprises. The skill requirements in management, administration, operation and maintenance are considerable. Unit cost of energy generation is relatively low; this is due to a decrease in specific investment cost with rising plant size, and the probability of higher load factors with a larger number of consumers. A problem is peak demand; big numbers of consumers tend to have their maximum individual demand during the same time-interval, which results in a largely uncontrollable peak of demand that must be met with increased capacity, such as standby installations and high cost pumped-storage.

From the engineering point of view, big hydro power calls for sophisticated technology in manufacturing electro-mechanical equipment, and high standards of

feasibility studies, planning and civil construction activities, because the risks involved are great. Long-term flow data are a necessity and gestation periods are long. It is possible to apply computer design technology and highly specialized fabrication technology to achieve very high performance efficiencies that may reach 96 % in the case of turbines. Needless to say, this process brings about very high cost, which however may be justified because of the large scale, where equipment cost is generally a relatively small fraction of total cost.
Big-scale hydropower stations require careful environmental considerations. Artificial lakes may change an entire landscape and inundate sizeable areas of arable land. Positive aspects are flood controlling capability and the creation of new recreational sites (boating, fishing, camping) although it is obvious that the benefits for recreation do not rise in proportion with size.

2.4.2 Small Hydropower :

Small, mini and micro or nano hydropower schemes combine the advantages of large hydro on the one hand and decentralized power supply, on the other. They do not have many of the disadvantages, such as costly transmissions and environmental issues in the case of large hydro, and dependence on imported fuel and the need for highly skilled maintenance in the case of fossil fuelled plants. Moreover, the harnessing of small hydro-resources, being of a decentralized nature, lends itself to decentralized utilization, local implementation and management, making rural development possible mainly based on self-reliance and the use of natural, local resources.

There are in fact many thousands of small hydro plants in operation today all over the world. Modern hydraulic turbine technology is very highly developed with the history of more than 150 years. Sophisticated design and manufacturing technology have evolved in industrialized countries over conventional technology the last 40 years. The aim is to achieve higher and higher conversion efficiencies, which makes sense in large schemes where 1 percent more or less may mean several MW of capacity. As far as costs are concerned, such sophisticated technology tends to be very expensive. Again, it is in the big schemes where economic viability is possible. Small installations for which the sophisticated technology of large hydro is often scaled down indiscriminately, have higher capital cost per unit of installed capacity. On the other hand environmental impacts due to small hydro stations are generally negligible or are controllable because of their size. Often they are non-existent.

Small hydro power plants are in large majority connected to the electricity grids. Most of them are of the “run-of-river” type, meaning simply that they do not have any sizeable reservoir (i.e. water not stored behind the dam) and produce electricity when the water provided by the river flow is available but generation ceases when the river dries-up and the flow falls below a predetermined amount. Power can be supplied by a small (or micro) hydro power plant in two ways. In a battery-based system, power is generated at a level equal to the average demand and stored in batteries. Batteries can supply power as needed at levels much higher than that generated and during times of low demand the excess can be stored. If enough energy is available from the water, an alternating current (AC) direct system can generate power. This system typically requires much higher power level than the battery-based system. Small hydropower in developing countries, on the other hand, implies decentralization. Energy produced is usually supplied to relatively few consumers nearby, mostly with a low-tension distribution network only.

Small hydro schemes have different configurations according to the head. High head schemes are typical of mountain areas, and due to the fact that for the same power they need a lower flow, they are usually cheaper. Low heads schemes are typical of the valleys and do not need feeder canal. Of the numerous factors which affect the capital cost, site selection and basic lay-out are among the first to be considered. Adequate head and flow are necessary requirements for hydro generation.

Most hydro power systems require a pipeline to feed water to the turbine. The exception is a propeller machine with an open intake. The water must pass first through a simple filter to block debris that may clog or damage the turbine. The intake is usually placed off to the side of the main water flow to protect it from the direct force of the water and debris during high flow.

High safety standards in construction works are often not necessary, even the rupture of a small dam would not usually threaten human life, and the risks are smaller anyway if initial costs are kept down. This makes it possible to use mainly local materials and local construction techniques, with a high degree of local labour participation.

Small hydro systems can require more maintenance than comparable wind or photovoltaic systems. It is important to keep debris out of the turbine. This is done by reliable screening and construction of a settling basin. In the turbine itself, only the bearings and brushes will require regular maintenance and replacement.

2.5 Basic Hydraulics :

The technology for harnessing hydro electric energy has been around for a long time. Basically, the amount of energy that can be generated at a given site is a function of the quantity of water available, the vertical distance the water falls, and the ability of the power plant to use the flow. To put this in mathematical terms:

Power (kW) = Head (meters) x Flow (m^3/second) x Gravity (9,81) x Efficiency .

Where the Power is the powerplant's capacity, the Head is the net head available to the turbine (Net head = Gross head -losses (m)) and the efficiency is the overall powerplant efficiency and depends on turbine/generator efficiency; it usually taken as 80% to 86% for estimating purposes.

Some of the first things must be determined in evaluating sites are:
How much head is potentially available, How much water is available in the river and the amount and timing of variation in the head and quantity of water.

- The Net Head

When determining head, both gross or "static" head, and net or "dynamic" head must be considered. Gross head is the vertical distance between the top of the penstock (the piping that conveys water, under pressure, to the turbine) and the point where the water discharges from the turbine. Net head is gross head minus the pressure or head losses due to friction and turbulence in the penstock. These head losses depend on the type, diameter, and length of the penstock piping, and the number of bends or elbows. So to keep these losses as minimum, careful design of trashracks, intakes and penstocks will increase the efficiency. The head can be relatively constant as in canal, but often it is highly variable.

- Stream Flow

Water supply to most hydroelectric installations is not constant. Most rivers, even when they have large reservoirs, are subject to periods of drought, as well as period of heavy rains and flood flows. These natural characteristics are a major consideration when selecting hydroelectric equipments.

- Losses in Pipeline systems:

In real fluid flows, losses occur due to the resistance of the pipe walls and the fittings to this flow and lead to an irreversible transformation of the energy of the flowing fluid into heat. Two forms of losses can be distinguished: losses due to friction and local losses.

Losses due to friction originate in the shear stresses between adjacent layers of water gliding along each other at different speed. The very thin layer of water adhering the pipe reach maximum velocity at the centre-line of the pipe. If the fluid particles move along smooth layers, the flow is called laminar or viscous and shear stresses between the layers dominate. In engineering practice however, the flow in a pipeline is usually turbulent, i.e. the particles move in irregular paths and changing velocities. It is important to use pipelines of sufficient diameter to minimize friction losses from the moving water. When possible the pipeline should be buried. This stabilizes the pipe.

Local losses occur at changes of cross sections, at valves and at bends. These losses are sometimes referred to as minor losses since in long pipelines their effect may be small in relation to the friction loss.

As explained above: Net head = Gross head -losses (m)

$$\textbf{Net head = Gross head - } \mathbf{h_f} \textbf{ - } \mathbf{h_a}$$

$\mathbf{h_f}$ = head loss due to friction = $\frac{flv^2}{2dg}$, $\mathbf{h_a}$ = abrupt loss = $\frac{C_a v^2}{2g}$

Where l = length of penstock

v = velocity of water

d = diameter of penstock

g = gravity

f = friction factor C_a = net abrupt loss coefficient

CHAPTER 3

HYDROELECTRIC POWER IN SUDAN

3.1 Hydrology of the Nile(6):

A schematic diagram of the Nile River system is given in Figure below. The Nile River system in Sudan comprises the Blue Nile and White Nile tributaries of the river that join together at Khartoum to form the Main Nile, which flows northward into Egypt.

Bahr El Jebel originates from Lake Victoria in Uganda and flows across the Sudan border upstream from Mongalla. The river enters the marshes of the Sudd area of Sobat where a large proportion of the flow is lost to evaporation before emerging and converging with the flow from the Bahr El Gazal and Sobat rivers at Malakal. The river flows northward to converge with the Blue Nile a short distance downstream from the Jebel Aulia reservoir at Khartoum.

The Blue Nile and its tributaries the Dinder and Rahad originate in the highlands of the Ethiopian Plateau. The Blue Nile flows from its source at Lake Tana in Ethiopia and enters the Sudan at EdDeim. The river is impounded in two reservoirs at Ed Damazin (Roseires) and Sennar and flows northwest to Khartoum to converge with the White Nile to form the Main Nile system.

The Atbara river with its source also in the Ethiopian highlands is the only major tributary of the Main Nile in Sudan. The Atbara river is impounded at Khashm El Girba Dam near Kassala. The Main Nile flows northward to Egypt and Lake Nubia impounded by the Aswan Dam.

(6)Source Long Term Power System Planning Study, Interim Report No.2 Sep2002

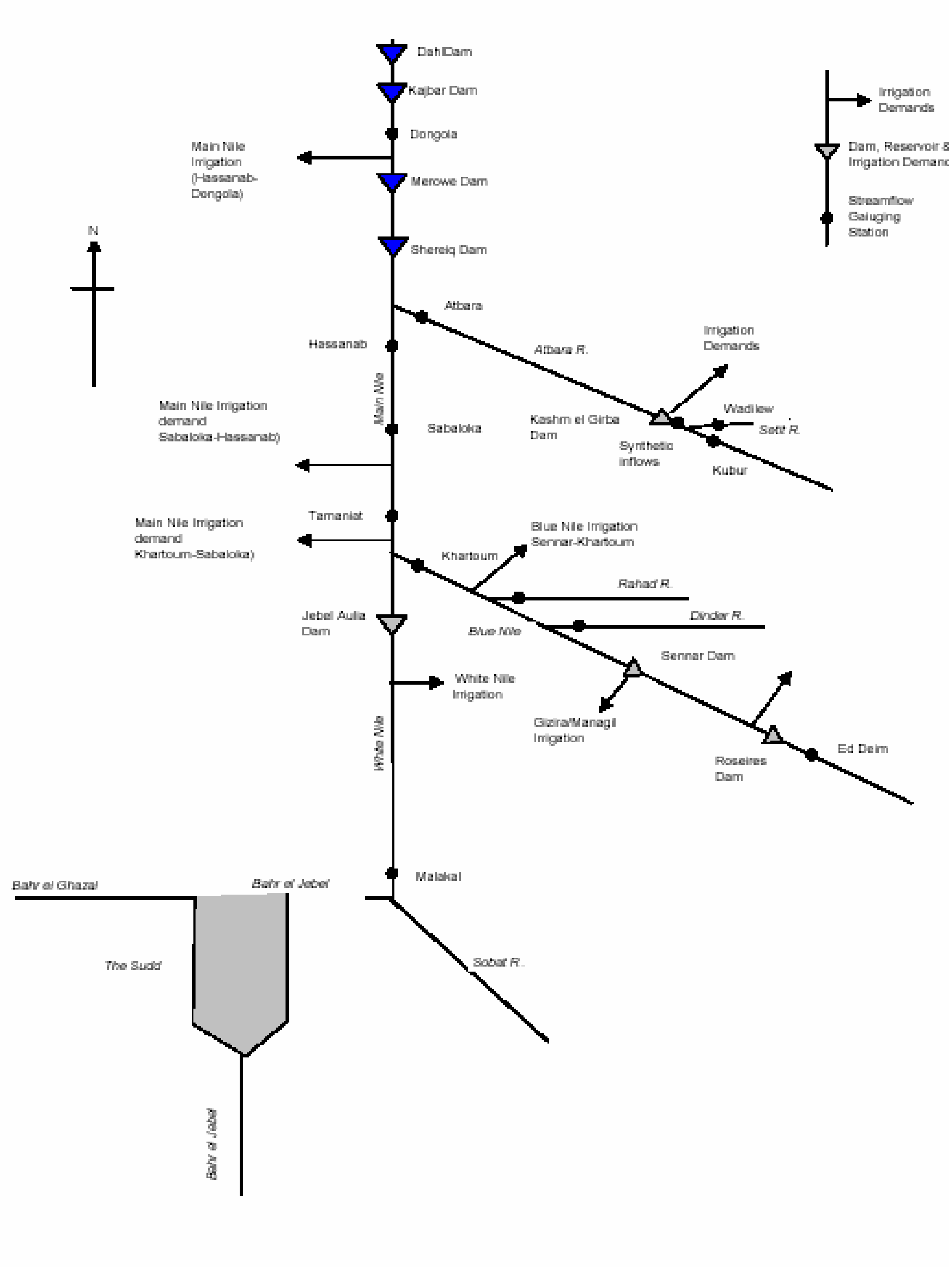


Figure 3.1: Schematic Diagram of the Nile River

Nile flows entering the Sudan are measured at river gauging stations near the border located at Ed Deim on the Blue Nile, and at Nimule and Mongalla on the Bahr el Jebel River in the south. There are flow records for the main inflows entering the White Nile from the Sobat and Bahr El Gazal rivers and at Malakal downstream from the confluence of these rivers. The main sources of ephemeral inflows into the Blue Nile are from the Dinder and Rahad rivers for which long-term flow records are available.

Similarly long-term flow records exist for Khartoum upstream from the confluence with the White Nile.

The flow of the Atbara river is measured a short distance upstream from the confluence with the Main Nile and at Khashm el Girba dam. River gauging stations are installed on the two tributaries of the Atbara River upstream of the dam and hence a short record of inflows to the reservoir is available. River gauging stations at Tamaniat, Hassanab and Dongola provide records of flows down the Main Nile.

-Operating rules:

Hydroelectric performance is determined not only by scheme design but also by the operating rules in force and, in the context of long-term planning, operation is conveniently defined in accordance with a variety of seasonal demand and reservoir rule curves. The Roseires, Sennar and Jebel Aulia reservoirs provide seasonal regulation of river flows to meet the needs of flood control together with irrigation and electricity supply. Another constraint on reservoir operation is the need to preserve storage capacity by controlling reservoir siltation. At Roseires this has dictated that the reservoir be held at minimum level each year until the bulk of the flood and entrained silt load has passed downstream, and then be filled at the very end of the flood season. Rules determining this operation have previously been reviewed in the context of the heightening of Roseires dam and among points that may now need to be confirmed for the heightened situation are:

i) a possible change to the reservoir minimum operating level,

ii) at what time or under what flow conditions should filling start in future, and

iii) Rules such that the larger reservoir then fills every year.

These are not independent considerations since an earlier start will be required to ensure filling and yet a higher minimum operating level would allow later filling.

The reservoirs are currently operated between minimum and full supply levels[7].

3. 2 Existing Hydroelectric Power Generation:

With the exception of Bahr el Jebel in the extreme south of the country, near the border with Uganda, all significant hydropower potential is located on the Blue Nile or on the Main Nile downstream of the confluence with the White Nile at Khartoum. The river is characterized by annual floods, with flow from Ethiopia in August exceeding the low flows in March and April by a factor of 50, and sediment concentration as high as 10 MT/day.

The two principal hydro plants in Sudan are Roseires and Sennar which are both located on the Blue Nile River. Roseires, by far the larger of the two, is located about 70 km from the Ethiopian border. Sennar is located about 175 km further downstream. Since both reservoirs are primarily intended for irrigation purposes, their operating regimes are similar.

3. 2.1 Roseires Hydro Power Station:

3.2.1.1 Main Features of the Dam[8]:

HYDROLOGY:

Total average annual flow of the Blue Nile at Roseires	50,000,000,000 m^3
Average peak flood discharge	6,300 m^3 /sec.
Maximum discharge capacity at 467.0m	6,400 m^3 / sec.
Maximum discharge capacity at 480.0m	16,500 m^3 / sec.
Maximum recorded flood (60 years)	10,800 m^3 / sec.
Average Low River flow	100 m^3 / sec.

(7) Feasibility Study for Roseries, Sennar and Jebel Aulia Hydo-Electric project, Final Report, Dec1997 Merz and Mclellan and Gibb.

(8) Manual of Roseires Dam, Ministry of Irrigation and Hydro Electric Power 1967

RESEVOIR at T . W . L. 480:

Volume	3,000,000,000 m^3
Area	290 sq . km.
Length	75 km.
At T . W . L 490	
Volume	7,400,000,000 m^3

DAM:

Central concrete section:

Top Water Level	480.0 m.
Roadway Level	481.80 m.
Maximum height above foundation	68.0 m.
Length	1,000 m.
Volume of concrete	850,000 m^3
Steel reinforcement	9,000 tonnes
Coping level	482.2 m.

Embankment dam section :

East length	4,000 m.
West length	8,500 m.
Total volume of fill	5.0 million m^3
Maximum height above foundation	30m.
Maximum width	230 m.

Irrigation potential :

Kenana canal headworks.	Maximum discharge. 360 m^3 / sec

Dinder canal headworks. Maximum discharge. 360 m^3 / sec

Hydro – electric potential:

Service power House 2 turbines of 1 MW Total 2 MW

Main power House 7 turbines of 40 MW Total 280 MW

It is at present the largest generating plant on NEC system. The development was initially conceived as an irrigation project being an indirect offshoot of 1959 Nile water treaty with Egypt. However before construction of Elroseires dam commenced, a decision was made to include a power plant in the main concrete structure. The plant contained a space for a maximum of seven generators with only three being installed during a first stage of development. The nominal operating head of the plant is 29m, although, because of the need to draw down the reservoir in the July- September period for slit flushing reasons, the head and consequently the Megawatts output of the machine is reduced considerably, so the turbines are of the Kaplan type in order to cope with this variations, the minimum operating head is 17 m.

In the first stage three units of 30 MW each were installed subsequent four units were rated 40 MWs, the former three units were uprated to 40 MWs.

The sequence in which the various units were installed is therefore as follows:

Unit	Date of Installation	MWs rating	Date of rewound
1	1971	40	1992

2	1971	40	1991
3	1972	40	1991
4	1979	40	-
5	1984	40	-
6	1984	40	-
7	1989	40	-

Table 3.1: Elroseries hydroelectric power station

At present there is no direct off take of water from the reservoir for irrigation. All releases are through one or more of the power house, low level sluices and the spillway to the natural river channel below, from which irrigation abstractions are made. The main concrete dam does, however, have eight outlets all of which are presently blocked off but could be activated.

Roseires Dam was originally designed and constructed as a first stage structure, with provision to raise the structure by 10 m. The increased storage capacity will allow for additional irrigation, restore some of the lost storage from sedimentation and give an additional head for power generation.

3.2.1.2 Design Of the Dam:

The dam is a concrete buttress type about 1,000 meters long, flanked on either side by earth embankments, 8.5 kilometers long to the west and 4 kilometers long to the east. The standard buttresses which make up nearly half of the total of 68 buttresses are spaced at 14.0 meter centers. The upstream water face has a slope of 3 in 10 and the water load is carried to the webs which are 3.0 meters thick down to R.L. 440, through the (T) heads with sloping haunches. The downstream face of the buttresses slopes at 6 in 10. The buttresses are built in trenches excavated to solid rock below the level of the weathered rock. Buttress web foundations for the future stage 2 dam have been constructed to above minimum tail water level or higher in the first stage. This is both for convenience and the safety of the structure and its equipment when the civil engineering works are recommenced for the final stage.

The Deep Sluice structure is sited in the main river channel and contains five sluice ways positioned as low as possible so that accumulations of silt in the reservoir can be kept to a minimum. Five radial gates 10.5 meters high by 6.0 meters wide control the discharge of water through the dam. An upstream emergency gate capable of closure under full flow conditions is also provided.

To the west of the Deep Sluices is the Surface spillway controlled by seven radial gates each 12.0 meters high by 10.0 meters wide. The Spillway will augment the deep sluice flow when it becomes necessary to pass the peak of the flood. The maximum design flood of about 18,750 m^3/sec can be passed. Making due allowance for the effect of the reservoir, without overtopping the dam. The maximum recorded flood over the past 60 years is 10,800 m^3/sec. The Spillway structure is sited in the diversion channel so that at maximum discharge the flow is dispersed over the full width of the natural trough in much the same manner as before construction commenced. A deflector bucket below the spillway throws the jet of water into a stilling basin clear of the dam. The stilling basin is an unlined excavation in the natural rock about 60 meters downstream of the Spillway.

During the peak of the flood, all spillway gates are kept fully open and the deep sluice gates are adjusted to maintain the reservoir at R.L. 467, if possible .At this time any floating debris reaching the dam can be passed down stream over the spillway. Should the flood exceed 6,400 m^3/sec, approximately the average peak discharge, the Reservoir will rise until the increased discharge balances the inflow. Keeping a low level in the reservoir during the flood ensures that the maximum quantity of sand and silt is passed through the dam to reduce the effect of siltation.

After the peak of the flood has passed, the high level gates are closed and the Deep sluices control the flow past the dam. At the tail end of the flood when the silt content in the water is reduced, impounding commences taking about 30 days to fill the reservoir to R.L.480.

Immediately west of the spillway structure, a small hydro – electric service station is contained between two buttress webs. The station provides power for the operation of the gates and for the township at Damazin. Further west the buttress spacing increases from 14.0 to 18.0 meters to take the seven intakes for the main power station.

The foundation for the power station was completed in June 1967. Each turbine has maximum output of 40 MW providing an ultimate installation at Roseires of about 280 MW. The power is transmitted to Khartoum over transmission line.

Near the western end of the concrete dam headwork had been constructed to divert water into the Kenana canal. The canal will be capable of carrying 360 m^3/sec to supply the proposed kenana irrigation scheme between the Blue and white Niles. A headwork's of similar capacity has also been built adjacent to the eastern end of the concrete dam to supply the Dinder and Roseires project areas. Concrete bulkheads now close off the intakes of both these headwork until the canals are built; the gates will then be installed and the civil engineering works completed.

At both end of the concrete dam, the transitions to the earth embankment consist of massive concrete gravity sections buried in the rising embankments with the buttress forms appearing above the rockfill face.

The design of the foundations for the concrete dam was great influenced by the irregular nature of the subsurface conditions. Elsewhere there was a considerable thickness of overburden and weathered rock. In all cases the dam was founded below the weathered zone and this resulted in trench excavation varying in depth to a maximum of about 18.0 metres for the Central standard Buttresses.

An extensive programme of contact and curtain grouting was carried out to reduce the rates of seepage through the rock strata under the dam and to consolidate the material directly adjacent to the constructed works. Subsequently drainage and pizometer holes were drilled downstream of the buttress heads to relieve and measure any uplift pressures developing in the rock foundation.

Three basic cross-sections have been designed for the earth embankments on both flanks. From the ends of the concrete dam to where the rise in ground level has reduced the stage 1 height to 7.5 meters , the embankment consists of clay core supported by upstream and downstream shells of silty or clean sand . These lengths, which together amount to 3.5 kilometers, are designed for heightening with a sloping core supported by an enlarged downstream shell.

n the transition, joining the high embankments to the ends of the concrete dam, the clay core is abutted against the end and upstream corner of the buttresses. End support to the embankment is provided by quarried rockfill, overlying gravel fill and filters . The construction allows much steeper slopes than on the rest of the embankment, thus considerably reducing the length of concrete dam in these transitions.

The upstream berm and shell are constructed for the ultimate (stage 2) height in order to avoid interference with reservoir operation when the dam is raised. The downstream shell is replaced by clay core where the initial height is between 7.5 meters and 2.5 meters and the rest of the embankment consist of clay with wave and rain protection only. The intermediate and low cross-section will become upstream berms when the dam is heightened.

The foundation soils consist of two layers of highly plastic clay, the top layer known as black cotton soil, separated by a zone of sand which varies in composition from clayey sand to clean, poorly graded sand. These soil overlie rock, which is generally very decomposed. The rock and the three main soil lavers outcrop successively as the ground rises from the river. The embankment forming the rockfill transitions between earth and concrete dams are founded generally on rock, and in these sections the grout curtain has been extended from the concrete dam to continue beneath the core of the earth embankments. Where the dam crosses the sand outcrops, seepage is obstructed by a clay-filled cut-off trench, which becomes unnecessary where the upper clay acts as an upstream blanket. Relief wells are provided downstream on the high sections and on part of the intermediate section.

The foundation clays are desiccated and fissured. They are very stiff in their natural state but they will soften considerably when they are wetted by seepage from the reservoir .In the course of time, further softening is liable to occur under the influence of the stresses imposed by the weight of the embankment

Fig 3.2: Passing flood water in Roseires dam

Fig3.3: Aerial view from the east bank

Fig 3.4: view of progress on the earth transition of the west embankment

Fig 3.5: General view of the dam from upstream

Photographs during construction of Roseries Dam

3.2.2 Sennar:

The Sennar Hydropower Plant is located on the left bank of the Blue Nile, some 275 km upstream from Khartoum. Although the barrage at Sennar was completed in 1925, the hydroelectric plant was not added until 1962. The scheme houses two generators each with a nominal rating of 7.5 MW. The generators are driven by Kaplan turbines operating at a head which varies between 17 m and 5.8 m.

NEC already have additional plan to add a second powerhouse 4 × 12.5MW on the opposite (right bank) of the river

Power Station	Installation date	Units No	Unit capacity Ins.(MW)	Total Capacity MW	
				Ins. Cap.	Available
Sennar	1962	2	7.5	15	14.5

Table 3.2 : Sennar - hydroelectric power station

3.2.3 Khashm El Girba:

The Khashm El Girba hydro power plant is located on the Atbara River with the dam located about 50 km west of the Ethiopian border. Like the other two hydro sites on the system, this installation was primarily designed for irrigation purposes with power generation being a secondary consideration. The main dam is of the rock fill type and the hydropower installation provides 12 MW of non-firm supply to the grid in Eastern Sudan. The units were commissioned between 1961 and 1963.

Utilization of the output of these units was improved following interconnection with the main grid in 1990. The main concrete section of the dam contains the main machine hall and comprises two 3.12 MW generators each driven by a Kaplan turbine, together with four 1900 HP electric motors driving supplementary irrigation pumps. In a separate machine hall, there are three reversible axial flow pump/turbines. Each of which is rated at 2.07 MW in the generating mode and 1.9 MW in the pumping mode. On the left abutment there is a structure which provides an off take for the irrigation canal.

Power Station	Installation date	Units No	Unit capacity Ins.(MW)	Total Capacity MW

				Ins. Cap.	Available
Elgirba Turbines	1964	2	3.12	6.24	6
Elgirba Pumps	1961	3	2.2	6.6	6

Table 3.3 :Khashm Elgirba- hydroelectric power station

Whilst there is no available capacity at present, NEC suggested that the refurbishment and up-rating of the pump turbines and the up-rating of the Kaplan turbines would result in an increased capacity of 5.3 MW rated output.

3.3 Future hydroelectric schemes:

3. 3.1 Roseires Dam heightening:

Roseires Dam is an existing structure on the Blue Nile close to the town of El-Roseires and has a principal function of water supply for irrigation with secondary ability to generate power. The dam was constructed between 1960 and 1966 as a first stage structure for the initial FSL of 480 masl with provision to raise the structure by 10 m. During the late eighties early nineties the Ministry of Irrigation decided to go ahead with the raising from FSL 480 to FSL 490 masl(9). The increased storage capacity will allow for additional irrigation, restore some of the lost storage from sedimentation and give an additional head for power generation. A preliminary analysis for the existing hydroelectric system confirm that the current irrigation demands, particularly from Blue Nile schemes, cannot be supplied with 100 per cent reliability, i.e. that in low-flow years irrigation supplies have to be curtailed somewhat. It is to be expected that this situation will worsen as siltation of the existing Roseires reservoir progresses, and it also seems clear that any significant irrigation expansion would be inadvisable unless additional storage is provided. It thus remains clear that the economic and financial justification for

(9) Long Term Power System Planning Study, Interim Report No.2, Sep2002

completing the work of dam heightening will rest largely on the irrigation benefits to be obtained. Nonetheless the increased regulating capability of the larger storage that will be provided by heightening together with the greater energy outputs obtainable with increased head will have significant value to the power system and will thus make a substantial contribution to this justification.

3.3.2 Kenana and Dinder extensions:

The M&M and Gibb study [(10)] developed a possible number of alternative scenarios for the Kenana and Dinder power station extensions. The engineering and updated capital cost data was done separately for both the proposed Kenana and Dinder extensions. All these following options and associated updated capital costs are based upon the premise that the dam is raised and that full supply level FSL is 490m. In addition the maximum permissible flow constraints at the Kenana and Dinder intakes are directly related to the assumption that the dam has been raised and that the minimum operating level increased. Raising the MOL will allow a higher maximum flow rate as well as increasing the available head.

For Kenana extension the provision for future headworks comprises five rectangular openings each 4 m wide x 5.3 m high on the left bank (the Kenana canal headworks).

For Dinder extension the provision for future headworks comprises three circular openings of 5 m on the right bank (the Dinder canal headworks). As the Dinder schemes were shown to be more attractive, development of a Kenana scheme may only be in addition to the Dinder Scheme.

3.3.3Sennar Dam:

Sennar Dam was completed in 1925 as a low head masonry dam and the power station which was commissioned in 1962, is located on the left bank. The reservoir has an

[(10)] Feasibility Study for Roseries, Sennar and Jebel Aulia Hydo-Electric project, Final Report, Dec1997 Merz and Mclellan and Gibb.

operating FSL of 421.70 masl. Also located on the left bank, is an approach canal feeding two sets of irrigation intakes which discharge into the main Gezira and Managil canals. Because the powerhouse at Sennar can discharge less than at Roseires, the spillage at Sennar is greater in volume and continues longer than at Roseires, despite the diversion of water for irrigation from the Sennar reservoir. The potential power and energy to be obtained through an extension at Sennar is limited to low heads, particularly during drawdown and flood conditions.

3. 3.4 Jebel Aulia Dam:

The Jebel Aulia Dam on the White Nile is about 40 km upstream of Khartoum and was completed in 1937 as a storage reservoir for irrigation in Egypt. The dam is constructed of masonry with a section some 445 m long having 60 sluices. A navigation lock is included, adjacent and on the right bank. The non-overflow sections are 570 m long on the west side and 404 m long on the east. Of the total of 60 sluices, 50 have gates installed and 10 on the west are closed with temporary bulkheads. The height of the sluice section of the dam is about 15 m with a 377.4 m FSL from the M&M/Gibb report. On the west side, the non-overflow section continues with a long embankment to the higher elevations on the left bank. The head between reservoir and tail water levels varies from 9.6 m at full reservoir and low discharges, to almost zero during the flood season. The head is affected by a raised tailwater which is caused mainly by the back-water effects of the Blue Nile flood. Now NEC with VA Tech company begins installing Hydromatrix turbines [(11)]. The Hydromatrix turbine is a module containing 2 sets of rated output 260.1 kW per set or 520.2 kW per module. VA Tech proposes to install 40 modules within 40 of the low sluice openings giving a possible combined total rated output of 20.8 MW.

[(11)] Jebel Aulia Dam, Technical Specifications, Hydro Matrix Power Plant, 40 modules with 2 units each, Va tech, sep 2000.

Construction and installation started in May 2002 and work was expected to be completed within a three year period, working mainly during the low water season, now the work is completed with 30.4 MW; the first set comes online in the middle of 2004.

3. 3.5 Merowe Dam:

The Government of Sudan is planning to construct Merowe Dam and a hydropower station at Merowe Island in the region of the fourth cataract on the Main Nile River approximately 350 km north of Khartoum. The development of the hydropower potential of the fourth cataract has been investigated since the 1940's and since that time various alternative project layouts have been studied up until the early 1990's when a definitive layout was selected and evaluated in more details. In mid 2000 the Merawi Dam Project Implementation Unit (MDIPU) of the ministry of Irrigation and water resources commissioned Lamheyer International[(12)] to carry out an assessment of project implementation.

Merowe HPP has several purposes, the most important of which is the production of energy from the proposed 1250 MW hydropower station. Other purposes include the development of centralized agricultural and irrigation schemes with the canal headworks at Merowe Dam and the protection of the Northern state from devastating high floods of the Main Nile river.

The scheme comprises the follow major components: -

- Powerhouse – 10 Francis turbines of 125 MW each having a total installed capacity of 1250 MW.
- Right bank dam – a 52m high x 4400 m long concrete faced rockfill dam
- Right bank saddle – a 4.9 m high x 310 m long earth embankment
- Left bank dam – a 65 m high x 2300 m long clay core rockfill dam
- Spillway – 12 number radial gated x 6 m wide x 10 m high low level sluices. In addition to the left and right of these sluices there are two surface spillways one on each side, 15 m wide.

[(12)] Merawi Dam Project, Project Assessment Report, Lamheyer International, Oct 2001

- Sediment sluices – 6 number x 4 m wide x 2.5 m high sediment sluices
- Reservoir full supply level = FSL 300 masl.

CHAPTER 4

FEASIBILITY STUDIES OF ENGINEERING PROJECTS

4.1 Investment Project Cycle and Type of Pre-investment Studies [133]:

The development of an industrial investment project from the stage of the initial idea until the plant is in operation can be shown in the form of a cycle comprising three distinct phases, the pre-investment, the investment and operational phases. Each of these three phases is divisible into stages. Several parallel activities take place within the pre-investment phase and even overlap into the succeeding investment phase. Thus, once an opportunity study has produced fairly dependable indications of a viable project, investment promotion and implementation planning are initiated, leaving the main effort to the final investment appraisal and the investment phase (figure 4.1).

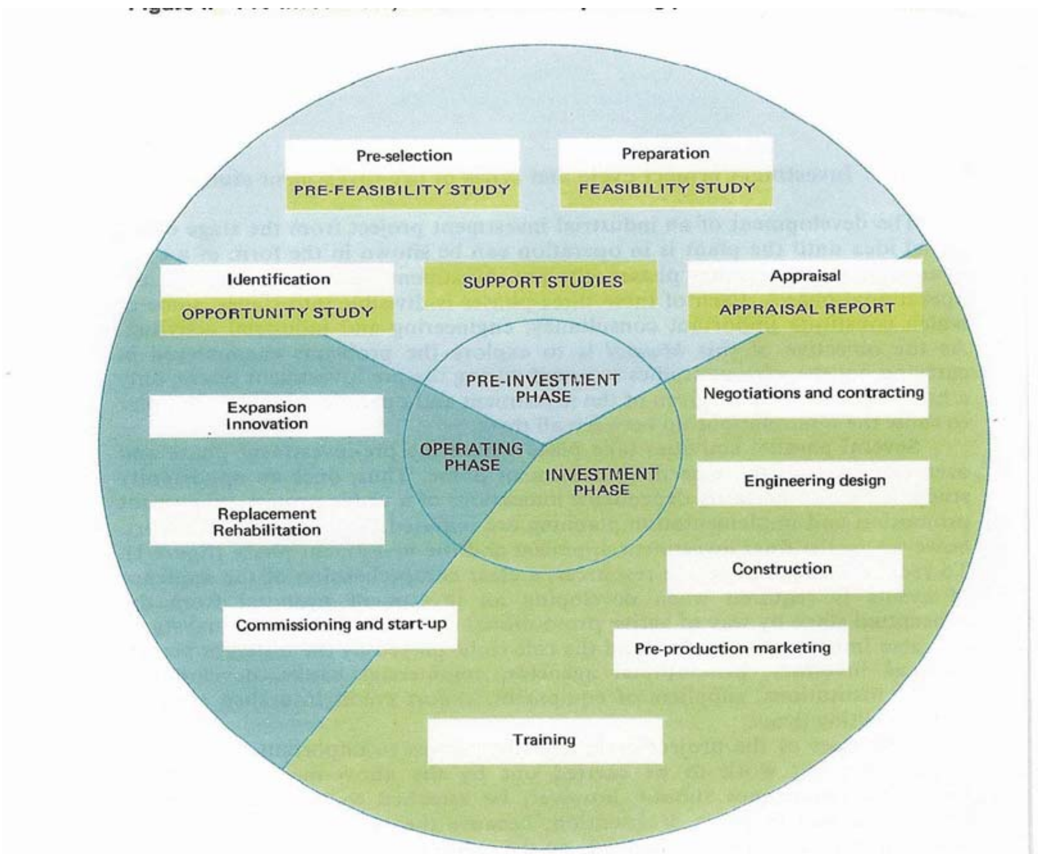


Figure 4.1: Pre-investment, Investment and Operating phases of the project cycle

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(133) Manual for the preparation of industrial Feasibility Studies, W.Berens, P.M Hawranek (Unido Publication)

4.1.1. The Pre-investment Phase:

The pre investment phase comprises several stages: identification of investment opportunities (opportunity studies); analysis of project alternatives and preliminary project selection as well as project preparation (pre-feasibility and feasibility studies); and project appraisal and investment decisions (appraisal report). Support or functional studies are also a part of the project preparation stage and are usually conducted separately. The development of a project through several stages also facilitates investment promotion and provides a better basis for project decisions and implementation by making the process more transparent.

4.1.2. The Investment Phase:

The investment or implementation phase (figure) of a project provides wide scope for consultancy and engineering work, first and foremost in the field of project management. The investment phase can be divided into the following stages:

- Establishment the legal, financial and organizational basis for the implementation of the project.
- Technology acquisition and transfer, including basic engineering.
- Detailed engineering design and contracting, including tendering, evaluation of bids and negotiation.
- Acquisition of land, construction work and installation.
- Pre-production marketing, including the securing of supplies and setting up the administration of the firm.
- Recruitment and training of personnel.
- Plant commissioning and start-up.

Detailed engineering design comprises preparatory work for site preparation, the final selection of technology and equipment, the whole range of construction planning and time-scheduling of factory construction, as well as the preparation of flow charts, scale drawing and a wide variety of layouts.

4.1.3. The Operational Phase:

The problems of the operational phase need to be considered from both a short- and long-term viewpoint. The short-term view relates to the initial period after commencement of production when a number of problems may arise concerning such matters as the application of production techniques, operation of equipment or inadequate labour productivity owing to a lack of qualified staff and labour. Most of these problems have their origin in the implementation phase. The long-term view relates to chosen strategies and the associated production and marketing costs as well as sales revenues. These have a direct relationship with the projections made at the pre-investment phase. If such strategies and projections prove faulty, any remedial measures will not only be difficult but may prove highly expensive.

4. 2. The Feasibility Study:

A feasibility study, is a tool for providing potential investors, promoters and financiers with the information required to decide whether to undertake an investment, and whether and how to finance such a project. A feasibility studies should provide all data necessary for an investment decision. The commercial, technical financial, economic and environmental prerequisites for an investment project should therefore be defined and critically examined on the basis of alternate solutions already reviewed in the pre-feasibility study.

There is no uniform approach or pattern to cover all industrial projects of whatever type, size or category. Moreover the emphasis on, and consideration of, different components varies from project to project. For most industrial projects, however the broad format described below is of general application–bearing in mind that the larger the project the more complex will be the information required.

The feasibility study should consist of the following items:

4.2.1. The Executive Summary:

A feasibility study should arrive at definitive conclusions on all the basic aspects of a project after consideration of various alternatives. These conclusions and any recommendations made with regard to decisions or actions required from parties involved in the project would have to be explained and supported by compelling evidence. For convenience of presentation, the feasibility study should begin with a brief executive summary outlining the project data (assessed and assumed) and the conclusions and recommendations, which would then be covered in detail in the body of the study; any supporting material (statistics, results of market surveys, detailed technical descriptions and equipment lists, plant layouts etc.), however, should be presented in a separate annex to the study. The executive summary should concentrate on and cover all critical aspects of the study, such as the following: the degree of reliability of data on the business environment; project input and output; the margin of error (uncertainty, risk) in forecasts of market, supply and technological trends; and project design.

The executive summary should have the same structure as the body of the feasibility study

4.2.2 Project Background and Basic idea:

To ensure the success of the feasibility study, it must be clearly understood how the project idea fits into the framework of general economic conditions and industrial development of the country concerned. The project should be described in detail and the sponsors identified, together with a presentation of the reasons for their interest in the project.

4.2.3. Market Analysis and Marketing Concept:

The basic objective of any industrial investment project is to benefit either from the utilization of available resources or from the satisfaction of existing or potential demand for the output of the project. For all investment projects, including those with the primary objective of resource utilization, market analysis is the key activity for determining the scope of an investment, the possible production programs, the technology required and often also the choice of a location. Market analysts must have an understanding of the quantity and quality of the products and by-products involved, and of possible alternatives with regard to the economic size, as determined by input availability and requirements, as well as by technological and locational constraints.

Once the present effective demand for the envisaged project output, the characteristics of the corresponding markets (unsatisfied demand, competition, imports, exports etc.) and possible marketing concepts have been determined, the desired production program, including the required material inputs, technology and human resources, as well as suitable locations, can be defined. The demand or market analysis must be carefully structured and planned in order to obtain the required information within the time and cost limits, and to determine the possible marketing and production strategies required to reach the basic or corporate objectives. Planning of marketing research requires an understanding of the marketing system, the determination of the objectives and scope of the research, and proper structuring of the market to be analyzed.

4.2.4 Raw Materials and Supplies:

The different materials and inputs required for the operation of the plant are identified and described, and their availability and supply, as well as the method of estimating the resulting operating costs, are analyzed and described. The selection of raw materials and supplies depends primarily on the technical requirements of the project and the analysis of supply markets. Important determinants for the selection of raw materials and factory supplies are environmental factors such as resource depletion and pollution concerns, as well as criteria related to project strategies, for example, the minimization of supply risks and of the cost of material inputs.

In order to keep the cost of feasibility studies at a reasonable level, key aspects are to be identified and analyzed in terms of requirements, availability, costs and risks, which may he significant for the feasibility of a project.

4.2.5. Location, Site and Environment:

Following the assessment of demand and the definition of basic project strategies with regard to the sales and production programs, plant capacity and input requirements, a feasibility study should determine the location and site suitable for an industrial project. Location and site are often used synonymously but must be distinguished. Tire choice of location should be made from a fairly wide geographical within which several alternative sites can be considered. An appropriate location could extend over a considerable area. Within a recommended location one or more specific project sites should be identified and assessed in detail. For each project alternative the environmental impact of erecting and operating the industrial plant should be assessed. In many countries, regulations also require the preparation of an environmental impact assessment in order to obtain the permits for the erection and operation of industrial plants.

4.2.6. Engineering and Technology:

An integral part of engineering at the feasibility stage is the selection of an appropriate technology, as well as planning of the acquisition and absorption of this technology and of the corresponding know-how. The required machinery and equipment must be determined in relation to the technology and processes to be utilized, the local conditions, the state of the art and human capabilities. Skill development needs to be planned through training programs at various levels.

The analysis must include all technical, managerial and administrative, as ell as external, sociocultural and economic aspects of the required maintenance system. It should also outline the specific requirements of each individual technology, if selected, and specify the need for technical documentation and maintenance procedures. In particular the analysis must include a thorough survey of spare parts and the format of the necessary lists of spare parts.

Environmental protection devices are an essential part of any company operation, in particular when they form part of the production process. The breakdown of such plant components can, lead to a temporary shut-down of the entire plant.

Estimates of Overall Investment Costs:

Capital Cost Estimates

Once the production program and plant capacity are defined, a preliminary order-of-magnitude estimate can be drawn up regarding the broad investment requirements of the project, particularly if a plant capacity is set at a fairly standardized level, and prices are available for plant and equipment at such capacities. In the case of preliminary cost estimates for opportunity or pre-feasibility studies, this can also be done through the use of certain broad ratios. For example, it is often estimated that the machinery and equipment for a project would constitute about 50 per cent of total investment costs, with the main plant costing about 30 per cent. Buildings and civil works are generally assumed to cost from 10 per cent to 15 per cent of total investment. Similar, though much smaller, percentages can be set for utilities, instrumentation, piping and other ancillary facilities and requirements. Such percentages, however, vary considerably from industry to industry and country to country and should be utilized with a great deal of caution. At the same time, these figures maybe useful at the project appraisal stage when analysing the structure of Investment costs. If, for example, the civil engineering cost estimates are relatively low in relation to plant machinery and equipment as compared with similar projects, then the plant machinery costs could be over estimated, or the cost projections for civil engineering may not cover all civil engineering works probably required for project implementation. To check the reliability of cost estimates, a detailed breakdown to the various cost items would be necessary.

On the basis of the estimates for technology, machinery and equipment and civil engineering works, the feasibility study should provide an overall estimate of the capital costs of the project. Such an estimate will undergo modification in accordance with the bids and offers received from suppliers and contractors, but will nevertheless provide a fairly realistic estimate of capital costs. The preliminary estimate is based on the process flow sheet after the scope of the project has been determined by those concerned with the preparation of an opportunity or pre-feasibility study. A physical contingency allowance is commonly added, but it would be preferable to have the probable cost range quoted.

The budget estimate required at the feasibility study level must be founded on a properly developed flow sheet and a full assessment of the site. It will be based on a fairly detailed equipment list, and costs of special or main plant items may be obtained through preliminary tendering. A typical degree of accuracy would be ±10 per cent. Careful consideration must be given to this estimate, and in particular to the contingencies allowed.

4.2.7. Organization and Overhead Costs:

The aim of this part is to describe the process of organizational planning and the structure of overhead costs, which can be decisive for the financial feasibility of the project. A division of the company into organizational units in line with the marketing, supply, production and administrative functions is necessary not only from the operational point of view, but also during the planning phase, to allow the assessment and projection of overhead costs. Furthermore, it is essential for the feasibility of a project that a proper organizational structure should be determined in accordance with the corporate strategies and policies.

The recommended organization will depend on the social environment as well as on techno-economic necessities. The organizational set-up depends to a large extent on the size and type of the industrial enterprise and the strategies, policies and values of those in a position of power in the organization. It should also be borne in mind that organizations are not static but develop with the project (pre-investment and investment phases, start-up and operation).

Overhead Costs:

In most feasibility studies little attention is paid to the planning of overhead Costs. Overhead Costs are frequently computed as a percentage surcharge on total material and labour inputs or other reference items, a procedure that, in most cases, is not sufficiently accurate. Admittedly, the amount of time and effort required to calculate overhead Costs should be positively related to the results to be obtained. Overhead costs should be grouped as outlined below.

Factory Overheads:

Factory overheads are costs that accrue in conjunction with the transformation, fabrication or extraction of raw materials. Typical cost are: Wages and salaries (including benefits and social security contributions) of manpower and employees not directly involved in production, Factory supplies, e.g. Utilities (water, power, gas, steam), Effluent disposal, Office supplies and Maintenance

These cost items should be estimated by the service cost centres where they accrue.

Administrative Overheads:

Administrative overheads should only be calculated separately in cases where they are of considerable importance, otherwise they could be included under factory overheads. Typical cost items are: Wages and salaries (including benefits and social security contributions), Office supplies, Utilities, Communications, Rent. .etc

These cost elements should be estimated for administrative cost centers such as management, bookkeeping and accounting, legal services and patents, traffic management and public relations.

Marketing Overheads:

Direct selling and distribution costs, such as special packaging and forwarding costs, commissions and discounts, should be calculated separately for each product, Indirect marketing costs that cannot be easily linked directly with a product are usually treated as marketing overhead costs. These costs are often included under administrative overheads. However, marketing costs should be shown in the feasibility study as a separate cost group, if the total represents a significant share of the total costs of products sold. Typical cost items, with chapter references, are listed below.

- Wages and salaries (including benefits and social security contributions)
- Office supplies, utilities, communication
- Indirect marketing costs, advertising, training etc.

Depreciation Costs:

Depreciation is an accounting method used to distribute the initial investment costs of fixed assets over the lifetime of the corresponding investment. Annual depreciation charges are frequently included under overhead costs. Since, however, these costs are treated differently for the discounted cash flow method, depreciation costs should be shown separately from overhead costs. In this way it is still possible to include them for the calculation of factory and unit costs, as well as for financial evaluation.

Depreciation costs should be calculated on the basis of the original value of fixed investments, according to the methods applicable (straight line, declining balance or accelerated depreciation method etc.) and rates adopted by management and approved by the tax authorities. The same applies for non-tangible assets, such as capitalized pre-production expenditures.

Financial Costs

Financial costs such as interest on term loans, should be shown as a separate item, because they have to be excluded when computing the discounted cash flows of the project, but are to be included for financial planning. When forecasting overhead costs, attention should be given to the problem of inflation. In view of the numerous cost items in overhead costs, it will not be possible to estimate their growth individually, but only as a whole. A sound judgment has therefore to be made as to the magnitude of the overall inflation rate of overhead costs.

4.2.8. Human Resources:

Once the production program, plant capacity, technological processes to be employed and plant organization have been determined, the human resource requirements at various levels and during different stages of the project must be defined, as well as their availability and costs. The successful implementation and operation of an industrial project needs different categories of human resources—management, staff and workers—with sufficient skills and experience. The feasibility study should identify and describe such requirements and assess the availability of human resources as well as training needs. The study should pay particular attention to the definition and assessment of those skills and experiences which may be critical for the success of the project.

On the basis of the qualitative and quantitative human resource requirements of the project, the availability of personnel and training needs, the Cost estimates for wages, salaries, other personnel-related expenses and training are prepared for the financial analysis of the project. In case an economic evaluation is intended, the costs of unskilled labour should be shown separately.

4.2.9. Implementation Planning and Budgeting

The project implementation phase embraces the period from the decision to invest to the start of commercial production. It is very important carefully to plan and analyze this critical phase of the project cycle, because deviations from the original plans and budgets could easily jeopardize the entire project. A primary objective is therefore to determine the technical and financial implications of the various stages of project implementation, with a view to securing sufficient finance to float the project until and beyond the start of production. The choice of financing as well as the financial implications of investment and production delays should receive particular attention.

A series of simultaneous and interrelated activities taking place during the implementation phase have to be identified, including the financial implications they might have for the project. When preparing the implementation plan for the feasibility study it should also be borne in mind that, at a later stage, this plan will be the basis for monitoring and controlling the actual project implementation. The implementation schedule must present the costs of project implementation as well as the schedule for the complete cash outflows (for all initial investments), in order to allow the determination of the corresponding inflows of funds, as required for financing the investments.

4.2.10. Financial Analysis and Investment Appraisal:

Given the conditions for investment appraisal, project preparation should be geared towards the requirements of financial and economic analysis. Financial analysis should accompany the design of the project from the very beginning, which is only possible when the financial analyst is integrated into the feasibility studies team at an early stage. From a financial and economic point of view, investment can be defined as a long-term commitment of economic resources made with the objective of producing and obtaining net gains (exceeding the total initial investment) in the future. The main aspect of this commitment is the transformation of financial resources into productive assets, represented by fixed investment and net working capital. While the interest in future net gains is common for each party investing in a project, the expected gains or benefits may differ considerably between them, and may also be valued differently.

Important aspects of financial analysis, such as basic criteria for investment decisions, pricing of project inputs and outputs, the planning horizon and project life, as well as risks and uncertainty, will be discussed, and then detailed consideration will be given to cost analysis, basic accounting principles, methods of investment appraisal (discounting and conventional methods), financing, financial efficiency and ratios, and financial analysis and project evaluation in conditions of uncertainty.

Risk and Uncertainty:

Investment projects are by definition related to the future, which a project analyst cannot forecast with certainty. Thus financial analysis and evaluation have to be carried out under conditions of risk and uncertainty. The difference between risk and uncertainty is related to the decision maker's knowledge of the probable occurrence of certain events. Risk is present when the probabilities associated with various outcomes may be estimated on the basis of historical data. Uncertainty exists when the probabilities of outcomes have to be assigned subjectively, since there are no historical data. The aspects and methods of financial analysis under uncertainty are discussed later in this chapter in the Section on break-even analysis, sensitivity analysis and probability analysis.

Analysis of Cost Estimates:

Since reliable cost estimates are fundamental to the appraisal of an investment project, it is necessary to check carefully all cost items that could have a significant impact on financial feasibility. The sensitivity analysis described later permits the identification of critical cost items, and the cost structure analysis helps to identify possible inconsistencies and unbalanced cost structures, especially when data for similar projects are available from a feasibility-studies data bank. In case of questionable estimates, it may be necessary to verify such cost projections by using other data sources.

The estimates should be grouped into local and foreign components and may be expressed either in constant or current prices (real or nominal terms) Depending on the price basis used in the feasibility study and for the financial analysis, allowances for price increases (contingencies) should be provided for.

Total Investment Costs:

Initial Investment Costs:

Initial investment costs are defined as the sum of fixed assets (fixed investment costs plus pre-production expenditures) and net working capital, with fixed assets constituting the resources required for constructing and equipping an investment project, and net working capital corresponding to the resources needed to operate the project totally or partially. At the pre--

investment stage, two mistakes are frequently made. Most commonly, working capital is included either not at all or in insufficient amounts, thus causing serious liquidity problems for the nascent project. Furthermore, total investment costs are sometimes confused with total assets, which correspond to fixed assets plus pre-production expenditures plus Current assets. The amount of total investment costs is, in fact, smaller than total assets, since it is composed of fixed assets and net working capital, the latter being the difference between current assets and current liabilities (see below).

Fixed Investment Costs:

Fixed investments should include the following main cost items, which may be broken down further, if required:

- Land purchase, site preparation and improvements
- Building and civil works
- Plant machinery and equipment, including auxiliary equipment
- Certain incorporated fixed assets such as industrial property rights and lump-sum payments for know-how and patents

The estimates include supply, packing and transport, duties and installation charges. Depending on the type and accuracy of the pre-investment study, provisions should also be made for physical contingency allowances, providing a safety factor to cover miscellaneous (unforeseen or forgotten) minor cost items.

4.3 Methods of Investment Appraisal:

4.3.1: Main Discounting Methods:

There are two main discounting methods used in practice for the appraisal of investment projects, as far as the evaluation of financial feasibility is concerned: the net-present-value method (often referred to as NPV method), and the internal-rate-of-return (IRR) method, sometimes also referred to as the discounted-cash-flow method.

Net Present Value

The net present value of a project is defined as the value obtained by discounting, at a constant interest rate and separately for each year, the differences of all annual cash outflows and inflows accruing throughout the life of a project. This difference is discounted to the point at which the implementation of the project is supposed to start. The NPV as obtained for the years of the project life are added to obtain the project NPV as follows:

$$NPV = \sum_{n=0}^{n=j} \frac{NCF_n}{(1+r)^n}$$

where NCF_n is the annual net cash flow of a project in the years *n* 1, 2, *j,* and a_n is the discount factor in the corresponding years, relating to the discount rate applied through the equation

$$a_n = (1+r)^{-n}$$

Discount factors (a_n) may be obtained from present value tables.

The *discount rate or cut-off rate* should be equal either to the actual rate of interest on long-term loans in the capital market or to the interest rate (cost of capital) paid by the borrower. The discount rate should basically reflect the *opportunity cost of capital,* which corresponds to the possible returns an investor (financier) would obtain on the same amount of capital if invested elsewhere, assuming that the financial risks are similar for both investment alternatives. In other words, the discount rate should be the *minimum rate of return,* below which an entrepreneur would consider that it does not pay for to invest,

If the computed NPV is positive, the profitability of the investment is above the cut-off discount rate. If it is zero, the profitability is equal to the cut-off rate. A project with a positive NPV can thus be considered acceptable, provided a sufficient margin of error above zero NPV to account for uncertainty has been included. If the NPV is negative, the profitability is below the cut-off rate (usually the opportunity cost of capital for this type of project), and the project should be dropped.

An important decision criterion of the investor is often not only the profitability of his investment, but also the answer to the question: how long does it take to get the money back including a certain minimum interest rate He may decide, for instance, to invest only if the investment is repaid in five years at an interest rate of 15 per cent per year, which would mean that the NPV must not be negative for a discounting rate of 15 per cent and a planning horizon of five years. The net cash return on equity would have to be used for discounting.

Net-Present-Value Ratio

If one of several project alternatives has to be chosen, the project with the largest NPV should be selected. This needs some refinement, since the NPV is only an indicator of the positive net cash flows or of the net benefits of a project. In cases where there are two or more alternatives, it is advisable to know how much investment will be required to generate these positive NPVs. The ratio of the NPV and the present value of the investment (PVI) required is called the net-present-value ratio (NPVR) and yields a discounted rate of return. This should be used for comparing alternative projects. The formula is as follows:

$$\text{NPVR} = \frac{\text{NPV}}{\text{PVI}}$$

If the Construction period does not exceed one year, the value of investment will not have to be discounted.

In summary, the NPV has great advantages as a discriminatory method compared with the payback period or the annual rate of return, discussed later, since it takes account of the entire project life and of the timing of the cash flows. The NPVR can also be considered as a calculated investment rate which the profit rate of the project should at least reach. The shortcomings of the NPV are the difficulty in selecting the appropriate discount rate and the fact that the NPV does not show the exact profitability of the project. For this reason the NPV is not always understood by business people used to thinking in terms of a rate of return on capital. It is therefore advisable to use the internal rate of return.

Internal Rate of Return:

The internal rate of return is the discount rate at which the present value of cash inflows is equal to the present value of cash outflows. In other words, it is the discount rate for which the present value of the net receipts from the project is equal to the present value of the investment, and the NPV is zero. Mathematically, it means that in the NPV equation discussed earlier, the value for r has to be found for which—at defined values for CF_0— the NPV equals zero. The solution is found by an iterative process, using either discounting tables or a suitable computer program.

The procedure used to calculate the IRR is the same as the one used to calculate the NPV. The same kind of table can be used, and, instead of discounting cash flows at a predetermined cut-off rate, several discount rates may have to be tried until the rate is found at which the NPV is zero. This rate is the IRR, and it represents the exact profitability of the project.

The calculation procedure begins with the preparation of a cash flow table. An estimated discount rate is then used to discount the net cash flow to the present value. If the NPV is positive, a higher discount rate is applied. If the NPV is negative at this higher rate, the IRR must be between these two rates. However, if the higher discount rate still gives a positive NPV, the discount rate must be increased until the NPV becomes negative.

If the positive and negative NPVs are close to zero, a good approximation of the IRR value can be obtained, using the following linear interpolation formula:

$$i_r = i_1 + \frac{PV(i_2 - i_1)}{PV + NV}$$

where i_r is the IRR, PV is the positive NPV (at the lower discount rate *i),* and NV is the negative NPV (at the higher discount rate i_2).

The absolute values of both PV and NV are used in the above formula. It should be noted that i_1 and i_2 should not differ by more than one or two percentage points (absolute). The above formula will not yield realistic results if the difference is too large, since the discount rate and the NPV are not related linearly.

4.3.2. Conventional Methods:

Payback Period:

The payback, also called pay-off period, is defined as *the* period required recovering the original investment outlay through the accumulated net cash flows earned by the project. It is important to note that the cash flows of a project are used to calculate the payback. It would be entirely wrong to compute the payback on the basis of the accumulated net profit after tax. Even when accumulated interest and depreciation are added back, there is the danger that investments for replacement, as usually necessary for continuing the operation of the plant, will not be included in the calculations.

The payback method is mainly criticized for its concentration on the initial phase of the production period, without taking into account, for the investment decision, the performance of the plant after the payback period. This critical argument would he justified if an investment decision is entirely based on the payback method. However, if applied for assessing risk and liquidity, and if used in combination with profitability measures, the payback can be a very practical and useful instrument.

Simple or Annual Rate of Return:

The simple rate of return method relies on the operational accounts. It is defined as the ratio of the annual net profit on capital. This ratio is often computed only for one year, generally a year of full production. However, it may also be calculated for various degrees of capacity utilization (sensitivity analysis) or for different years during the start-up phase. For investment appraisal two rates of return—on total capital employed (total investment) and on equity capital—are usually of interest.

The (annual) rate of return on total capital invested *Rj* is

$$Rj\,(percent\;) = \frac{NP\;+I}{K} \times 100$$

and the (annual) rate of return on equity capital paid *RE* is

$$REj\,(percent\,) = \frac{NP}{Q} \times 100$$

where *NP* is the net profit (after depreciation, interest charges and taxes), *I* the interest, *K* the total investment costs (fixed assets and working capital, and Q the equity capital.

The retained profits (reserves accumulated in a firm) should, however, be included when calculating the efficiency of the investor’s financial share. The sum of equity capital and retained profits *(PR)* is also known as the net worth of a company. For the computation of the return on net worth, Q in the above formula would have to be replaced by Q + *PR.* A shareholder, if mainly interested in the dividends paid, would evaluate the profitability of involvement by comparing the annual (average) dividend received net of tax with capital investment.

The simple rate of return method has a few serious disadvantages. For example, which year is the normal (representative) year to be taken as a basis for computing the rate of return? Since the simple rate of return uses annual data, it is difficult and often impossible to choose the most representative year of the project. In addition to the varying levels of production, especially during the initial years, and the payment of interest, which can also differ annually, there are certain other factors that cause changes in the level of net profit in particular years (tax holidays, for instance).

Net Present Value Ratio:

When the present value of the accumulated net benefits of a project (that is the annual output of the project net of annual operating expenditures and income taxes, discounted and accumulated over the planning horizon) is related to the present value of the total capital invested, the NPVR, which has already been described in this chapter, is obtained.

Break-even Analysis:

The purpose of break-even analysis is to determine the equilibrium point at which sales revenues equal the costs of products sold. When sales (and the corresponding production) are below this point, the firm is making a loss, and at the point where revenues equal costs, the firm is breaking even. Break-even analysis serves to compare the planned capacity utilization with the production volume below which a firm would make losses. The break-even point can also be defined in terms of physical units produced, or of the level of capacity utilization at which sales revenues and production costs are equal. The sales revenues at the break-even point represent the break-even sales value, and the unit price of a product in this situation is the break-even sales price. If the production program includes a variety of products, for any given break-even sales volume there would exist a variety of combinations of product prices, but no single break-even price.

Before calculating the break-even values, the following conditions and assumptions should be satisfied:

- Production and marketing costs are a function of the production or sales volume (for example, in the utilization of equipment);
- The volume of production equals the volume of sales;
- Fixed operating costs are the same for every volume of production;
- Variable costs vary in proportion to the volume of production, and consequently total production costs also change in proportion to the volume of production;
- The sales prices for a product or product mix are the same for all levels of output (sales) over time. The sales value is therefore a linear function of the sales prices and the quantity sold;
- The level of unit sales prices and variable and fixed operating costs remain constant, that is, the price elasticity of demand for inputs and outputs is zero;
- The break-even values are computed for one product; in case of a variety of products, the product mix, that is, the ratio between the quantities produced, should remain constant.

Since the above assumptions will not always hold in practice, the break-even point (capacity utilization) should also be subject to sensitivity analysis, assigning different fixed and variable costs as well as sales prices. For the interpretation of the results of break-even analysis, a graphical presentation (see figure) is very useful, because from the angle of the cost and sales curves, and the position of the equilibrium point in relation to total capacity, analysts can often identify potential weaknesses.

Break-even production is the number of units U necessary to produce and sell in order fully to cover the annual fixed costs C_f for a given unit sales price P_s and the variable unit costs C_v, or

$$(P_s - C_v,)U = C_f$$

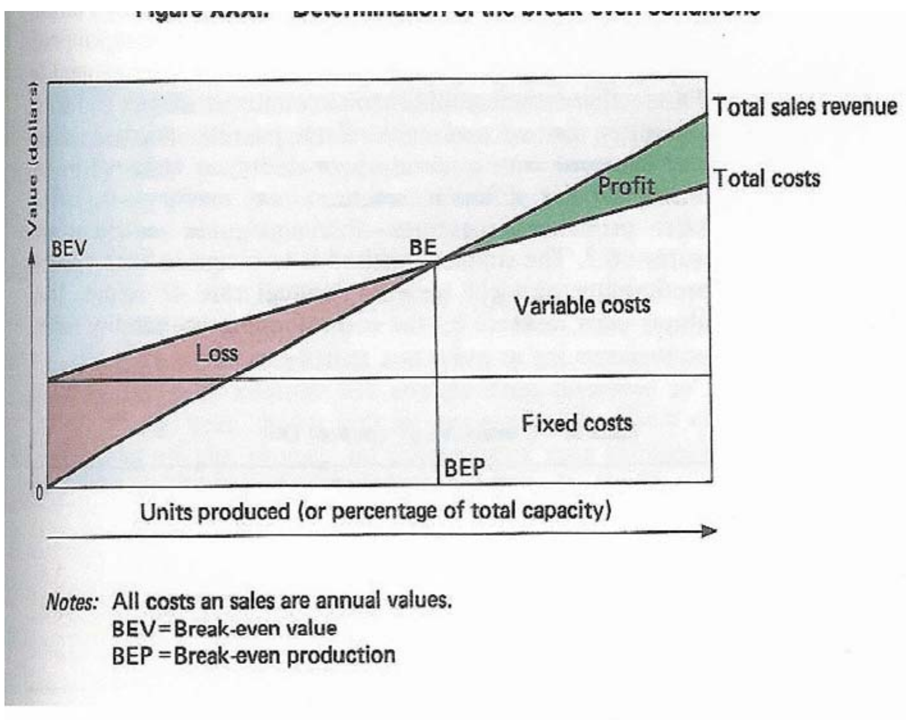


Figure 4.2. Determination of the Break-even Conditions

In the above equation, the number of units U (or the rate of capacity utilization) is computed for given values of P_s, C_v and C_f. It is also possible to compute the break-even sales price for a given production volume and defined costs.

The break-even analysis may be carried out excluding and including costs of finance. In the latter ease, the annual costs of finance need to be included in the fixed costs. Since the interest payable depends on the outstanding debt balance, the total annual fixed costs are usually not constant over the start-up and initial operating period. The break-even analysis should therefore be carried out for each year during this phase of the project.

CHAPTER 5

HYDROELECTRIC POWER ECONOMICS & RESULTS

5.1 Simulation and Decision Models:

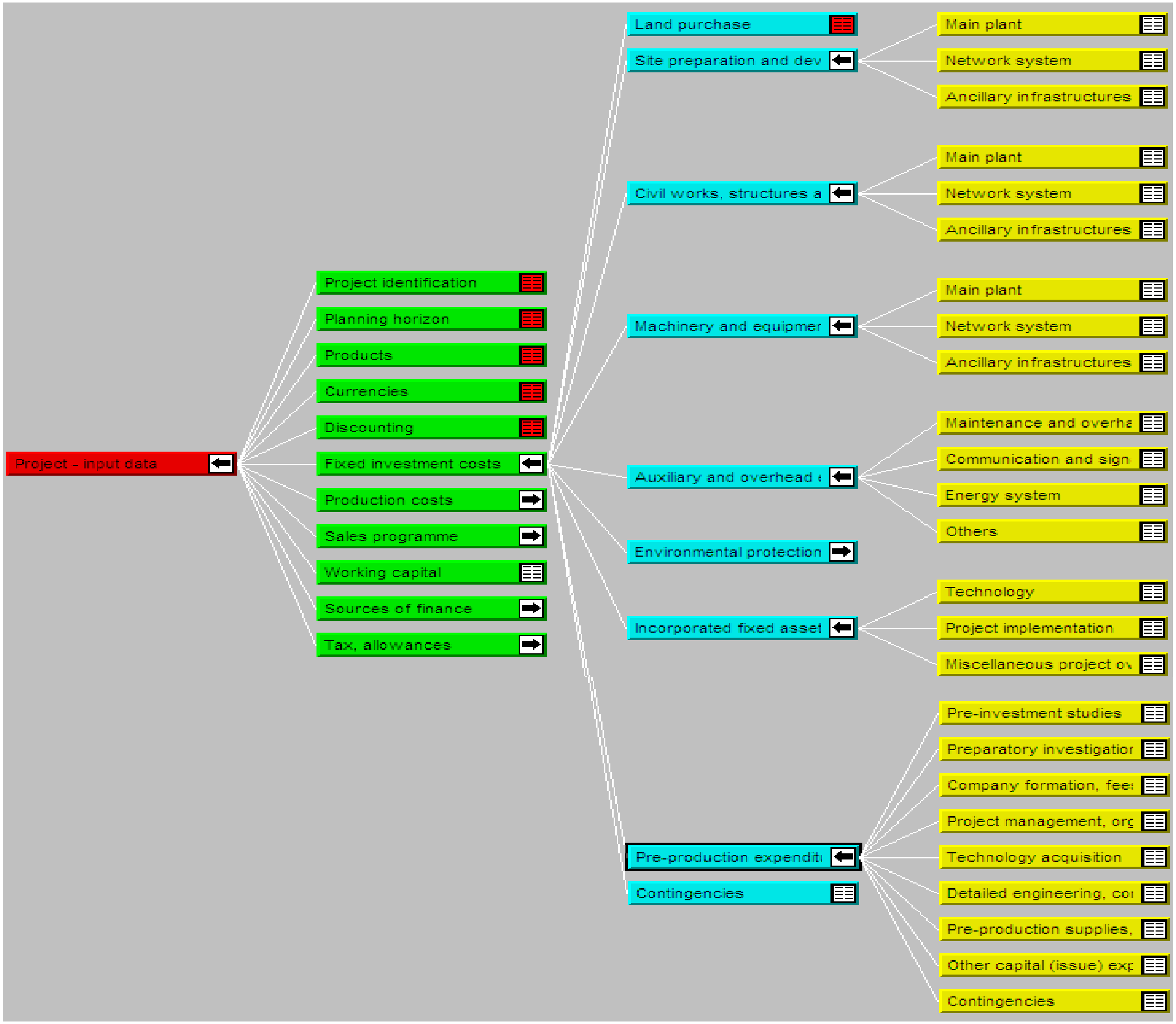
For the analysis of the feasibility of an investment project and the impact of changing project parameters, simulation models are used for feasibility studies including market models, production models and financial statements. Decision models help decision makers to determine which project alternative is preferable under certain conditions, one of them is COMFAR

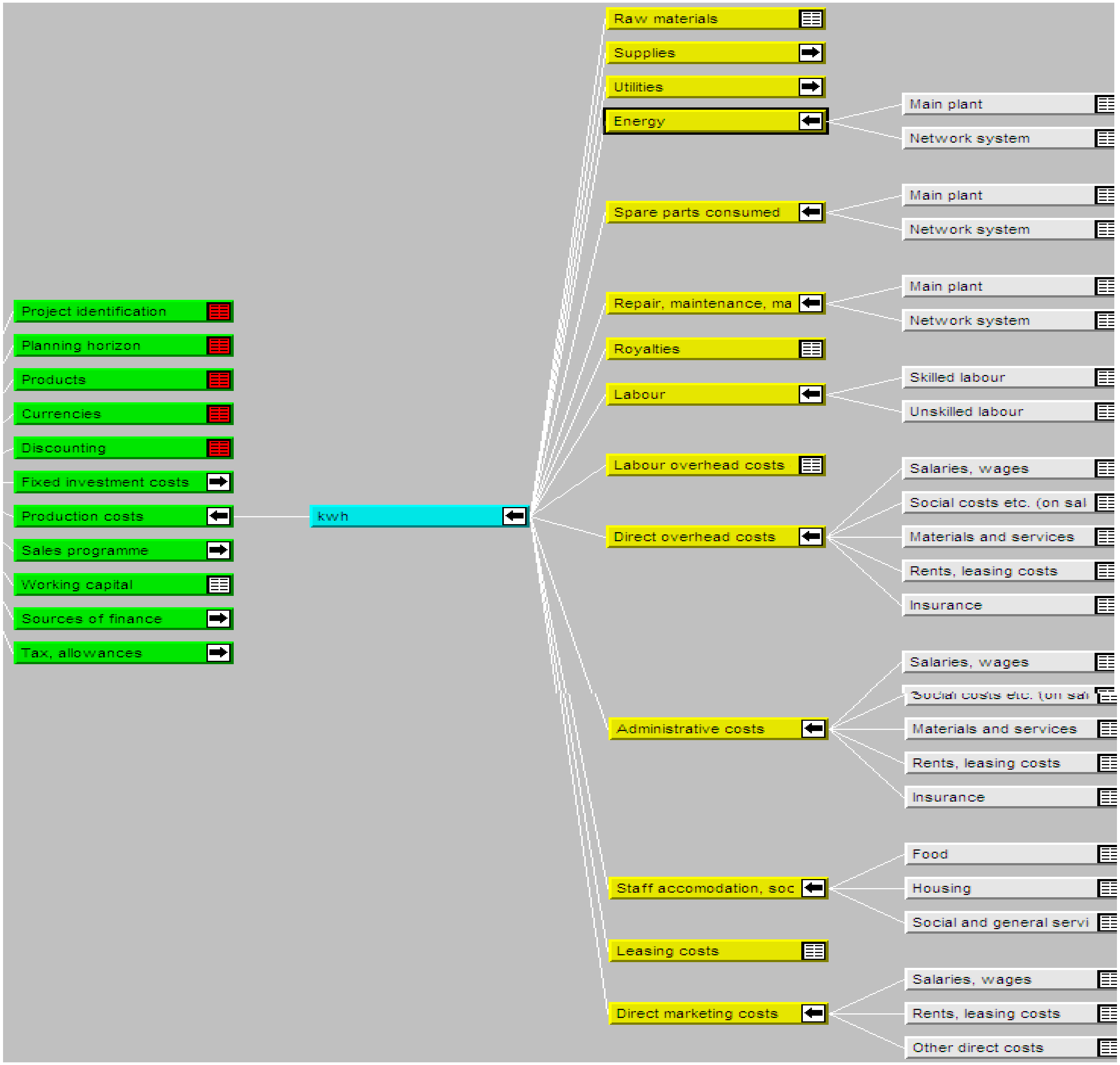
COMFAR Software:

It is a software system developed by UNIDO (United Nations Industrial Development Organization). It supports the preparation, appraisal and evaluation of pre-investment studies.
COMFAR is basically a standardized model for financial and economic analysis, directing the user through the physical operation of the personal computer on which this software is installed and guiding him also in the entry of data and the computation of statements and various financial and economic indicators and ratios as required for project analysis.
Detailed description is in appendix B

5.2 Hydroelectric Power Economics:

All hydroelectric projects in Sudan are river schemes where a dam is required to create the hydraulic head and the intake and power house are located at the water retaining structures so its capital cost would be very high. In order to analyze the economics of hydroelectric power generation in Sudan taking Roseries, Jebl Aulia and Merawi Hydroelectric power stations as examples, COMFAR software can be used taking infrastructure model whose inputs are detailed below:


Project - input data
Project identification
Planning horizon
Products
Currencies
Discounting
Fixed investment costs
Production costs
Sales programme
Working capital
Sources of finance
Tax, allowances
Land purchase
Site preparation and dev
Civil works, structures a
Machinery and equipmer
Auxiliary and overhead
Environmental protection
Incorporated fixed asset
Pre-production expenditu
Contingencies
Main plant
Network system
Ancillary infrastructures
Main plant
Network system
Ancillary infrastructures
Main plant
Network system
Ancillary infrastructures
Maintenance and overha
Communication and sign
Energy system
Others
Technology
Project implementation
Miscellaneous project ov
Pre-investment studies
Preparatory investigation
Company formation, fees
Project management, org
Technology acquisition
Detailed engineering, co
Pre-production supplies,
Other capital (issue) exp
Contingencies



Project identification
Planning horizon
Products
Currencies
Discounting
Fixed investment costs
Production costs
Sales programme
Working capital
Sources of finance
Tax, allowances
kwh
Raw materials
Supplies
Utilities
Energy
Main plant
Network system
Spare parts consumed
Main plant
Network system
Repair, maintenance, ma
Main plant
Network system
Royalties
Labour
Skilled labour
Unskilled labour
Labour overhead costs
Direct overhead costs
Salaries, wages
Social costs etc. (on sal
Materials and services
Rents, leasing costs
Insurance
Administrative costs
Salaries, wages
Materials and services
Rents, leasing costs
Insurance
Staff accomodation, soc
Food
Housing
Social and general servi
Leasing costs
Direct marketing costs
Salaries, wages
Rents, leasing costs
Other direct costs

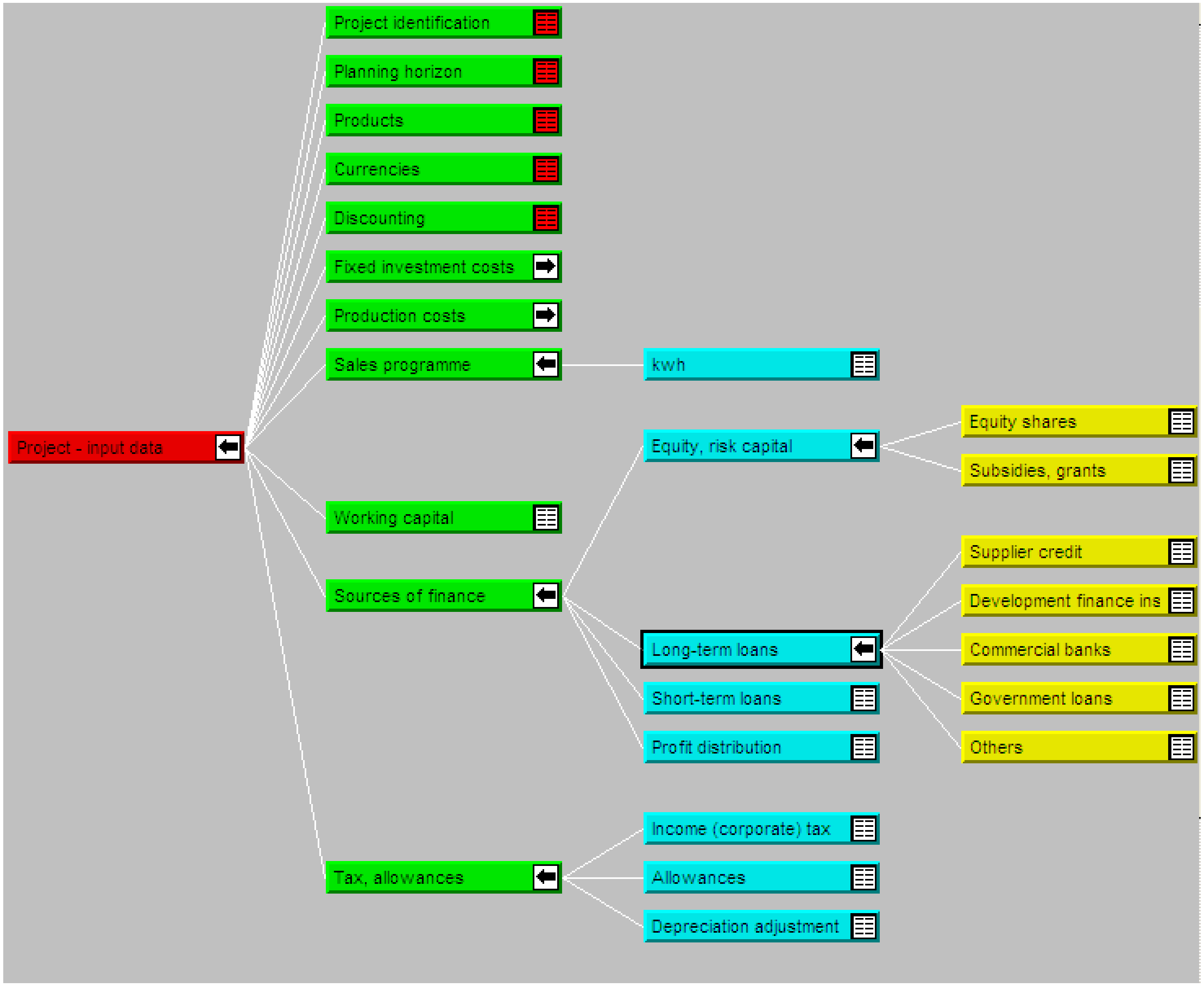


Figure 5.1: Infrastructure Model Of COMFAR Software

5.2.1 Roseries Hydroelectric Power Economics [27]:

Data for Roseries Dam is as follows where the head is between (20m - 30m), so vertical axis Kaplan turbine is used.

Full supply level = 480m

Draw down level = 467m

Details of cost of capacity for power generation and dam construction is as follows:

Civil Works:

For the main civil works for the intakes, penstock, suction cone and draft tube and powerhouse which consist of 7 units each 40 MW installed capacity with contingency 20% so the total cost of replacement (present worth value) of civil work (construction cost for power house) is equal to 184.8 $\times 10^6$ US dollars.

Mechanical Equipments:

The mechanical equipment includes the Turbines and governers, power intake equipment, inlet valves, draft tubes gates, mechanical Services, spillway gates, sluices gates

So the total of mechanical cost is equal to 92.4 $\times 10^6$ US dollars.

Electrical Equipments:

The electrical equipment includes the following: generators and exciters, isolated phase bus duct, cabling and generator breakers, generators step-up transformers, all electrical control equipments, auxiliary equipment and services, switchyard equipment at the plant substation

So the total of electrical equipment cost is equal to 30.8 $\times 10^6$ US dollars

The contingency for electrical and mechanical is 10%

So total cost of Civil works for the power house and electrical and mechanical equipments is equal to 308 $\times 10^6$ US dollars.

([27]) Long term power system planning. National Electricity Corporation, final report, 1993

Total Project Costs:

The total project cost of capacity is summarizes as:

Dam construction cost (present worth value) = 418.76 $\times 10^6$ US dollars.

Total capital cost (civil for powerhouse, electrical and mechanical) = **308** $\times 10^6$ US dollars

So the total capital (with dam) cost is **726.76** $\times 10^6$ US dollars (cost of replacement) .

(2) All other cost:

Operation and maintenance cost = 0.78 $\times 10^6$ US dollars.

Labour cost = 0.2 $\times 10^6$ US dollars.

General expenditure = 3.22 $\times 10^6$ US dollars.

So all these cost are = 11.22 $\times 10^6$ US dollars.

5.2.2 Jebl Aulia Hydroelectric Power Economics[(28)]:

Electromechanical equipments and civil work = 33.870 $\times 10^6$ Euro

Transmission plant	= 4 $\times 10^6$ Euro
Contingencies	= 0.6 $\times 10^6$ Euro
So capital cost	= 38.47 $\times 10^6$ Euro
Operation and maintenance cost	= 0.120 $\times 10^6$ Euro
Spare Parts	= 0.900 $\times 10^6$ Euro
Corporate tax	= 35% after 10 years

5.2.3 Merawi Hydroelectric Power Economics[(29)]:

The cost estimates of Merawi hydroelectric power covers all construction activities of the generation facilities, namely: civil works, hydraulic steel structure, mechanical and electrical equipments.

Civil Works:

([28]) Jebel Aulia Dam, Technical Specifications, Hydro Matrix Power Plant, 40 modules with 2 units each, Va tech, sep 2000.

([29]) Merawi Dam Project, Project Assessment Report, Lamheyer International, Oct 2001

The approach used in cost estimates of civil works is the direct cost which includes actual production items and site installation, contractor's indirect cost including insurance, contractor's overhead, profit and miscellaneous items and contingencies.
Total cost of civil work is 650.201 $\times 10^6$ US dollars.

Electromechanical Equipments:

The cost estimates of electromechanical equipments of this project is considered as: hydraulic steel structures such as spillway and power house and intake structure and irrigation headworks so total hydraulic steel structure is 77.220 $\times 10^6$ US dollars.
And mechanical equipment such as power house and its total cost is 128.735 $\times 10^6$ US dollars.
And electrical equipments which includes generator and excitation and control and instrumentation system and the total cost of it is 109.070 $\times 10^6$ US dollars
So total electromechanical work is 315.025 $\times 10^6$ US dollars.

Total Project Costs:

The total project cost of capacity is summarizes as:
1133.472 $\times 10^6$ US dollars which includes contingencies and engineering and project management

5.3 Calculations:

Using the above cost data with more details in the model, the NPV and IRR of the projects were calculated using three methods:

1. Computer financial model has been developed by the company who works in the system (consultant) in appendix C.
2. Using the dynamic financial model presented below.
3. Also using Comfar software with the data available.

Then the over all economics of hydroelectric power generation at **Roseires** is estimated to be (using consultant model):
Project IRR: 20%

Project NPV: 465.88 $\times 10^6$ US dollars.

For the **Jebl Aulia** hydromatrix turbine power plant

the project IRR = 16.2% in the company model and the NPV = 98.9 $\times 10^6$ US Dollars.

For **Merawi** Dam

Project IRR: 17.7%

Project NPV: 5153.5 $\times 10^6$ US dollars.

The over all results is as follows:

		Merawi	**Jebl Aulia**	**Roseries**
Consultant Software Model	IRR	17.7%	16.2%	N/A
	NPV	5153 mUS$	98.8 mUS$	N/A
Dynamic Financial Model	IRR	N/A	16.2%	20%
	NPV	N/A	94.8 mUS$	465.88 mUS$
Comfar	IRR	15.3%	22.87%	14.52%
	NPV	380 mUS$	209.48 mUS$	474 mUS$

5.4 Comments:

Comfar software is a useful tool for calculating all economic parameters and for evaluating a project in all types of business: manufacturing, agricultural, infrastructure etc. but still it needs some enhancement in its capability, so by the time of finishing this thesis another version of this software (version 3) is now available at Unido headquarter, but because of time and also because of the hasp drive (for security) which needs to be replaced with this new version in order to make the program work perfectly, I suggest that further work must be done in this field so as to make the result more accurate. (new features of Comfar in Appendix B).

1. Summary sheet

Project title: infrastructure feasibility study
Project description: feasibility studies of Roseries Hydroelectric power station
Date and time:

Project classification: New project

Construction phase: 7/1967 - 6/1971
Length: 4 years
Production phase: 7/1971 - 12/2020
Length: 50 periods

Accounting currency: us dollars ($)
Units: Absolute
Local currency: Sudanese Dinars (SD)
Exchange rate: 1.0000 $ = 1.0000 SD

INVESTMENT COSTS

	Total construction	Total production	Total investment
Total fixed investment costs	307,078,000.000	10,050,000.000	317,128,000.000
Total pre-production expenditures	0.000	0.000	0.000
Pre-production expenditures (net of interest)	0.000	0.000	0.000
Interest	0.000	0.000	0.000
Increase in net working capital	0.000	24,153,483.919	24,153,483.919
TOTAL INVESTMENT COSTS	307,078,000.000	34,203,483.919	341,281,483.919

SOURCES OF FINANCE

	Total construction	Total production	Total inflow
Total equity capital	307,078,000.000	0.000	307,078,000.000
Foreign	0.000	0.000	0.000
Local	307,078,000.000	0.000	307,078,000.000
Total long-term loans	0.000	0.000	0.000
Foreign	0.000	0.000	0.000

Local	0.000	0.000	0.000
Accounts payable	0.000	2,016,843.345	2,016,843.345
TOTAL SOURCES OF FINANCE	307,078,000.000	2,016,843.345	309,094,843.345

INCOME AND COSTS, OPERATIONS

	First year 7/1971-12/1971	Reference year 7/1971-12/1971	Last year 2020
SALES REVENUE	30,134.400	30,134.400	213,150,000.000
Factory costs	6,809.990	6,809.990	16,099,929.876
Administrative overhead costs	0.600	0.600	2,097.603
OPERATING COSTS	6,810.590	6,810.590	16,102,027.479
Depreciation	0.070	0.070	0.000
Financial costs	0.000	0.000	0.000
TOTAL PRODUCTION COSTS	6,810.660	6,810.660	16,102,027.479
Marketing costs	0.571	0.571	1,997.717
COSTS OF PRODUCTS	6,811.231	6,811.231	16,104,025.196
Interest on short-term deposits	0.000	0.000	0.000
GROSS PROFIT FROM OPERATIONS	23,323.169	23,323.169	197,045,974.804
Extraordinary income	0.000	0.000	0.000
Extraordinary loss	0.000	0.000	0.000
Depreciation allowances	0.000	0.000	0.000
GROSS PROFIT	23,323.169	23,323.169	197,045,974.804
Investment allowances	0.000	0.000	0.000
TAXABLE PROFIT	23,323.169	23,323.169	197,045,974.804
Income (corporate) tax	0.000	0.000	0.000
NET PROFIT	23,323.169	23,323.169	197,045,974.804

RATIOS

Net Present Value of Total Capital Invested	at 8.00 %	474,814,451.191
Internal rate of return on investment (IRR)	14.52 %	
Modified IRR on investment	11.21 %	
Net Present Value of Total Equity Capital Invested	at 10.00 %	244,639,725.361
Internal rate of return on equity (IRRE)	14.52 %	
Modified IRRE on equity	11.21 %	

Yearly results
Periodical results
OK

Roseries Results using COMFAR

1. Summary sheet

Project title: Jebl Aulia Hydro electric Power Station
Project description:
Date and time:

Project classification: New project

Construction phase: 1/1 - 12/2
Length: 2 years
Production phase: 1/3 - 12/42
Length: 40 periods

Accounting currency: EURO (euro)
Units: Absolute
Local currency: Sudanese Dinars (SD)
Exchange rate: 1.0000 euro = 3,200.0000 SD

INVESTMENT COSTS

	Total construction	Total production	Total investment
Total fixed investment costs	57,705,000.000	38,470,000.000	96,175,000.000
Total pre-production expenditures	0.000	0.000	0.000
Pre-production expenditures (net of interest)	0.000	0.000	0.000
Interest	0.000	0.000	0.000
Increase in net working capital	0.000	577,857.570	577,857.570
TOTAL INVESTMENT COSTS	57,705,000.000	39,047,857.570	96,752,857.570

SOURCES OF FINANCE

	Total construction	Total production	Total inflow
Total equity capital	57,705,000.000	0.000	57,705,000.000
Foreign	38,470,000.000	0.000	38,470,000.000
Local	19,235,000.000	0.000	19,235,000.000
Total long-term loans	0.000	0.000	0.000
Foreign	0.000	0.000	0.000

Local	0.000	0.000	0.000
Accounts payable	0.000	364,361.160	364,361.160
TOTAL SOURCES OF FINANCE	57,705,000.000	364,361.160	58,069,361.160

INCOME AND COSTS, OPERATIONS

	First year 3	Reference year 3	Last year 42
SALES REVENUE	4,995,457.920	4,995,457.920	2,272,546,561.626
Factory costs	213,600.000	213,600.000	4,372,333.921
Administrative overhead costs	0.000	0.000	0.000
OPERATING COSTS	213,600.000	213,600.000	4,372,333.921
Depreciation	0.000	0.000	0.000
Financial costs	0.000	0.000	0.000
TOTAL PRODUCTION COSTS	213,600.000	213,600.000	4,372,333.921
Marketing costs	0.000	0.000	0.000
COSTS OF PRODUCTS	213,600.000	213,600.000	4,372,333.921
Interest on short-term deposits	0.000	0.000	0.000
GROSS PROFIT FROM OPERATIONS	4,781,857.920	4,781,857.920	2,268,174,227.705
Extraordinary income	0.000	0.000	0.000
Extraordinary loss	0.000	0.000	0.000
Depreciation allowances	0.000	0.000	0.000
GROSS PROFIT	4,781,857.920	4,781,857.920	2,268,174,227.705
Investment allowances	0.000	0.000	0.000
TAXABLE PROFIT	4,781,857.920	4,781,857.920	2,268,174,227.705
Income (corporate) tax	0.000	0.000	0.000
NET PROFIT	4,781,857.920	4,781,857.920	2,268,174,227.705

RATIOS

Net Present Value of Total Capital Invested	at 14.00 %	209,477,075.984
Internal rate of return on investment (IRR)	22.87 %	
Modified IRR on investment	17.48 %	
Net Present Value of Total Equity Capital Invested	at 12.00 %	367,743,996.646
Internal rate of return on equity (IRRE)	22.87 %	
Modified IRRE on equity	17.48 %	

Yearly results

Periodical results

OK

Jebl Aulia Results using COMFAR

1. Summary sheet

Project title: infrastructure feasibility study
Project description: feasibility studies of Merawi Hydroelectric power station
Date and time:

Project classification: New project

Construction phase: 1/2004 - 12/2007
Length: 4 years
Production phase: 1/2008 - 12/2057
Length: 50 periods

Accounting currency: Foreign currency ($)
Units: Absolute
Local currency: Sudanese Dinars (SD)
Exchange rate: 1.0000 $ = 250.0000 SD

INVESTMENT COSTS

	Total construction	Total production	Total investment
Total fixed investment costs	370,034,680.000	761,720.000	370,796,400.000
Total pre-production expenditures	0.000	0.000	0.000
Pre-production expenditures (net of interest)	0.000	0.000	0.000
Interest	0.000	0.000	0.000
Increase in net working capital	0.000	113,346.029	113,346.029
TOTAL INVESTMENT COSTS	370,034,680.000	875,066.029	370,909,746.029

SOURCES OF FINANCE

	Total construction	Total production	Total inflow
Total equity capital	370,034,680.000	0.000	370,034,680.000
Foreign	0.000	0.000	0.000
Local	370,034,680.000	0.000	370,034,680.000
Total long-term loans	0.000	0.000	0.000
Foreign	0.000	0.000	0.000

Local	0.000	0.000	0.000
Accounts payable	0.000	8,827.436	8,827.436
TOTAL SOURCES OF FINANCE	370,034,680.000	8,827.436	370,043,507.436

INCOME AND COSTS, OPERATIONS

	First year 2008	Reference year 2008	Last year 2057
SALES REVENUE	103,368.000	103,368.000	144,776,560.000
Factory costs	70.585	70.585	98,860.506
Administrative overhead costs	1.076	1.076	1,506.391
OPERATING COSTS	71.660	71.660	100,366.897
Depreciation	0.000	0.000	0.000
Financial costs	0.000	0.000	0.000
TOTAL PRODUCTION COSTS	71.660	71.660	100,366.897
Marketing costs	1.786	1.786	2,501.060
COSTS OF PRODUCTS	73.446	73.446	102,867.957
Interest on short-term deposits	0.000	0.000	0.000
GROSS PROFIT FROM OPERATIONS	103,294.554	103,294.554	144,673,692.043
Extraordinary income	0.000	0.000	0.000
Extraordinary loss	0.000	0.000	0.000
Depreciation allowances	0.000	0.000	0.000
GROSS PROFIT	103,294.554	103,294.554	144,673,692.043
Investment allowances	0.000	0.000	0.000
TAXABLE PROFIT	103,294.554	103,294.554	144,673,692.043
Income (corporate) tax	0.000	0.000	0.000
NET PROFIT	103,294.554	103,294.554	144,673,692.043

RATIOS

Net Present Value of Total Capital Invested	at 10.00 %	380,386,632.843
Internal rate of return on investment (IRR)	15.30 %	
Modified IRR on investment	11.46 %	
Net Present Value of Total Equity Capital Invested	at 8.00 %	673,104,782.240
Internal rate of return on equity (IRRE)	15.30 %	
Modified IRRE on equity	11.46 %	

(•) Yearly results
( ) Periodical results

OK

Merawi Results using COMFAR

SERIES PROJECT

			1	2	3	4	5	6	7	
neration Annuity (m$)			27.36	27.36	27.36	27.36	27.36	27.36	27.36	27
neration O&M Indexed (2.5%)			(2.60)	(2.67)	(2.73)	(2.80)	(2.87)	(2.94)	(3.02)	(3.
nsmission Annuity			(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.
nsmission O&M indexed (1.5)			(2.60)	(2.64)	(2.68)	(2.72)	(2.76)	(2.80)	(2.84)	(2.
tribution Annuity			11.70	11.70	11.70	11.70	11.70	11.70	11.70	11
tribution O&M indexed (2%)			(3.90)	(3.98)	(4.06)	(4.14)	(4.22)	(4.31)	(4.39)	(4.
TAL Gen.,Trans.& Dist. Cost			59.03	59.21	59.39	59.58	59.78	59.97	60.18	60
al Cost after Lossess			(72.01)	(72.23)	(72.46)	(72.69)	(72.93)	(73.17)	(73.42)	(73.
count Rate		12%								
sent Worth of Toatal Cost			(615.94)							
ctricity Sale										
exed	2.0%	(615.94)	109.2	111.38	113.61	115.88	118.20	120.57	122.98	125
rnal Rate of Return (IRR)		20%								
fit & Loss			37.19	39.15	41.15	43.19	45.27	47.40	49.56	51
V Profit	465.88	(615.94)	37.19	76.34	117.49	160.68	205.95	253.35	302.91	354

9	10	11	12	13	14	15	16	17	18	19	20
27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
(3.17)	(3.25)	(3.33)	(3.41)	(3.50)	(3.58)	(3.67)	(3.77)	(3.86)	(3.96)	(4.06)	(4.16)
(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)
(2.93)	(2.97)	(3.02)	(3.06)	(3.11)	(3.16)	(3.20)	(3.25)	(3.30)	(3.35)	(3.40)	(3.45)
11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70
(4.57)	(4.66)	(4.75)	(4.85)	(4.95)	(5.05)	(5.15)	(5.25)	(5.35)	(5.46)	(5.57)	(5.68)
60.59	60.81	61.03	61.25	61.48	61.71	61.95	62.19	62.44	62.69	62.95	63.21
(73.92)	(74.18)	(74.45)	(74.72)	(75.00)	(75.29)	(75.58)	(75.87)	(76.18)	(76.48)	(76.80)	(77.12)
127.95	130.50	133.11	135.78	138.49	141.26	144.09	146.97	149.91	152.91	155.96	159.08
54.02	56.32	58.66	61.05	63.49	65.97	68.51	71.10	73.73	76.42	79.16	81.96
408.71	465.03	523.69	584.74	648.23	714.20	782.71	853.81	927.54	1003.96	1083.13	1165.09

21	22	23	24	25	26	27	28	29	30	31	32	33
27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
(4.26)	(4.37)	(4.48)	(4.59)	(4.70)	(4.82)	(4.94)	(5.06)	(5.19)	(5.32)	(5.45)	(5.59)	(5.73)
(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)
(3.50)	(3.55)	(3.61)	(3.66)	(3.72)	(3.77)	(3.83)	(3.89)	(3.94)	(4.00)	(4.06)	(4.12)	(4.19)
11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70
(5.80)	(5.91)	(6.03)	(6.15)	(6.27)	(6.40)	(6.53)	(6.66)	(6.79)	(6.93)	(7.06)	(7.21)	(7.35)
63.48	63.76	64.04	64.33	64.62	64.92	65.22	65.53	65.85	66.18	66.51	66.85	67.19
(77.45)	(77.79)	(78.13)	(78.48)	(78.83)	(79.20)	(79.57)	(79.95)	(80.34)	(80.74)	(81.14)	(81.55)	(81.97)
162.27	165.51	168.82	172.20	175.64	179.15	182.74	186.39	190.12	193.92	197.80	201.76	205.79
84.82	87.73	90.69	93.72	96.81	99.96	103.17	106.44	109.78	113.19	116.66	120.20	123.82
1249.91	1337.63	1428.33	1522.05	1618.85	1718.81	1821.97	1928.41	2038.20	2151.38	2268.04	2388.25	2512.06

34	35	36	37	38	39	40	41	42	43
27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
(5.87)	(6.02)	(6.17)	(6.32)	(6.48)	(6.64)	(6.81)	(6.98)	(7.16)	(7.33)
(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)
(4.25)	(4.31)	(4.38)	(4.44)	(4.51)	(4.58)	(4.65)	(4.72)	(4.79)	(4.86)
11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70	11.70
(7.50)	(7.65)	(7.80)	(7.96)	(8.11)	(8.28)	(8.44)	(8.61)	(8.78)	(8.96)
67.55	67.91	68.27	68.65	69.03	69.43	69.83	70.24	70.65	71.08
(82.41)	(82.85)	(83.29)	(83.75)	(84.22)	(84.70)	(85.19)	(85.69)	(86.20)	(86.72)
209.91	214.11	218.39	222.76	227.21	231.76	236.39	241.12	245.94	250.86
127.50	131.26	135.09	139.00	142.99	147.06	151.20	155.43	159.74	164.14
2639.57	2770.83	2905.92	3044.92	3187.91	3334.97	3486.17	3641.60	3801.34	3965.49

44	45	46	47	48	49	50
27.36	27.36	27.36	27.36	27.36	27.36	27.36
(7.52)	(7.71)	(7.90)	(8.10)	(8.30)	(8.51)	(8.72)
(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)	(10.87)
(4.93)	(5.01)	(5.08)	(5.16)	(5.23)	(5.31)	(5.39)
11.70	11.70	11.70	11.70	11.70	11.70	11.70
(9.14)	(9.32)	(9.51)	(9.70)	(9.89)	(10.09)	(10.29)
71.51	71.96	72.41	72.88	73.35	73.83	74.33
(87.25)	(87.79)	(88.34)	(88.91)	(89.49)	(90.08)	(90.68)
255.88	260.99	266.21	271.54	276.97	282.51	288.16
168.63	173.20	177.87	182.63	187.48	192.43	197.48
4134.12	4307.32	4485.19	4667.82	4855.30	5047.73	5245.20

Roseires Project Results using Dynamic Financial Mod

JEBL AULIA PROJECT

Years		1	2	3	4	5	6	
Capital cost		0	0	1693500	1693500	1693500	1693500	16935
transmission line				115000	115000	115000	115000	1150
Sum				1808500	1808500	1808500	1808500	18085
Labour cost				3600	3960	4356	4792	52
Operating cost				60000	64800	69984	75583	816
metainance cost				60000	64800	69984	75583	816
spare parts				90000	97200	104976	113374	1224
Total operation and maintenance cost				213600	230760	249300	269331	2909
Total operation per kwh				0	0	0	0	
Annual energy output				99.6	111.5	111.5	111.5	11
Tariff (8% inflation)				0.0	0.0	0.1	0.1	
total revenue				4302720	5200278	5616300	6065604	65508
earing before depreciation				4089120	4969518	5367000	5796273	62598
earning before tax				2280620	3161018	3558500	3987773	44513
tax								
net profit(tax=35%)				2280620	3161018	3558500	3987773	44513
Cash from operation				4089120	4969518	5367000	5796273	62598
Working capital				340760	414126	447250	483023	5216
,+/- change in working capital				340760	73366	33124	35773	386
income incorporate tax								
replacment cost								
Free cash				3748360	4896151	5333876	5760500	62212
Equity input during construction			30776000	7694000				
IRR	16.2%	-30776000	-7694000	3748360	4896151	5333876	5760500	62212

10	11	12	13	14	15	16	17	
1693500	1693500	1693500	1693500	1693500	1693500	1693500	1693500	16935
115000	115000	115000	115000	115000	115000	115000	115000	1150
1808500	1808500	1808500	1808500	1808500	1808500	1808500	1808500	18085
7015	7717	8489	9337	10271	11298	12428	13671	150
102829	111056	119940	129535	139898	151090	163177	176232	1903
102829	111056	119940	129535	139898	151090	163177	176232	1903
154244	166584	179910	194303	209848	226635	244766	264347	2854
366918	396412	428280	462712	499915	540114	583549	630482	6811
0	0	0	0	0	0	0	0	
111.5	111.5	111.5	111.5	111.5	111.5	111.5	111.5	111
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0
8252187	8912362	9625351	10395379	11227010	12125170	13095184	14142799	152742
7885269	8515950	9197072	9932668	10727094	11585056	12511635	13512317	145930
6076769	6707450	7388572	8124168	8918594	9776556	10703135	11703817	127845
			2843459	3121508	3421795	3746097	4096336	44745
6076769	6707450	7388572	5280709	5797086	6354762	6957038	7607481	83099
7885269	8515950	9197072	9932668	10727094	11585056	12511635	13512317	145930
657106	709662	766423	827722	893925	965421	1042636	1126026	12160
48665	52557	56760	61300	66202	71497	77215	83390	900
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7836604	8463393	9140311	7027909	7539384	8091765	8688323	9332591	100283
7836604	8463393	9140311	7027909	7539384	8091765	8688323	9332591	100283

21	22	23	24	25	26	27	28	
1693500	1693500		0	0	0	0	0	
115000	115000	115000	115000	115000	115000	115000	115000	115
1808500	1808500	115000	115000	115000	115000	115000	115000	115
20016	22017	24219	26641	29305	32235	35459	39005	42
239761	258942	279657	302030	326192	352288	380471	410909	443
239761	258942	279657	302030	326192	352288	380471	410909	443
359642	388413	419486	453045	489289	528432	570706	616363	665
859180	928314	1003020	1083746	1170978	1265243	1367107	1477185	1596
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5800705	6315259	7463688	8063834	8711974	9411947	10167897	10984301	11865
10772737	11728338	13861136	14975692	16179381	17479330	18883238	20399416	22036
18381942	19852097	21439824	23154526	25006355	27006277	29166135	31498716	34017
1531828	1654341	1786652	1929544	2083863	2250523	2430511	2624893	2834
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-5800705	-6315259	-7463688	-8063834	-8711974	-9411947	-10167897	-10984301	-11865
	-13548000	-3387000						
12467796	-133675	10456825	14947800	16140062	17427670	18818250	20320034	21941
12467796	-133675	10456825	14947800	16140062	17427670	18818250	20320034	21941

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0	0	0	0	0	0	0	0
115000	115000	115000	115000	115000	115000	115000	115000
115000	115000	115000	115000	115000	115000	115000	115000
57107	62818	69100	76010	83611	91972	101169	111286
559036	603759	652060	704225	760563	821408	887121	958090
559036	603759	652060	704225	760563	821408	887121	958090
838555	905639	978090	1056337	1140844	1232112	1330681	1437135
2013735	2175976	2351310	2540797	2745581	2966900	3206091	3464602
0	0	0	0	0	0	0	0
111.5	111.5	111.5	111.5	111.5	111.5	111.5	111.5
0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7
44863349	48452417	52328611	56514900	61036092	65918979	71192497	76887897
42849615	46276442	49977301	53974103	58290511	62952079	67986406	73423295
42734615	46161442	49862301	53859103	58175511	62837079	67871406	73308295
14957115	16156505	17451805	18850686	20361429	21992978	23754992	25657903
27777499	30004937	32410495	35008417	37814082	40844102	44116414	47650392
42849615	46276442	49977301	53974103	58290511	62952079	67986406	73423295
3570801	3856370	4164775	4497842	4857543	5246007	5665534	6118608
264424	285569	308405	333067	359701	388464	419527	453074
-14957115	-16156505	-17451805	-18850686	-20361429	-21992978	-23754992	-25657903
27628076	29834368	32217090	34790350	37569381	40570638	43811887	47312318
27628076	29834368	32217090	34790350	37569381	40570638	43811887	47312318

Jebl Aulia Project Results using Dynamic Financial M

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction:

Hydroelectric power projects are normally appraised by their direct benefits and the monetary value they can earn on invested capital. Projects likely to fall short of usual targets of such investments are discarded.

From the previous chapter it is understood that feasibility studies play an important role in investigation of projects. Their importance for decision makers are also undisputed. If the investigated project can be constructed and equipped, operated and maintained over the life of the project and not in any way represents any danger of risks to the environment, the people concerned and the public in general, - such a project is stated to be “Technically Feasible”.

The second main criterion for feasibility studies concerns the economic and financial viability of the project.

To be judged economically and financially sound, a project must be able to “earn its own way”. This means that the project must be sufficiently attractive economically to raise investment funds.

The project must also be able to generate sufficient income to service the capital invested, pay for operation, maintenance and rehabilitation costs, pay taxes and other public expenses and create funds for further investments.

6.2 Conclusion:

Project internal rate of return (IRR) measures the viability of the project based on its net cash flows; if it is higher then it is more viable. All hydroelectric projects have high IRR.

Net present value (NPV) analysis is an investment appraisal tool which helps to decide whether to invest or not, appositive result indicates an increase of the profit.

From the previous calculations it is understood that all the three projects which are investigated in this thesis (Roseries, Jebal Aulia and Merawi); whose their feasibility study was done by a consulting company are viable and very efficient compared to thermal and other generation types.

Also it can be noticed that the Internal rate of return of Merawi hydroelectric power project is less than that of Roseries because the construction of dam itself is included in its capital cost since the main purpose of Merawi is generating hydroelectric power not like the other two (Jebl Aulia, Roseries) which their main purpose of construction is irrigation.

6.3 Recommendations:

It was indicated that the demand for electric power and energy plan in the Sudan especially National Grid will grow from 1200 MW in year 2004 to 4561MW in year 2010, to meet this demand generation facilities required are studied. The most economical viable and financial sound option must be used.

Sudan has two main energy sources, hydro power and thermal power, which could be used to meet growing demands for electrical energy. Other sources include geothermal as well as biomass, solar and wind energy have been studied but they are not suitable for large scale of energy.

On the basis of assessment of power and energy potential and site identification studies of the Nile river and their tributaries in Sudan and inventory of potential hydroelectric power sites has been assembled studies indicate that technically feasible potential totals 4404 MW and 24132 GWH/year from 13 indicated sites, the existing utilized sites represents only 6% of the total potential. These sites are:

Site: Roseries(Dinder+Kenana) Fula Shukoli Lakki Dal Shirri

MW:	339	720	210	210	780	400

Site: bedden	Sheraik	Dagash	Kagbar	Mograt	Sennar
MW: 400	350	285	300	240	100

Site: Sabaloka
MW: 120

A study was done for the most suitable one to be done first, by ranking them by tariff, capacity, energy and utilization.

The study ranks the sites for the main Nile as:

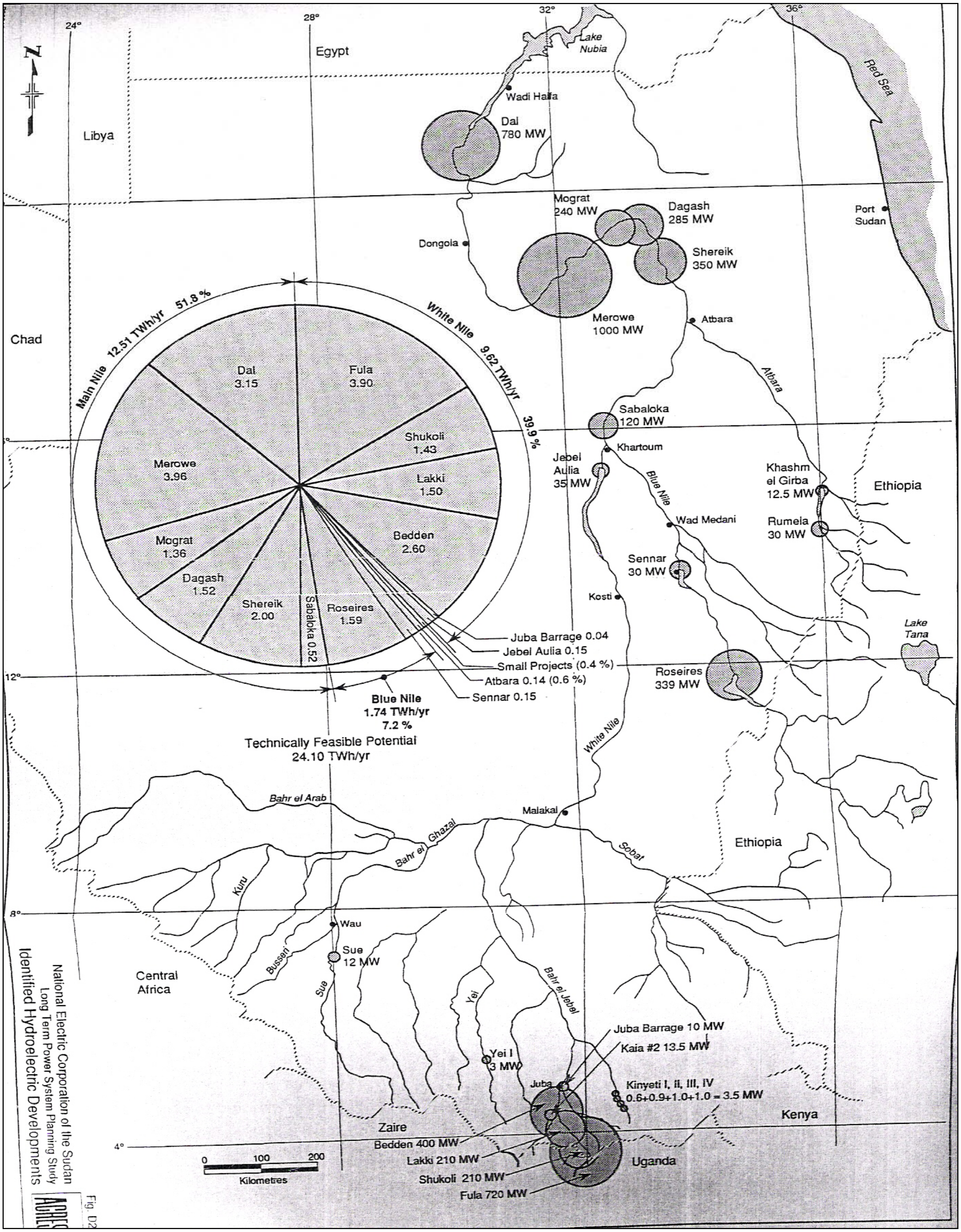
Sheriek – Dagash - Roseries- Dal - Kagbar- Mograt – Sabaloka – Sennar.

And for the Upper Nile :

Fula – Bedden – Lakki - Shoukoli.

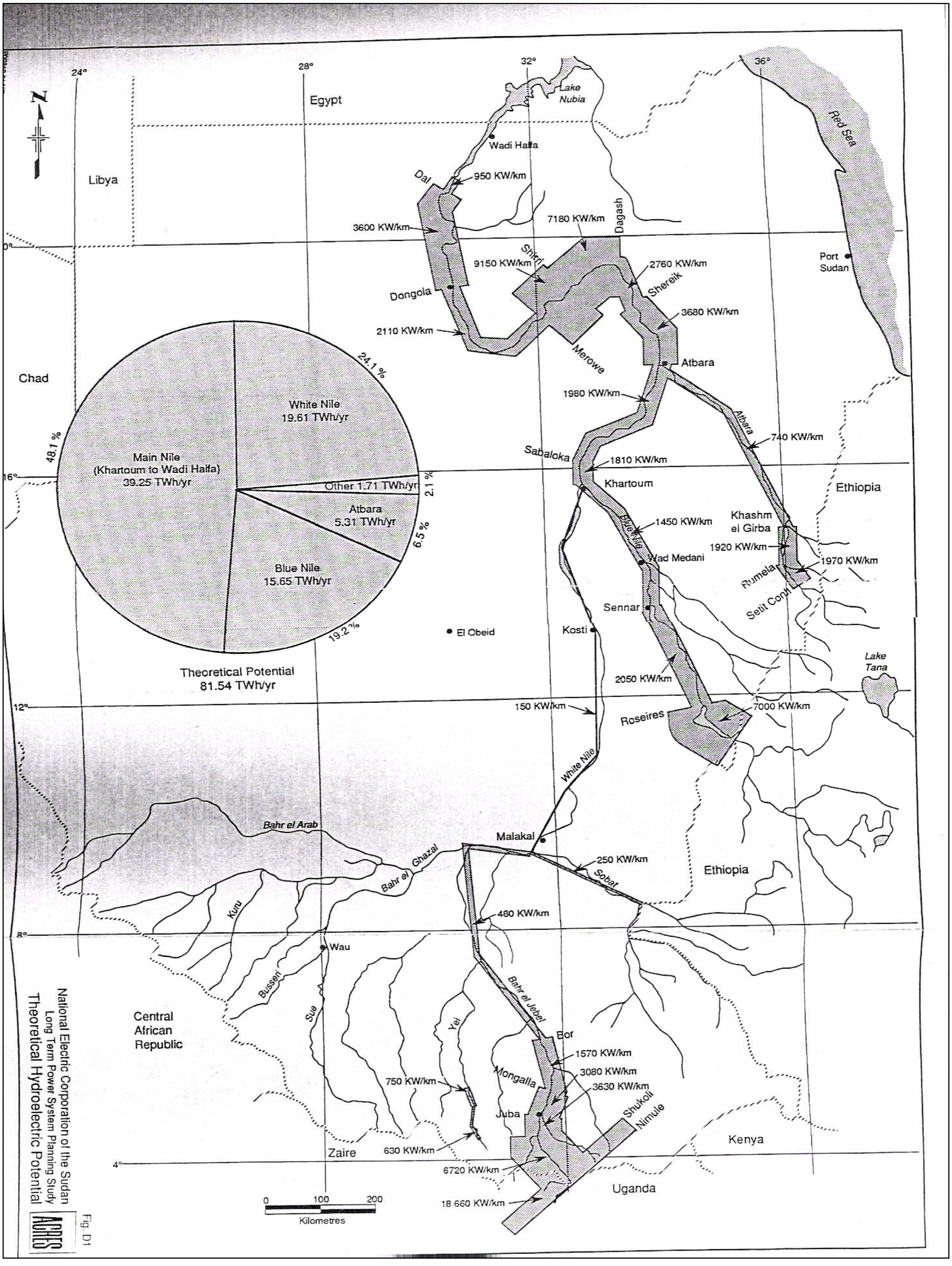
So after finishing Jebl Aulia and Merawi projects, NEC can begin implementing these sites since hydroelectric power is the cheapest source of power.

The feasibility study of them can be done by using Comfar software as well as the consulting company and the results can be compared together, and I suggest that further work and effort must be done so as to know this software since it is a very useful tool and it is easy to work if someone knows all its feature well.



National Electric Corporation of the Sudan
Long Term Power System Planning Study
Identified Hydroelectric Developments
Fig. D2
ACRES
Egypt
Libya
Chad
Central Africa
Zaire
Uganda
Kenya
Ethiopia
Red Sea
Lake Nubia
Lake Tana
Wadi Halfa
Dal 780 MW
Mograt 240 MW
Dagash 285 MW
Shereik 350 MW
Merowe 1000 MW
Dongola
Port Sudan
Atbara
Sabaloka 120 MW
Khartoum
Jebel Aulia 35 MW
Khashm el Girba 12.5 MW
Rumela 30 MW
Wad Medani
Sennar 30 MW
Kosti
Roseires 339 MW
Malakal
Wau
Sue 12 MW
Yei I 3 MW
Juba
Juba Barrage 10 MW
Kaia #2 13.5 MW
Kinyeti I, II, III, IV 0.6+0.9+1.0+1.0 = 3.5 MW
Bedden 400 MW
Lakki 210 MW
Shukoli 210 MW
Fula 720 MW
White Nile
Blue Nile
Atbara
Bahr el Arab
Bahr el Ghazal
Sobat
Kuru
Bussen
Sue
Yei
Bahr el Jebel
Main Nile 12.51 TWh/yr 51.8 %
White Nile 9.62 TWh/yr 39.9 %
Blue Nile 1.74 TWh/yr 7.2 %
Dal 3.15
Fula 3.90
Shukoli 1.43
Lakki 1.50
Bedden 2.60
Merowe 3.96
Mograt 1.36
Dagash 1.52
Shereik 2.00
Sabaloka 0.52
Roseires 1.59
Juba Barrage 0.04
Jebel Aulia 0.15
Small Projects (0.4 %)
Atbara 0.14 (0.6 %)
Sennar 0.15
Technically Feasible Potential 24.10 TWh/yr
0 100 200
Kilometres
24°
28°
32°
36°
12°
8°
4°

Proposed Hydroelectric Sites


Egypt
Libya
Chad
Lake Nubia
Wadi Halfa
Red Sea
Dal
950 KW/km
3600 KW/km
7180 KW/km
Dagash
Port Sudan
Shiri
9150 KW/km
2760 KW/km
Shereik
Dongola
3680 KW/km
2110 KW/km
Merowe
Atbara
1980 KW/km
Atbara
740 KW/km
Sabaloka
1810 KW/km
Khartoum
Ethiopia
Blue Nile
1450 KW/km
Khashm el Girba
Wad Medani
1920 KW/km
1970 KW/km
Rumela
Setit Conf.
Sennar
Kosti
El Obeid
Lake Tana
2050 KW/km
150 KW/km
7000 KW/km
Roseires
White Nile
White Nile 19.61 TWh/yr
24.1 %
Main Nile (Khartoum to Wadi Halfa) 39.25 TWh/yr
48.1 %
Other 1.71 TWh/yr
2.1 %
Atbara 5.31 TWh/yr
6.5 %
Blue Nile 15.65 TWh/yr
19.2 %
Theoretical Potential 81.54 TWh/yr
Bahr el Arab
Malakal
Bahr el Ghazal
250 KW/km
Sobat
Ethiopia
Kuru
480 KW/km
Wau
Bussen
Sue
Yei
Bahr el Jebel
Central African Republic
Bor
1570 KW/km
Mongalla
3080 KW/km
3630 KW/km
750 KW/km
Juba
Shukoli
Nimule
Zaire
630 KW/km
Kenya
6720 KW/km
Uganda
18 660 KW/km
0 100 200
Kilometres
National Electric Corporation of the Sudan
Long Term Power System Planning Study
Theoretical Hydroelectric Potential
ACRES
Fig. D1

Proposed Hydroelectric Sites