TECHNICAL AND ECONOMIC STUDY FOR IMPROVING ELECTRICPOWER GENERATION

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Abstract
This study deals with the shortage of electrical power generation in Port Sudan town in Sudan in 2005, and tries to suggest a solution to this problem. Information on the existing power plant and the grid in the town was analyzed. in addition, an estimation of the power demand on the current grid and its future expansion for ten years was made. Options through which the generation can be improved were presented. The advantages and limitations of every option were discussed, and a combined cycle power plant was chosen. Economic analysis has been carried out for the combined cycle power plant, and finally, the study suggested that the appropriate option based on technical and economic aspects was to use a combined cycle power plant.
Keywords: Combined cycle, technical and economic, load survey, steam turbines, gas turbines

1. Introduction

Electricity was first introduced in Sudan in 1908 when a 100 KW steam power station (i.e. reciprocating engine and direct current generators) was installed. In 1925 the plant capacity was increased to 3000 KW. In 1956, four steam turbines were installed in Burri power station with a total capacity of 30 MW. In 1962 the first hydro power station of 15 MW capacity was erected in Sinnar , which is 300 km South of Khartoum, then there were two hydro power stations built in Elgirba with 12.6 MW and Elrosieris with 280 MW respectively. In 1982 Water Corporation was separated from Electricity Corporation so that each should develop separately and render services independently. The total installed power capacity is increased in the national grid to about 335.6 MW of hydro generation and 656.72 MW of thermal generation. In addition to this, there are many thermal power stations for the isolated areas with a total installed capacity of 93.35MW. Power stations for the national grid and power stations for isolated areas are illustrated in Tables 1 and 2 which are shown below. In addition several projects are underway to increase Sudanese generating capacity. The largest includes the proposed 1,250MW Merowe hydroelectric facilities in northern Sudan [1] – [7].

Table 1 Power stations for the National grid

Power station	*Number of units*	*Capacity, MW*		
		Per Unit	*Total*	
			Installed	*Available*
Hydropower stations				
Rossiers	7	40	280	280
Sennar	2	7.5	15	14.5
El Girba turbines	2	5.3	10.6	10.6
El Girba Pumps	3	2.4	7.2	7.2
Jebl Awlia	30	0.76	2.8	21.6
Total			**335.6**	**333.9**
Steam power stations				
Khartoum North 1	2	30	60	56
Khartoum North 2	2	60	120	110
Total			**180**	**166**
Diesel power stations				
El Girba 1	1	3	3	2.5
El Girba 2	2	3.5	7	3
Kassala 1	3	1.6	4.8	4.8
Kassala 2	5	31.552	7.76	4.4
Elduem	2	1.98	3.96	3.5
Alfaw	2	6.6	13.5	12
Total			**39.72**	**33.7**
Gas power stations				
Khartoum north 1	1	20	20	17
Khartoum north 2	2	25	50	38
Kuku	1	12	12	9
Garri	3	41	123	96
total			205	160
Combined power station	2	116	232	200
total			232	200
Total			**992.32**	**893.6**

Table 2 Power Station for the Isolated Areas

Power station	Number of units	Capacity (MW) Installed	Available
River Nile area.			
Atbara	5	15	9
Shendi	6	6	3.2
North area			
Dongola	5	3.6	3
Wadi Halfa	3	1.8	1.5
N. Kurdofan Area. Elobied	3	9.5	8.2
Umrawaba	2	1.2	1
Red sea area			
Port Sudan (A)	1	5.2	2.5
Port Sudan (B)	6	5.35	3.9
Port Sudan (C)	3	17.1	12.5
Port Sudan (D)	3	6.9	6
N. Darfor area			
Elfasher	6	6	1.8
S/W . Darfor area			
Nyala	4	9.4	0.8
Elginina	3	1.1	0.6
W. Bahr Elgabal			
Juba	3	3	2
W. Bahr Elgazal area			
Wau	2	1.6	0.6
Upper Nile area			
Malakal	1	0.6	0.4
Total		**93.35**	**57**

A. Brief Survey of Port Sudan Town

Location, Geography and Climate: Port Sudan is the second important city in Sudan due to its strategic location as the major Sea Port of Sudan and its unique outlet to the outside world. It lies between latitudes 19°35′N and longitude 37° 13′ E in the north eastern Sudan. It is the major town and the capital of the Red Sea State and it is considered as a large population, commercial and industrial center in the region. Port Sudan is about 2m high above sea level and its climate is wet and hot during summer and rainy and moderate during winter. In spite of its great importance as a port and a commercial center, its power generation capacity is very low (i.e. Thermal power station with installed capacity of 64.35MW). This does not match with the accelerating rate of development and progress in Sudan and the surrounding region at large [8] – [11].

Transportation Media: There are several transportation means connecting Port Sudan with the different districts in the State, the various parts in Sudan and the outside world. The important and the cheapest are the railway lines connecting Port

Sudan with the political capital Khartoum and with Atbara town (i.e. the headquarters of Railway Corporation). Also, the airlines and road transport are other means of transport and are used to link the town with the other parts of Sudan. In addition, shipping lines link the town with the outside countries of the world. The availability of various means of transport adds elasticity in selecting the suitable one and also utilizes the advantages of each method that result in reducing the transportation cost to other region.

Population Density: The last official population census was carried out in 1993 which estimated the population as 306,836. The annual rate of growth is found to be in the range of 5.2% to 5.7% and is determined using the statistical data of population estimations of the years from 1973 to 1993, and then it is used to approximate the population forecast for the years 2005 to 2016, as shown below:

Calculation of population projection:

Population census in 1993 with regard to the town of Port Sudan is approximately 306,836.

Rate of growth for the years 2005 to 2009 = 5.7 (calculated)

Rate of growth for the years 2010 to 2015 = 5.9 (calculated)

Since 2005 population of Port Sudan will be estimated by some method of population projection and using the same method the population projections for 2005 to 2015 will be estimated using geometric method.

Population growth is 5.7 for 2005 to 2009, and 5.9 for 2010 to 2015 calculated by the equation:

$P_n = P_t ((1+(i/100))^n$

Where:

P_t = number of population in base year
P_n = number of population in projection year
n = average population growth rate

Projection in 2005

$P_n = P_t\ ((1+(i/100))^n$
$P_{2005} = P_{1993}\ ((1+(5.7/100))^{12}$
$=306{,}836((1+(5.7/100))^{12}$
=596, 769

Projection in 2006

$P_{2006} = P_{2005}\ ((1+(5.7/100))$
= 596,769((1+(5.7/100))
=630,785

Projection in 2007

$P_{2007} = P_{2006}\ ((1+(5.7/100))$
= 630,785((1+(5.7/100))
=666,739

Projection in 2008

$P_{2008} = P_{2007}\ ((1+(5.7/100))$
= 666,739((1+(5.7/100))
=704,744

Projection in 2009

$P_{2009} = P_{2008}\ ((1+(5.7/100))$
= 704,744((1+(5.7/100))
=744,914
And, during 2010 to 2015 using growth rate = 5.9

Projection in 2010

$P_{2010} = P_{2009}\ ((1+(5.9/100))$
= 744,914 ((1+(5.9/100))
= 788,863

Projection in 2011

$P_{2011} = P_{2010}\ ((1+(5.9/100))$
= 788,863 ((1+(5.9/100))
= 835,407

Projection in 2012

$P_{2012} = P_{2011}\ ((1+(5.9/100))$
= 835,407 ((1+(5.9/100))
= 884,696

Projection in 2013

$P_{2013} = P_{2012}\ ((1+(5.9/100))$
= 884,696 ((1+(5.9/100))
= 936,893

Projection in 2014

$P_{2014} = P_{2013}\ ((1+(5.9/100))$
= 936,893 ((1+(5.9/100))
= 992,170

Projection in 2015

$P_{2015} = P_{2014}\ ((1+(5.9/100))$
= 992,170 ((1+(5.9/100))
= 1,050,708

Projection in 2016

$P_{2016} = P_{2015}\ ((1+(5.9/100))$
= 1,050,708 ((1+(5.9/100))

= 1,112,700

The growth of population in Port Sudan is illustrated in Table 3 which is shown below:

Table 3 The growth of population in Port Sudan

Design year	Population expected
2005	596.769
2006	630.785
2007	666.739
2008	704.744
2009	744.914
2010	788.863
2011	835.407
2012	884.669
2013	936.893
2014	992.170
2015	1.050.780
2016	1,112,700

Population Activities: The main population activities in the region include the commercial activities, small industries and small scale agricultural projects.

B. Historical Background of Power Generation in Port Sudan

Three power stations named A,B and C were installed in Port Sudan. Stations A,B and C details are illustrated in table 4 below.

Table 4 Old Power Station in Port Sudan

Power station	Number of Units	Installed capacity, MW	Available capacity, MW	Type of units
Port Sudan (A)	1	5.2	2.5	Diesel
Port Sudan (B)	6	5.35	3.9	Diesel
Port Sudan (C)	3	17.1	15	Diesel

In 2003 the power station A was replaced by a new one which consists of 39 units and produces about 30 MW total available capacity. In 2004 a new power station was bought from Daewoo Company and added to the local grid. This station consists of three units and its total available capacity amounted to 6 MW.

C. Technical Specifications of Power Stations in Port Sudan

The technical specifications of the present different power stations in Port Sudan are illustrated in Tables 5, 6, 7 and 8 below.

Table 5 Technical Specification of Power Station A in Port Sudan

Units Details	KAT 50-G3
Number of Units	39
Installed capacity of units, MW	35.100
Available capacity of units, MW	30
Number of cylinders	16
Stroke (mm)	159
Bore (mm)	159
Unit specific fuel consumption	0.22 kg/kwh
Type of fuel	GAS Oil

Table 6 Technical Specification of Power Station B in Port Sudan

Units Details	KAT
Number of Units	6
Installed capacity of units, MW	5.35
Available capacity of units, MW	3.7
Number of cylinder	12
Stroke (mm)	190
Bore (mm)	170
Unit specific fuel consumption	0.2 kg/kwh
Type of fuel	Gas oil

Table 7 Technical Specification of Power Station C in Port Sudan

Units Details	silzer
Number of Units	3
Installed capacity of units, MW	17.1
Available capacity of units, MW	15
Number of cylinders	12
Stroke (mm)	400
Bore (mm)	480
Unit specific fuel consumption	0.2 kg/kwh
Type of fuel	Diesel

Table 8 Technical Specification of Power Station D in Port Sudan

Units Details	MAN D & W
Number of Units	3
Installed capacity of units, MW	6.9
Available capacity of units, MW	6
Number of cylinders	12
Stroke (mm)	320
Bore (mm)	280
Unit specific fuel consumption	0.18 kg/kwh
Type of fuel	Furnace

Total available capacity for all units at Port Sudan amounts to: 30+3.7+15+6=54.7 MW at present.

D. Objectives of the Present Study

The main objective of this study is to suggest a solution for the electrical power shortage in Port Sudan town and its effect on the different sectors and institutions in the region. To accomplish this study a proposal of establishing a new power station capable of generating enough power to the town and its expected future extensions has been made through the following procedures:

1. Study the history of electricity generation in Port Sudan town from its inception in 1980 to the present.
2. Preparation of technical feasibility study to determine the site of the project, suitable type and capacity of the plant and other important specifications depending on the statistical data of population density, future industry and development projects in the region.
3. Preparation of an economic feasibility study to determine the present and future annual cash flows of the project through its life span by utilizing different financial and economic measurements

e.g. profit and loss account, annual rate of return, payback period, internal and external rates of return.

2. Load Survey

A. Estimation of power demand at present

The main source of electricity generation in the region is the four power stations. They, as mentioned previously in section 1, supply the town with about 54.7 MW of available capacity. However due to some mechanical and electrical problems and other unforeseen factors, the generation doesn't reach to the designed capacity stated above.

The mechanical factors can be summarized as follows:

1- Although the action of humidity on engine performance is not affected by change of air pressure (altitude) or air temperature, the effect of humidity is to decrease the engine indicated power in proportion to the concomitant decrease of dry air pressure which consequently increases the fuel consumption.

2- The maximum obtainable indicated power of an engine is limited by the mass rate of air consumption.

3- Also the high relative humidity accelerates the rate of corrosion and leads the plant to mechanical failure which increases the cost of maintenance and also increases the time of intermittent stoppages of the plant and hence reduces available power.

The electrical limitations are as follows:

1- The operators of the control room of power station A were observed to trip the other feeders if such a surge or rain causes a trip to one line. Three or four feeders were seen to be tripped by the operator which was not a good practice and in fact a bad trend that causes instability to the system.

2- Due to high humidity in Port Sudan and during the dusty, and rainy seasons most of the overhead lines experience many problems and disturbances which appears as short circuit or line to line fault which means that the insulation layer have been broken down.

B. Power Consumption

The electricity consuming groups are divided into five main groups. These groups include the residential, commercial, industrial, agricultural and government sectors.

The annual power consumption of the above mentioned sectors in GWh is illustrated in Table 9 below.

Table 9 The power Consumption of Different Sectors (2004) in GWh

Month	Residential sector	Commercial sector	Industrial sector	Agricultural sector	Government sector	Total consumption
Jan.	2.239	0.317	0.687	0.005	0.162	3.41
Feb.	2.428	0.384	0.718	0.004	0.176	3.71
Mar.	2.416	0.387	0.681	0.004	0.194	3.682
Apr.	2.3	0.376	0.658	0.005	0.178	3.517
May.	2.294	0.381	0.699	0.005	0.196	3.575
Jun.	1.977	0.314	0.653	0.005	0.192	3.141
Jul.	2.074	0.301	0.628	0.005	0.195	3.203
Aug.	2.3	0.381	0.69	0.004	0.193	3.568
Sep.	2.07	0.3	0.611	0.004	0.192	3.177
Oct.	2.416	0.384	0.681	0.004	0.195	3.68
Nov.	2.3	0.381	0.687	0.004	0.193	3.565
Dec.	2.416	0.387	0.686	0.004	0.194	3.687
Total	27.23	4.293	8.079	0.053	2.26	41.915
Percentage	64.965%	10.242%	19.275%	0.126%	5.392%	

Fig. 1 below shows that the residential sector is the biggest consumer. It consumed more than 60% of the power in the town in 2004.

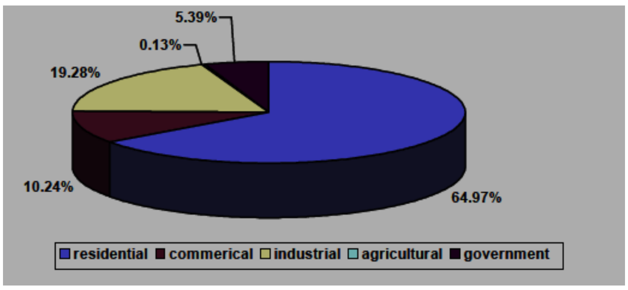


Fig. 1 Consumption of Electrical Power for Different Sectors in 2004

The power generation from the power stations A, B, C and D for the year 2004 in MWh is shown below in Table 10.

Table 10 Port Sudan Power Generated (MWh) in Year 2004

Station	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
A	1435.79	1080.98	1746.72	2203.229	2608.52	2430.79	3643.63	402207	4675.83	5462.92	4287.34	1545.06	35142.88
B	80.82	10.28	0	46.354	94.85	60.43	14.128	0	10.396	34.19	0	0	351.448
C	2545	2415	3099	3391.6	4945	4457.3	4743	5323	4532	4905.5	5900.3	4900.3	5115.7
D	2010.8	2046.48	1905.2	1721.72	2042.92	1785.64	1547.6	784.8	669.2	0	0	0	14514.36
Total	6072.41	5552.74	6750.92	7362.903	9691.29	8734.16	9948.358	10129.87	9887.426	10402.61	10187.64	6445.36	101165.7

It is clear that the power generated was very low in comparison with the installed capacity; some of the power stations are cut off during summer and high humidity season, in addition to the failure of overhead lines effect in transmission, which takes long time for maintenance.

The maximum expected generation of the grid is estimated as 77.775 GWh during year 2004 and the actual generation in the power stations is only 59.403 GWh. Table 11 below shows that there is an obvious lack in power generation in the town.

Table 11 Estimation of Expected Generation, Actual Generation and Lack of Power Generation in the Town (2004) in GWh

Month	Expected generation	Actual Generation	Lack or Deficit
Jan.	5.12	5.002	0.118
Feb.	6.605	5.002	1.603
Mar.	6.605	4.605	2
Apr.	6.605	5.513	1.092
May.	6.605	3.605	3
Jun.	6.605	3.841	2.764
Jul.	6.605	4.727	1.878
Aug.	6.605	5.156	1.449
Sep.	6.605	4.298	2.122
Oct.	6.605	4.483	1.775
Nov.	6.605	6.756	0
Dec.	6.605	6.415	0.19
Total	77.775	59.403	18.372

C. Estimation of Power Demand in the Future

The field surveys of studying the urgent needs and the future expansions of private and governmental institutions have encountered many obstacles. This is due to the poor statistical data and the lack of past records of population size.

Estimation of the Expected Load:

General assumption: In this study, it is assumed that the region concerned (Port Sudan town) will be provided with electricity in two stages. The first stage includes the first years of operation in which all the sectors will be joined to the grid. In the second stage, an annual incremental rate will be proposed so as to cover the future.

Consumer's groups: The consumers are classified into five main groups: commercial, industrial, agricultural, governmental services, and residential.

The existing grid does not cover all new expansions of the town. It is then necessary to assume an increasing rate of the grid for the coming ten years. Table 12 below illustrates the annual future demand from the year 2005 to the year 2015 with a percentage growth rate depending on the sectors concerned.

Table 12 Maximum Power demand (MW)

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Residential	30	33	36	39	42	45	48	51	54	57	60
Governmental	20	22	24	26	28	30	32	34	36	38	40
Industrial	60	69	78	87	96	105	114	123	132	141	150
Commercial	15	17	19	21	23	25	27	29	31	33	35
Agricultural	5	6	7	8	9	10	11	12	13	14	15
Total	130	147	164	181	198	215	232	249	260	283	300

The maximum power demand depends upon the increasing of population density and immigration of the region. The total maximum power demand in Table 12 varies from 130 MW in 2006 to 300 MW in 2016. Fig. 2 below shows that the percentage of peak MW power demand in Port Sudan town.

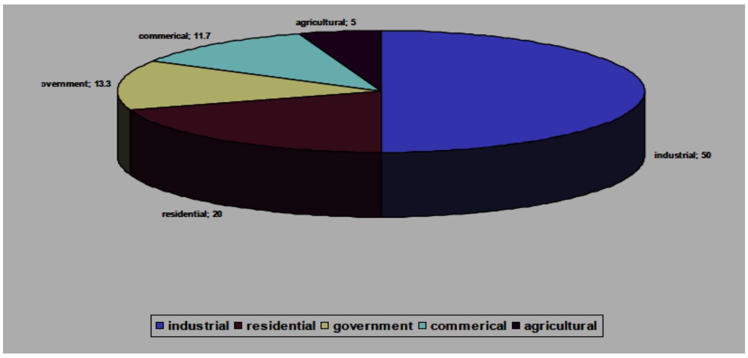


Fig. 2 The Percentage of Maximum Power Demand in the Town in MW (2016)

3. Technical Study

A. Options of Solution

The following part illustrates theoretically the alternatives to solve the electrical power generation problem in Port Sudan [12] – [14].

First option: Gas Turbine Power Plant: The proposed power plant can use gas turbines. Its advantages can be cited as follows:

Comparison with steam power plant:

1. Space requirement for a gas turbine plant is smaller compared to a condensing steam plant of equal size.
2. The gas turbine unit is three times less in initial starting time than a steam plant of the same size and capacity.
3. Plant installation period is less than an equivalent steam turbine plant.
4. The rate of heat generation for a gas turbine unit is generally higher than that of the steam turbine unit.
5. Specific weight of steam turbine is generally more than twice of the specific weight of gas turbine.
6. The operation of turbine is simpler and its capital and maintenance costs are lower than those of steam turbine plant.
7. Foundations and buildings are less costly.

Comparison with diesel power plants:

1. Gas turbine plants have easier maintenance and reduced attendance changes.
2. As gas turbine units are rotating machines, they will be balanced at all speeds, and the vibration effects are less.
3. The rate of heat generation for a gas turbine is generally better than that for diesel engines.
4. The gas turbine unit is able to operate with lower grades of fuel oils than is possible with diesel engines.

On the other hand, the limitations of using gas turbine plant are:

1. Gas turbine is perhaps most sensitive to atmospheric air condition (i.e. temperature, pressure and relative humidity).
2. The turbines are far more expensive than the alternative reciprocating engines of the same size.
3. Needs large quantities of air.
4. Cannot be repaired in place.
5. The maximum r.p.m of gas turbine is limited by stresses in the blade and rotors.
6. Lower mechanical efficiency than reciprocating engines.
7. High irreversibility of the gases in the expansion and compression processes which requires high work input to the compressor and low work output to the turbine compared to the steam turbine and the diesel engine cycles.
8. The running cost of gas turbines is higher than the running cost of steam turbines and diesel engines.
9. Gas turbine can use a wide variety of fuels, solid, liquid and gases. The ideal fuel is a natural gas but this is not always available.

Second Option: Diesel Engines Power Plant: The diesel power plants have got several advantages over other types of power plants as listed below:
1. Handling of fuel is easier and smaller storage is needed for the fuel, and there is no refuse to be disposed of.
2. The size of the plant is comparatively small for the same capacity which results in reduced cost of foundations and building.
3. Diesel power plants maintain high operation efficiency irrespective of load.
4. Cooling water requirement is limited.
5. Thermal efficiency of diesel power stations is always higher than that of a steam plant of equivalent size.
6. Better fuel economy.
7. The plant layout is very simple, (i.e. installation and commissioning of diesel engine plant doesn’t take much times).

On the other land, the limitations compared with a gas and steam turbines are that they employ a large number of moving parts which increase the probability of set failures and that, even at steady load, all reciprocating parts undergo cyclic stressing.

Third Option: Steam Turbine Plant: The steam turbine plant as compared to a diesel engine and a gas turbine of the same capacity can be summarized into the following points as shown in Table 13 below.

Table 13 Comparison between Diesel engine, Gas turbine and Steam Turbine Based Plant (parametric form)

Parameter	*Steam turbine plant*	*Gas turbine*	*Diesel engine*
Power generation capacity	1 MW to 1000 MW	100 kW to 100 MW	10 kW to 10 MW
Efficiency	0.30 to 0.40	0.20 to 0.40	0.35 to 0.40
Fuel	Medium to low grade fuel, may be gaseous, liquid or solid fuel	High to medium grade, may be liquid or gas fuel	High grade fuel, liquid fuel of diesel grade
Size and weight	Large	Small	Medium
Lubrication requirement	Negligible	Oil topping up	Frequent oil and filter changes weekly and monthly
Maintenance period	Daily	Monthly and annual	Weekly and monthly
Plant life	25 to 35 years	15 to 30 years	10-20 years

Therefore, the advantages of steam turbine unit can be briefed as follows:
1. High overall efficiency.
2. Any type of fuel may be used.
3. Heat supplied to power ratios can be varied through flexible operations.

4. Wide range of sizes available.
5. Long working life span.
On the other hand, the limitations of using a steam power plant can be cited as follows:
1. High heat supplied to power ratio.
2. High initial cost.
3. Slow start-up.

Fourth Option: Combined Cycle Power Plant: The combination of gas and steam turbine cycles aims at utilizing the heat of exhaust gases from the gas turbine and thereby to improve the overall plant efficiency.

The heat content of gas turbine exhaust is quite substantial. Gas turbine exhaust has a temperature of around 500 ^oC. The oxygen content in this exhaust is around 16% compared with 21% in atmospheric air. A simple cycle gas turbine plant wastes this energy to atmosphere while a regenerative gas turbine plant recovers much of this heat to raise overall thermal efficiency. But instead we can use the gas turbine exhaust as a heat source for a steam power cycle. Current commercially available power-generation combined cycle plants achieve net plant thermal efficiency typically in the range of 50 to 55%. Further development of gas turbine, high temperature, materials and hot gas path, metal surface cooling technology show promise for near –term future power generation combined – cycle systems capable of reaching 60% or greater thermal efficiency [13].

Additional gas turbine technological development, as well as increases in steam turbine stage design enhancement, are expected to achieve further combined – cycle efficiency improvement.

Combined – cycle systems that utilize steam and air as working fluids have a derived wide spread commercial applications due to the following reasons:
1. High thermal efficiency through application of two complementary thermodynamic cycles.
2. Heat rejection from the gas turbine cycle at a temperature that can be utilized in a simple and efficient manner.
3. Working fluids are readily available, inexpensive, and non-toxic.

In this study, the combined system is chosen to be the optimum option solution due to the following reasons:
1. High thermal efficiency compared to other conventional power generation systems.
2. A wide spectrum of fuels may be used, ranging from clean natural gas and distillate oil fuels.
3. Combined – cycle systems provide flexibility in operation for both base load and wide – range duty with daily startup.
4. Combined – cycle plants can be installed and operated in less time than that required for conventional steam plants.
5. High reliability operation which results from evolutionary design development that improves parts or components, and quality manufacturing programs that offer operational factory listing. Also high availability is advanced through development of sound operation and maintenance practice.
6. Low operation and maintenance costs are achieved through quality design, prudent operation, and equipment design that allows convenient access for component inspection.
7. Combined – cycle systems can provide high efficiency in small capacity increment, i.e. The installation can provide from about 50 MW to several thousand Megawatts of power generation at essentially constant plant thermal efficiency.

B. Classification of Proposed Power Plant

Introduction: The combination of steam and gas turbine cycle provides the highest efficiency turbine system available at the present time. The efficiency of the combined cycle is higher than efficiency of standard regenerative cycle gas turbine.

There are three popular designs of the combination cycles:
1. Gas turbine exhaust gases are used for feed water heating.
2. Employing the exhaust gases as a combustion air in the steam boiler.

3. Employing the gases from a supercharged boiler to expand in the gas turbine. Design of the combination cycles is illustrated in Figs. 3 and 4 below.

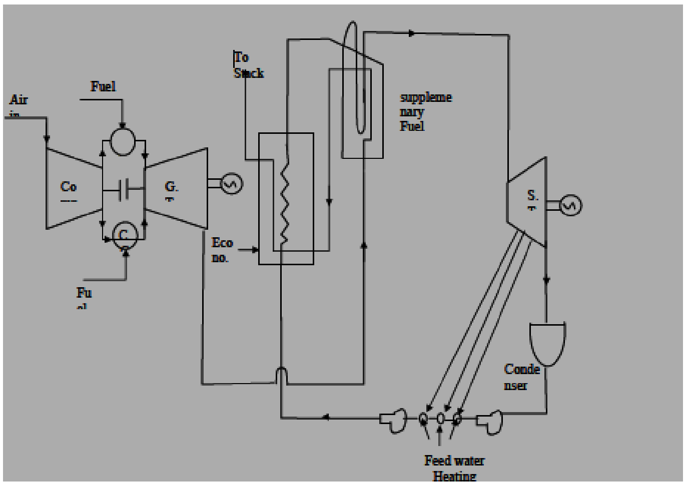


Fig. 3 Combined Gas and Steam Plant (Heat Recovery Boiler)

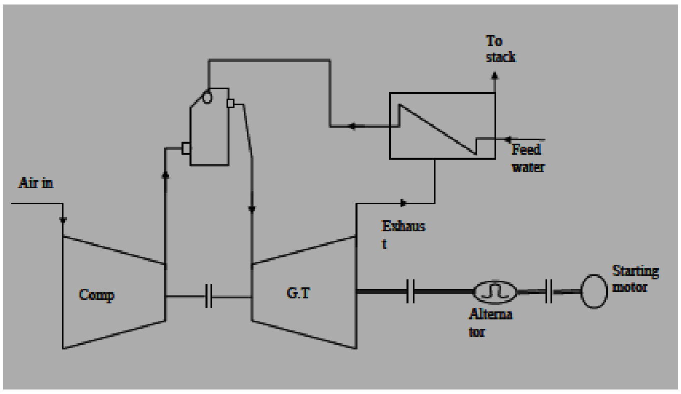


Fig. 4 Flow Diagram of Supercharged Boiler Cycle

Technical Analysis of a Proposed Power Plant: The proposed combined cycle power plant includes two gas turbine generating units of 100 MW each with their individual heat recovery steam generators and common steam turbine generator units to produce an additional 100 MW. Fig. 5 shows the plant diagrammatically and Figs. 6 and 7 show the plant on T-S diagrams.

The plant is to be designed as one block. It consists of two gas turbine units (G.T), a heat recovery steam generator (HRSG), one steam turbine unit (ST) with steam and water systems as well as all associated auxiliary equipment. Fuel will be crude oil (Nile Blend). Each gas turbine exhaust gas is led to its associated heat recovery steam generator. There is a diverter damper between the gas turbine exhaust and the heat recovery steam generator which allows the gas turbine to operate either in open cycle mode or in combined cycle mode. Ambient air is filtered and led to the compressor of the gas turbine, where it is compressed and led to the combustors. In the combustors the compressed air is heated up to the turbine inlet temperature. Fuel is combusted before expanding in the turbine. The flue gas is led to the heat recovery steam generator, which generates steam by heat transfer from the flue gas to the feed water. From heat recovery steam generator the superheated high pressure steam is fed into the steam turbine, where it expands and then condenses in water – cooled condenser. Air and non-condensable gases entering the water / steam cycle are collected at the coldest part of the condenser. During normal operation the vacuum is maintained with liquid-Ring vacuum pump. The condensate and make-up water accumulating in condenser hot well is delivered by one of the two condensate pumps to the deaerator water tank. The feed water is fed back to the heat recovery steam generators by three constant speeds low pressure circulation pumps. To increase the operational flexibility during startup, shut down and abnormal operating conditions separated by pass station for high pressure steam source is provided from heat recovery steam generator. In the crude oil heating, steam is taken from auxiliary boiler when unit start-up or in single cycle. In normal operation crude oil heating steam is taken from steam turbine extraction.

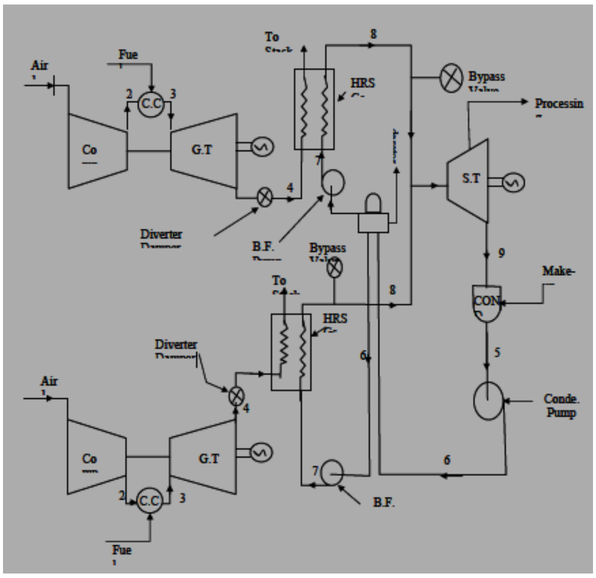


Fig. 5 Diagrammatic Representation of the Combined Cycle Power Plant

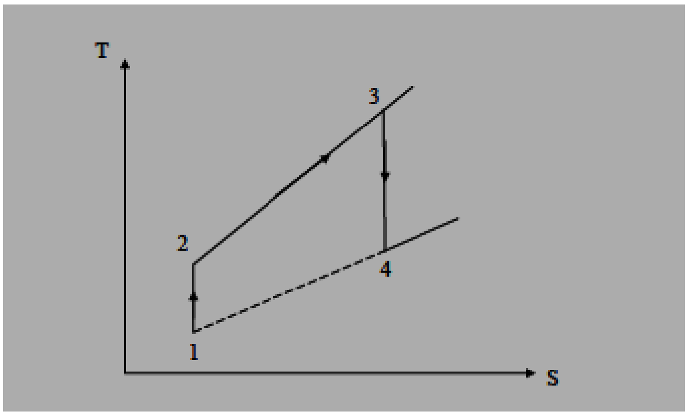


Fig. 6 Gas Turbine on T-S diagram

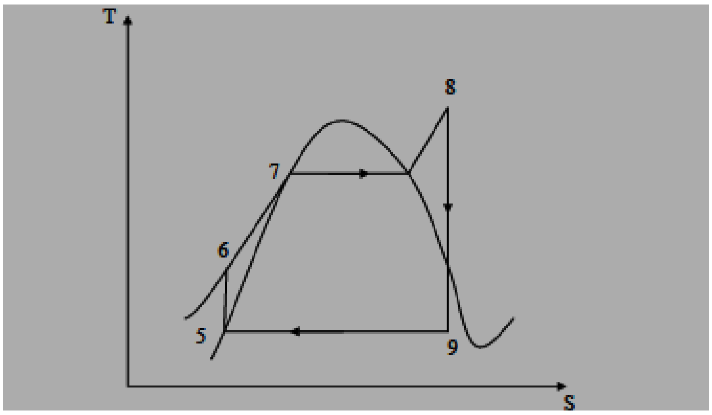


Fig. 7 Steam Turbine on T-S diagram

The plant is to be designed as one block. It consists of two gas turbine units (G.T), a heat recovery steam generator (HRSG), one steam turbine unit (ST) with steam and water systems as well as all associated auxiliary equipment. Fuel will be crude oil (Nile Blend). Each gas turbine exhaust gas is led to its associated heat recovery steam generator. There is a diverter damper between the gas turbine exhaust and the heat recovery steam generator which allows the gas turbine to operate either in open cycle mode or in combined cycle mode. Ambient air is filtered and led to the compressor of the gas turbine, where it is compressed and led to the combustors. In the combustors the compressed air is heated up to the turbine inlet temperature. Fuel is combusted before expanding in the turbine. The flue gas is led to the heat recovery steam generator, which generates steam by heat transfer from the flue gas to the feed water. From heat recovery steam generator the superheated high pressure steam is fed into the steam turbine, where it expands and then condenses in water – cooled condenser. Air and non-condensable gases entering the water / steam cycle are collected at the coldest part of the condenser. During normal operation the vacuum is maintained with liquid-Ring vacuum pump. The condensate and make-up water accumulating in condenser hot well is delivered by one of the two condensate pumps to the deaerator water tank. The feed water is fed back to the heat recovery steam generators by three constant speeds low pressure circulation pumps. To increase the operational flexibility during startup, shut down and abnormal operating conditions separated by pass station for high pressure steam source is provided from heat recovery steam generator. In the crude oil heating, steam is taken from auxiliary boiler when unit start-up or in single cycle. In normal operation crude oil heating steam is taken from steam turbine extraction.

Gas turbine system: The gas turbine system includes gas turbine, generator, compressor, and three auxiliary equipment. The exhaust gas flow and temperature
characteristics at the gas turbine exhaust will be changed with their load.

Heat recovery steam generator and its auxiliary system: The heat recovery steam generator is single-pressure boiler, natural circulating, non-additional firing, and horizontal type. The auxiliary system includes deaerator and its storage tank for heat recovery steam generator, low-pressure circulation system, sampling system, heat recovery steam generator inlet and outlet flue gas duct, flue bypass stack and diverter damper, and feed water system.

The main steam and Bypass System: The main steam system which is connected to the heat recovery steam generators supplies steam to one steam turbine which is impulse condensing type with extraction steam to crude oil heating. The superheated steam piping of heat recovery steam generator supplies the steam headers located on steam turbine bypass system de-superheated prior to entering the condenser.

C. Selection of Optimum Fuel used in Power Station

For the purpose of power plant industry excluding the nuclear power stations, fuel may be defined as any material that combines chemically with oxygen and liberates heat. The various fuels which are commonly used for combustion in the power plants are oil, coal and gas. The selection of the particular type of fuel is a problem of economics. These fuels are known as hydrocarbons. There are two types of fuels which can be used in the station, one of them is the crude oil and the other is the gas oil. The earlier one is chosen to be the main fuel of the plant because it is abundant and cheaper, and the later one may be used in the future depending on the time of extraction from Suakin, which is rich in gas oil due to the technical survey studies conducted in the region [8].

D. Crude Oil as a Power Generation Fuel

The use of crude oil as a power generation fuel recently has received considerable attention. The factors that have promoted this use are fuel availability, cost, safety and environment aspects. The crude oil must be fluid or pump able, and it should have low ash and sulfur content to reduce the emissions. Crude oil used in the combined cycle also must have very low metallic content to ensure adequate turbine
blades performance and comply with the manufacture’s requirement. The specification of crude oil is illustrated in Table 14 below.

Table 14 Specification of crude oil

Type of Crude	Nile Blend
Place of sample	Crude oil tank
Density (15°c) , kg/m^3	849.4
API°	35.1
Kinematics Viscosity (100°c), mm^2/s	6.232
Solidification Point, °c	32
Carbon residue, m%	3.4
Water content, m%	0.15
Salt content, mg Na Cl/L	4
Acid number, mg KOH/g	0.25
Sulfur Content, %	0.06
Nitrogen Content, PPM	-
Pour point, °c	40

E. Location of the Project and Basic Features

As Port Sudan town is chosen for establishing this project, the following conditions for selecting a location are satisfied:

i) Port Sudan is the largest town in the Red Sea State. It contains the headquarters of Sea Ports Corporation and therefore, it has the largest labors aggregation of different technical and managerial specializations, and consequently this leads to labors availability.

ii) It is the capital of the Red Sea state.

iii) It is the terminal point of the railway lines which passes through Khartoum and other important states.

iv) It is the main sea port in Sudan and therefore, it represents a gate to the outside world for exporting agricultural product. This excellent location gives it a commercial, economical and subsequently a political importance.

v) Cheapest means of transport inside the town due to the good established road infrastructure.

F. Availability of Inputs

Undoubtedly, the cost of transporting inputs from its source to the site of the project raises the cost of generation and subsequently the final selling price of electricity services. The inputs which are needed in such kind of industry are generating equipment and fuel oils, which can be obtained easily through the Sea Port and from the refinery, situated in Port Sudan and from other refineries in Sudan using pipelines or railway transports.

In Port Sudan town there are several proposals of selecting the site of the project, but the location near Port Sudan refinery and power station (C) is the optimum one for the following reasons:

i. Enough space for plant installation and for future expansion.

ii. Its closeness to the refinery gives it the advantage of easy provision of the required fuel oil.

iii. Its closeness to the Red Sea coast secures abundant water supply to the station.

iv. The site is far away from the high density populated areas, this alleviates the effects of pollution and noise on inhabitants.

4. Economic Study

A. Introduction

The function of a power station is to supply power at a minimum cost per kilowatt hour. The total cost consists of fixed charges with interest on the capital, taxes, insurance, depreciation and management, and operating charges such as cost of fuel, water, labor, repairs and maintenance etc.

The economics of generation and distribution of power is affected by several design and operational factors. Understanding of these factors is helpful in better power plant management which results in lowering the cost of power generation, cost of transmission and distribution, and miscellaneous costs (i.e. building, overheads of establishment, taxes, etc.).

Power generation economics is important in controlling total power costs to the consumer. The economic study also assists in power plant selection, and in introducing cost reduction techniques in plant operation.

B. Cost Analysis

The cost of power generation depends upon two basic factors which include:

1. Capital cost or fixed cost, and
2. Operational cost

Capital or Fixed Cost of the Project:

The capital cost is the capital investment in the installation of a complete plant. It includes initial cost, interest, taxes, insurance and depreciation.

The type of proposed power plant used in this study is a combined – cycle consists of two units of gas turbines, each unit has a design capacity estimated at 100 MW. There is also steam turbine unit with capacity of 100MW coupled with them. Therefore, the total capacity of the plant is estimated at 300MW. With rapid improvements in the design and construction of plants, obsolescence factor is of enormous importance. Availability of better models with lesser overall cost of generation makes it imperative to replace the old equipment before its useful life is spent. The actual life span of the plant is therefore, taken as 30 years. The cost of the plant in this study is estimated about 213,821,138.2 dollars, given that the generation of one MW costs about 712,737.127 dollars, including the initial cost, interest, depreciation, taxes and insurance. Other fixed cost as engineering consultancy and civil works are estimated as 15% and 8% of the total capital cost respectively. Therefore, the total capital

cost including the consultancy and civil work is estimated as 263,000,000 dollars [15].

Annual Operational Costs:

It includes the following costs:

1. Fuel cost: the fuel used in the plant is crude oil. The fuel consumption estimated is about 0.185 Kg/KWh which costs about 118,770,000 dollars per year as it is calculated in the following equation[15]:

annual fuel cost = rate of fuel consumption (kg/KWh) × number of operating hours per day × price per Kg × number of days per year

= 0.185x1000 Kg/MWh x 24h/day x (0.3$ / 0.864 Kg) x 360 day x 214 MW

∴ Annual fuel cost = 118,770,000 $

2. Maintenance cost: It is divided into three types as follows:

i) Fixed maintenance: it is estimated as 2400$ / MW and which amounts to 513,600 $.

ii) Overhead maintenance: it is estimated as 4$/MWh and which amount to 7,395,840 $ per year.

iii) Annual depreciation: it is calculated using the following equation;

Annual depreciation cost = C/N. [15].

Where:

C = capital cost – engineering consultancy cost.

N = expected life time.

Therefore, annual depreciation = (263,220,000-32,100,000)/30

=7,696,660$

Therefore, the total annual operating cost amount to about 134,376,100 $ and when adding a 10% of this value as an unforeseen expenses, the total cost reaches a value of 147,813,710$

C. Annual Revenues of the Project

In reference to the tariff price of kilowatt hour which is taken from the recent records of the national electricity corporation, it is evident that the corporation follows variation method in determining the price of KWh according to different factors which may be summarized in the following points:

i) Expectation of increase of demand in different sectors such as industrial, agricultural, commercial and residential complex at different times during day and night, and seasonally.
ii) Expansion plans to meet the expected growing demands.
iii) The costs and expenses required to execute the plan when summing up and analyzing the previous mentioned points, they are classified according to the potential difference levels, the different consumption modes of the users, the different loading
times of the plant and subsequently the variations of operation cost due to utilizing different fuels.
In this study, the price of kilowatt hour supply is taken as a common value and to all consumers groups equivalent to 0.14$.
As shown in chapter (2), and table (2.4), the electricity demand increases yearly due to the increase of population and industrial, agricultural and commercial expansion. It increases with a rate of 10% yearly from a value of 130 MW in 2006 to a maximum capacity of 300 MW in 2016. Therefore, an average value of 214 MW per year is assumed through the life span of the project .
Once the station is established it is assumed to work with full capacity.
After Port Sudan town is connected to the national grid the surplus generation will be sold to the national electricity corporation .This will be expected to be done soon next year as it is planned to extend Merowe Dam electricity to Port Sudan next year.
The total revenues are determined using the following equation:
Total annual revenues = power generation in MW ×average sale's price in $/MWh ×number of hours per day × number of days per year [15].
= 214 x 140 x 24 x 360 **= 258,854,400$**

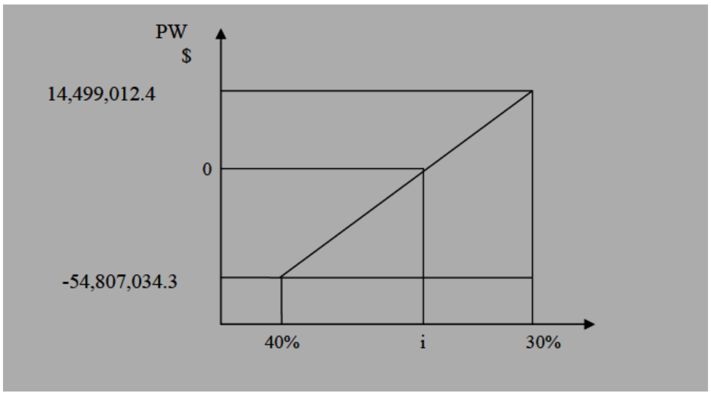
D. Profit and Loss Account

Total annual revenues = 258,854,400 $
Total operating cost = 147,813,710 $
Gross profit = 111,040,536$
Taxes (about 25%) = 27,760,172.5 $
Net profits after taxes = 83,280,517.5 $
Therefore, the annual net profit is 83,280,517.5 $

E. Financial Evaluation of the Project

The following assumptions are considered to determine financial feasibility of the project:
i) Discount rate will be used to determine the net present value through the useful life of the project which is determined to be 30 years
ii) The salvage value at the end of the 30 year will not be considered as a revenue.
iii) Assume a discount rate of 30% which represents the available substitute opportunity for investing the capital.
iv) To determine whether the project is feasible or not the following methods of evaluating investment projects are used:
1. Accounting Method: Annual rate of return (i.e. percentage profit) =
(Net profit / investment capital) × 100%. [15].
= (83,280,517.5/263,000,000) × 100%
= 31.7
2. Payback Period:
Payback period = (investment capital/Net annual profit). [15].
= (263,000,000$ / 83,280,517.5)
= 3.16 years ≅ **4 years**
Therefore, the project will recover its investment capital before the completion of the fourth year of its age.
3. Internal Rate of Return (I.R.R):
It is the most used method of evaluating project, and it is defined as the discount rate that gives the project a present value of zero. Using interest rate tables.
PW (30%) = - 263,000,000+83,280,517.5 (P/A, 30%, 30 years)
= -263,000,000+83,280,517.5 × 3.3321

= 14.499.012.4 dollars
PW (40%) = - 263,000,000+83,280,517.5 (P/A, 40%, 30 year)
= - 263,000,000+83,280,517.5x2.4999
= -54,807,034.3 dollar
Interpolation method is used to determine the suitable internal rate of return as follows:



i = 30 +((0- 14,499,012.4)/(– 54,807,034.3 – 14,499,012.4))×(40-30) **= 32.1 %**
It is clear that the net present worth is equal to 14,499,012.4 $ (positive value) when using discount rate equivalent to 30% and is equal to 54,807,034.3 (Negative value) when using a discount rate equivalent to 40%.
Therefore, and due to the justifications mentioned above, the project is considered economically feasible. [15].
4. External rate of return (E.R.R): It determines the interest rate which generates a future worth equivalent to zero assuming reinvestment of a capital with the minimum attractive rate of return (MARR). Using the following equation:[15]

$$\sum_{C=0}^{n} R_{jt}(1+r_t)^{n-t} = \sum_{t=0}^{n} C_{jt}\,(1+i)^{n-t}$$

Where:
I = External rate of return
C_{jt} , R_{jt} = positive and negative net cash flows:
For investment j during period t, respectively
Rt = reinvestment rate for positive cash flows occurring in period t and normally equals the minimum alternative rate of return (MARR)
n = useful life time of the project
83,737,152 (F/A, 30% , 30) = 263,000,000 $(1+i)^{30}$
1+i = 1.30
i =30%
Since, the external rate of return is equivalent to 30% which is the same as that of the minimum attractive rate of return (MARR), therefore, the investment is considered acceptable.

5. Conclusions

The objectives of the present study were satisfied through the technical and economic feasibility studies which had been introduced in chapters three and four of this research. Therefore, the conclusions drawn out of this research can be summarized in the following points:
1) The historical background of power generation in Sudan at present and future, the technical specification of power stations in towns and the lack of power generation, have been investigated in the present study.
2) A field survey study including the population size and, geography and climate of the region and the activities, capacity of the power generation plants already existed was conducted.
3) Estimations of power demand at present and in future have been prepared so as to determine the real needs of power for different consumers such as residential, industrial, commercial and governmental. In addition to summarizing the problems of generation (mechanical and electrical), and estimating the peak MW demand for the year 2005 to the year 2015 [16] – [20].

4) Based on the collected data, a 300 MW combined cycle power plant has been suggested for Port Sudan. The plant is composed of two turbines each one produces 100 MW of power and a heat recovery unit producing steam to drive a 100 MW steam turbine.
5) The project is proved to be technically feasible through different measures such as site selection, availability of fuel and water supply, provision of spare parts and maintenance necessities.
6) The objective of any aspect of power station design is to achieve the lowest capital cost and ease of construction together with simplicity and efficiency in the operation and maintenance of the station. In this study the different economic measures such as
annual, internal and external rate of return were taken and the economic feasibility is proven to be within the standard prescribed measures.
7) The economic analysis performed showed that the project is feasible and it will pay back its investment capital in a period of less than 4 years of operation. The total initial cost of the project amounts to 263 million dollars.

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