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Decrease in Operational Efficiency and Its Impact on the Production Capacity of the Combined Power Plant in Zawia

Amal Al-Maawi Saeed Al-Jamal[1*]

[1] Power Engineering Department Higher Institute of Science and Technologie, Sabratha, Libya

*Amalalalagi393@gmail.com

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Abstract

The Zawiya Combined Cycle Power Plant is considered one of the most important power generation stations in Libya, as it includes gas and steam units that contribute to supplying the national electricity grid. This research aims to examine the factors influencing the decline in the plant's operational efficiency, most notably fuel quality, ambient air temperature, compressor efficiency in gas units, in addition to the deterioration of some auxiliary equipment and systems. Based on the operational data of the gas unit (GT12) during the period from January to June 2023, the results showed that efficiency decreased to (27.6%) compared to the design efficiency of (35%), representing a difference of (7.4%). This decline was reflected in the reduction of production capacity from (165) to (127) MWh per unit, resulting in a daily deficit estimated at (912) MWh, which negatively affected the overall daily output of the plant.

Keywords: Operational efficiency – Production capacity – Zawia Combined Power Plant – Gas turbines – Energy loss – Maintenance

I. Introduction

Electricity is a form of energy produced by the presence of elementary particles carrying different electrical charges, such as electrons and protons. Electricity arises from the accumulation of charges, or through the movement and flow of electrons in a conductive body, which is commonly known as current[1].

Steam power stations are known to convert the potential energy of fuel (chemical energy) into thermal energy through combustion, and then convert thermal energy into mechanical rotational kinetic energy in the turbine, and then into electrical energy in the generator. By utilizing the exhaust gas temperature, it is used to heat water to produce steam for the purpose of rotating a steam unit. . [2,7]

Electricity generation stations are one of the main pillars for ensuring the continuity of electricity supply and meeting consumer needs. However, the operational challenges faced by these stations can directly affect their performance and efficiency[3] . The Zawia combined cycle power plant is considered one of the most important stations in Libya, playing a pivotal role in meeting the demand for energy. The actual problem lies in the decrease and fluctuation in the productivity of the plant, which directly affects the operational efficiency of the plant. The importance of studying this problem stems from the significance of electricity in our lives and the increasing demand for electrical energy from consumers in various aspects of life. The research focused on reducing energy loss and identifying the causes of decreased production efficiency and addressing those causes to improve efficiency.

Productivity at Its Best

To achieve the highest productivity and to provide the required electrical energy at the lowest costs. Through this research, practical data will be collected from the reality of the stations that were conducted on some stations in Libya and also on some previous studies. In the third section, the types of stations were generally identified in the field and practical study of the fifth hydroelectric station. In the sixth section, the results were discussed, and in the seventh and eighth sections, the results were summarized, and recommendations were mentioned

II. Related Work

This research relied on sources close to the topic, including: a study titled "Exergy Analysis of a Third Unit at the Z" [4]. The design efficiency of the third unit in the station shows that the exergy efficiency was approximately 37.55%, while under actual operating conditions it dropped to 72.3%; the exergy losses reached 232 MW (70.2%) in design and 332 MW in reality. A study titled "Energy and Exergy Analysis of the Benghazi Station" [5]. The most important results were a comprehensive analysis showing that the total energy efficiency of the station is about 33% and the exergy efficiency is about 30%; the largest exergy loss was in the combustion chamber (~272 MW), followed by HRSG (~35.7 MW).

A study on "Operational Performance Analysis of a Steam Power Station in Nigeria". [2] focused on analyzing the operational performance of steam stations, confirming that these stations are the main source of electrical energy. The research also addresses the efficiency of these stations and their use of different types of fuel.

A study on "Improving the efficiency of the Zawia Combined Cycle Power Plant (ZCCPP) by using the fog cooling system"[6] This study was presented at the Third Engineering Conference of the Zawiya Society of Engineering Professions. It investigates the impact of the fog cooling system on enhancing the efficiency of the plant under hot ambient conditions.

A study on "Performance enhancement of gas turbines of Zawia Combined Cycle Power Plant (ZCCPP) using absorption chiller system"[7] This theoretical research compares the scenario with an absorption chiller system and the scenario without it, in order to evaluate the improvement in production and efficiency when the temperature of the air entering the gas turbine compressor is reduced.

A study on "Performance Evaluation of The Blackout and Power Outages in Libyan Power Grid – Al-Zawia Combined Cycle Power Plant Case Study" [8]This conference paper evaluates the cases of blackouts and power outages in the Libyan power grid, focusing on the Zawia Combined Cycle Power Plant as a case study.

A study on "Improving Efficiency Using Absorption Cooling" [9] concluded that using an absorption cooling system to reduce the inlet air temperature for gas turbines increases productivity compared to efficiency and capacity, without cooling. There is also a detailed study on the decrease in turbine efficiency, examining various temperature ranges produced for several operational conditions and the thermal efficiency between the turbine air inlet and 17 – 37 degrees Celsius[10], with the aim of investigating the reasons for the decrease in thermal efficiency. Additionally, there is a study on gas turbines, focusing on types, efficiencies, defects, characteristics, and operational lifespan of turbines, and calculating the thermal load for the turbines[11].

III. Types of Generating Stations.

The process of generating or producing electrical energy is, in fact, a process of converting energy from one form to another, depending on the available energy sources in the centers of demand for electrical energy and the required quantities of this energy. This determines the types of generating stations, as well as the types of consumption and types of fuel and their sources, all of which affect the determination of the type and location of the station and its capacity. The types of generating stations used globally and locally were as shown in Figure (1) and listed in Table 1.

Figure 1: Shows the diversity of electricity generating stations

The following table illustrates the types of electrical power generating stations used worldwide.

Table 1: Shows the types of power stations

NO	Type
1.	Steam generating stations.
2.	Nuclear power stations.
3.	Hydropower stations Tidal power stations
4.	Tidal power stations
5.	Internal combustion generating stations (diesel – gas)
6.	Wind power stations
7.	Solar generating stations

IV. Steam Generating Stations

Steam generating stations are considered energy converters and these stations use various types of fuel such as coal, liquid petroleum, natural gas, or industrial fuel according to the available types. Steam stations are characterized by their large size and low costs relative to their massive capacities, and they are also distinguished by their ability to be used for desalinating saline water, which makes them dual-purpose, especially in countries where fresh water sources are scarce.[2,17]

1. Site Selection of Steam Power Station

Several factors influence the selection of suitable sites for thermal power generation stations, including:

a. Proximity to fuel sources and ease of transportation to these sites, as well as the availability of economical transportation means.

b. Proximity to cooling water sources, as the condenser requires large quantities of cooling water. Therefore, these stations are usually built near rivers, on the shores of seas, or close to water channels.

c. Proximity to electricity consumption to reduce the costs of establishing transmission lines. The areas of high consumption are usually residential areas, commercial complexes, and industrial zones.

Steam generation stations rely on the use of special boilers to convert the chemical energy in the available fuel and burn it in the fuel boilers to generate steam. The thermal energy in the flame resulting from the combustion process is used to heat water in the boilers, then this steam is directed to turbines or steam turbines designed for this purpose. The rapid steam rotation turns the turbine shaft, thus converting thermal energy into mechanical energy. [13]

2.The Axis of These Turbines

The axis of the steam turbines rotates the axis of the electric generator directly connects the axis of the electric generator (ALTERNATOR) with the rotor (ROTOR) and the stator (STATOR) of the generator. The necessary electrical energy is generated at the ends of the stator. The representative diagram number illustrates the series of energy conversion from the initial burning of fuel to the production of electrical energy. [10,18]

There are no fundamental differences between steam power stations that use different types of fuel, except in the methods of fuel transportation, storage, handling, and burning. The use of coal was common in the late last century and early this century, but the discovery and extraction of petroleum and its products brought about a radical change in thermal power stations, where it is now used in ninety percent of cases due to the ease of its transportation, storage, and burning, whether in liquid or gaseous form. [2]

3. Components of Steam Generation Stations.

Steam generation stations consist of the following main components :

1. Furnace: It is a large vessel for burning fuel. The type of fuel used in this vessel varies according to the type, and the shape and type of the vessel differ. It is accompanied by means for storing, transporting, handling the fuel, and disposing of solid waste.
2. Boiler: It is a large vessel that contains pure water heated by burning fuel to convert this water into steam. The furnace and boiler often have a direct connection between the burning fuel and the water being heated. The size of the boiler and the amount of steam produced vary according to the size of the station and the quantity of steam produced per unit of time.
3. Turbine: It is a steel turbine with an axis connected to a body in the shape of a rotor. It rotates at a very high speed, approximately 2222 revolutions per minute, where steam collides with it, causing it to rotate. The design and shape vary according to the size of the steam and its pressure and temperature, depending on the size of the generation station.
4. Generator: It is an electric generator consisting of a rotating member directly connected to the turbine axis and a stationary member. Both members are wound with insulated copper wires to transfer the rotating magnetic field and convert it into electrical current in the stationary member. The shape of this generator varies according to the size of the station.

5. Condenser: It is a large steel vessel into which steam from the turbine enters from the top after it has lost much of its pressure and temperature. A stream of cooling water enters this condenser from below through spiral pipes that work to convert the weak steam back into water, where this water returns to the boiler via special pumps.
6. Chimney: It is a cylindrical brick chimney that is very tall and works to expel and reduce environmental pollution by discharging gas emissions into the atmosphere at a high altitude to expel the combustion waste surrounding the station.
7. Auxiliaries: This includes a large number of pumps and mechanical and electrical motors, as well as steam roasting equipment that helps complete the work in the generation stations.

V. The Dual Power Station of Al-Zawiya

1. The dual cycle power station of Al-Z is one of the power generation stations that addresses the deficit in electrical energy in the country. The dual cycle consists of three combined gas and steam units, and each combined unit consists of two gas units that operate on the exhaust of the gas units, where the heat is returned to operate a steam unit. The steam unit operates on a heat recovery system that utilizes the exhaust heat from the gas turbine, which reaches a gas temperature of 520 degrees to produce the necessary steam to operate the steam turbine.

Figure 2: Shows a diagram of Al-Zawiya Dual Power Plant.

Figure 2 shows a schematic of the dual cycle power station of Al-Z. This type of turbine is also characterized by having a circular combustion chamber and has a (72) EV burner in a circular shape on the combustion chamber with a compressor (21 stage) and the turbine (5 simple stages), and the efficiency of the turbine at the cycle reaches 33%. When operating in the cycle, it reaches 60 %, and the produced power reaches 165 MW when operating on natural gas.

2. The establishing of the Dual cycle Power station of AL-Z

2-1 First Phase. A. *Establishment of four gas units*: Direct work on surveying and preparing the site began on 1/11/1998 AH, with the executing company being the Swiss company (A B B), and the supervising office being the consulting company. The project was completed on 23/12/2000 AH, with a production capacity of the four generating units reaching 600 MW, and the design efficiency of the generating units was 35% with four gas generating units of type GT13E2.

B. *Accessories for GT13E2 gas generation units*: Liquid fuel and natural gas system, Electrical systems, Control and monitoring system, Two desalination and water treatment units, Fire extinguishing system, Administrative buildings, workshops, and warehouses. The ignition of the first gas unit GT11 was on 23/5/2000.

2-2 Second Phase. Addition of two gas units: The executing company is the Swiss company ALSTOM. The supervising office is the Arab Engineering Consulting Company. The supervising office is the Arab Engineering Consulting Company, and the first unit was operated on 17/9/2005 and the second unit was operated. On 19/9/2005, the productivity of the generation units reaches a capacity of 330 MW when operating on natural gas. Gas generation units are classified as environmentally friendly.

3. The fuel used to operate the station

The maintenance department operates the station using light fuel, and now all units have started working on natural gas. Routine and periodic operations and maintenance of all parts of the station are carried out by qualified national Libyan elements that have been prepared and trained internally and externally.

4. The Main components of the gas turbine (GT13E2)

- **Axial flow compressor**: The compressor consists of (21) stage containing fixed and moving blades, where each stage is considered a basic component of gas turbines and is called the axial flow compressor because air enters at the beginning of the compressor and exits to direct the variable air. This is to provide the necessary air for the combustion process, to direct the drawn air, and to control its quantity. The function of the axial flow compressor is to compress the air on the moving blade stage to direct it through the compressor axis. The axial flow compressor is characterized by high efficiency and has a compression ratio ranging between (15:1). The compression ratio of the air compressor depends on the angle of the moving and fixed blades, and the values of the blades and the angle of the compressor blades are controlled by changing the angle of the moving blades.

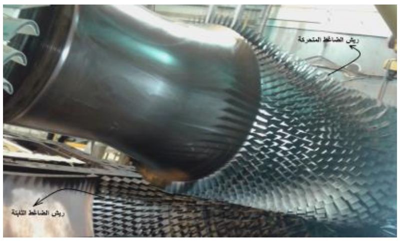


Figure 3: shows the axial compressor of the GT13E2 turbine.

- **The Combustion chamber**: The gas turbine contains a single annular combustion chamber where ignition and fuel combustion occur through a main opening equipped with (72) burners arranged in two concentric rows with environmentally friendly conical burners surrounding the body. In the combustion chamber, the chemical energy of the fuel is converted into hot gases with a very high temperature in the form of thermal energy, where combustion occurs at constant pressure.

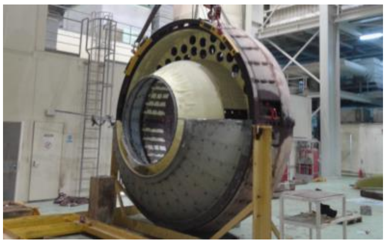


Figure 4: shows the combustion chamber of a GT13E2 turbine.

To ensure proper combustion, a set of environmentally friendly burners called environmentally friendly associated burners is used.

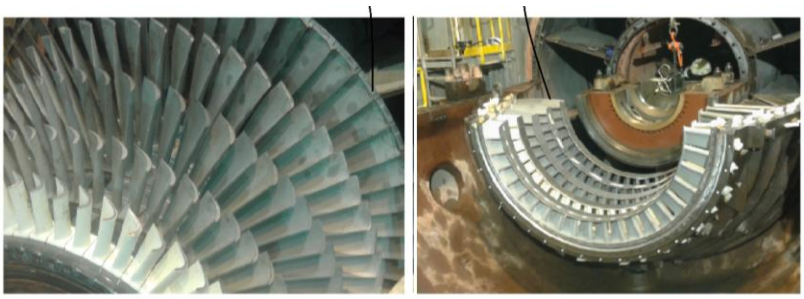
• **The Turbine**: The turbine converts the thermal energy resulting from the combustion gases into mechanical energy by means of blades.

a. The Blades in the Turbine

- *The Fixed blades*: They are installed on the hot gases in the turbine cover, and through them, the gas is directed optimally towards the moving blades.

- *The Moving blades*: They are mounted on the shaft, and through them, mechanical energy is distributed to the column.

Each row consists of one and all the blades are installed in a symmetrical manner so that the gas passes over them one after the other. Each row of fixed blades with a row of moving blades is called a stage inside the turbine, which consists of



five stages. The hot gases enter through specific openings in the fixed

blades, where they are directed to the moving blades, causing a rotation that leads to expansion, and thus the pressure and temperature inside the turbine will decrease.

Figure 5: Shows the turbine blades present in the GT13E2 type.

5. Programs and auxiliary systems in the gas turbine.

1. The Auxiliary Systems in the Gas Turbine:
2. Air Intake System.
3. Lubrication Oil System.
4. Water Cooling System.
5. Air Cooling System.
6. Liquid Fuel System.
7. Gas Fuel System.
8. Ignition System.
9. Oil System.
10. Column Rotation System.
11. Exhaust System.

6. The Dual Cycle of the Power Plant: The dual cycle power plant consists of gas and steam turbines. It consists of 6 gas turbines and 3 steam turbines, each 2 gas turbine operates one, and the steam turbines operate at a high temperature. The gas turbine exhaust is used to heat water, where the steam turbine is powered by the steam produced from the exhaust, and then the steam turbine is operated.

The productive capacity of one gas turbine is 150-160 MW, while when operating with one steam turbine, it operates at half load of 70 MW, and when operating with two steam turbines, it operates at 130 MW.

7. The Main Components of the Gas Turbine

1. Turbine 2. Generator 3. Compressor

At the beginning of operation, the engine starts via the starter or the starting motor, drawing from the grid to operate the generator with a certain speed initially, then the turbine relies on itself, meaning it provides electricity for itself. The gas turbine operates on gas fuel (natural gas) obtained from the Mellitah Gas Company or on light fuel (kerosene) emitted from the gas turbine, meaning it operates on free fuel. The steam turbine operates from the heat.

8. Steam Turbines

The steam turbine does not have a generator and the water compressor specific to the steam turbine has special specifications, and the water that the gas turbine operates with has a closed circuit. The gas turbine produced megawatts, and the more the steam turbine increased, the more it produced.

9. Special Gas Step-Up Transformers

The voltage of the generator is 15.7, which enters the transformer and exits at 220 kV. As for the steam turbine, its voltage enters from the generator at 13.7 and exits at 400 kV. The steam turbine has a higher voltage. For example, when the turbine's temperature is 15 and humidity is 75 or 70, the MWh production increases. The lower the temperature, the better the production. The maximum production achieved by the turbines was 170 MW.

10. The Operational Basis for the Station.

10-1 Finding the Thermal Efficiency of The Turbines.

Through the operational basis, we were able to know the field method for the electricity station and the method used to calculate thermal efficiency when the gas unit operates on gas fuel and light liquid fuel. The efficiency department at the station informed us that the equation used for thermal efficiency when the unit operates on light liquid fuel is:

$$\eta_{th} = \frac{(W_{net} - W_{cons}) * 3600 * 1000}{M_{f} * LHV * \rho_f} \quad \rightarrow \quad (1)$$

Where:

W_{net} represents the net power produced over 24 hours in megawatt-hours.

And M_f represents the mass of fuel consumed over 24 hours,

ρ_f is the density of light liquid fuel.

And W_{cons} represents the net power consumed within the station over 24 hours in MWh.

The following data was collected from the electricity station on a working day in one of the winter days, and one of the gas turbines operating on light liquid fuel was selected.

Table 2: Shows the data related to the efficiency equation.

Temperature	17℃
Produced power (W_net)	3130 Mw h
Net power consumed by this turbine	15 Mw h
Mass of fuel consumed	938 m^3
Calorific value of light liquid fuel	kj/kg = (LHV) 42710

Amount of air entering the turbine	ρ_f=850.5 kg/m^3

By substituting the values in the previous table into equation (1), we obtain the following:

$$\eta_{th} = \frac{(3130L - 15) * 3600 * 1000}{938 * 42710 * 850.5} \times 100 = 32.9\%$$

The **Result 1:**

Efficiency 32.9% for a gas turbine

10-2 Test Another Day in Summer.

On a working day, the following data was collected from the Al-Z summer power station, and one of the gas turbines operating on light liquid fuel was selected. The data was as follows

Table 3; Shows the data related to the efficiency equation.

Temperature	37 ℃
Produced power (W_net)	1334 Mw h
Net power consumed by this turbine	20 Mw h
Mass of fuel consumed	585 m^3
Calorific value of light liquid fuel	kj/kg (LHV) 42710
Amount of air entering the turbine	ρ_f=850.5 kg/m^3

By substituting the values in the previous table into equation (1), we obtain the following:

$$\eta_{th} = \frac{(1334 - 20) * 3600 * 1000}{585 * 42710 * 850.8} \times 100 = 22.3\%$$

Result 2:

Efficiency 22.3% for one of the gas turbines

From the previous result, we notice the amount of change in the efficiency of the turbine. By using the arithmetic mean of the two results, we find that the average efficiency value of the dual turbine for the Al-Z power station equals:

Result 3:

(22.3+32.9)/2 = 27.6%

From result (3), the amount of dual efficiency is a decrease in efficiency at the Al-Z power station compared to the design efficiency of the manufacturer, which equals 35%:

Result 4: 35-27.6=7.4%

This means that the average productive efficiency of the GT112 unit throughout the year is 27.7%, which leads to a decrease in the productive capacity of the unit from 165 MWh to 127 MWh. This decrease in efficiency will result in a deficit in the produced capacity of the unit by 912 MWh for each working day of the GT112 unit

After knowing the amount of decrease in efficiency using theoretical and computational methods, we will find the efficiency of the dual gas turbines for electricity through the recorded data from the control room of the Al-Z station in the operations department, where a set of daily data for the station was obtained. A set of daily data for a period of 6 days from 6 months was randomly selected, as shown in tables from (4 to 9).

Table 4: Daily Report for Monday, 16/01/2023

الشركة العامة للكهرباء
الإدارة العـــامة للإنتـــاج
محطة كهرباء الزاوية المزدوجة
التقرير اليومي

الاثنين	التقرير اليومي ليوم
16/01/2023	الموافق

مركب 1			
GT12	GT11		البيان
تعمل	تعمل		حالة الوحدة
120	165	MW	المتاح
123	171	MW	أقصى حمل
122	162	MW	أدنى حمل
123	171	MW	حمل الذروة
2,868	0	MWh	الطاقةالمنتجة بالخفيف
0	3,941	MWh	الطاقة المنتجة بالغاز
*****		MWh	الطاقة المنتجة بدون وقود
2,868	**3,941**	**MWh**	**إجمالي الطاقة المنتجة**
14	5	MWh	الطاقة المستهلكة
800	0	m³	إستهلاك الوقود الخفيف
0	967050	m³	إستهلاك الغاز الطبيعي
0	34	m. feet³	إستهلاك الغاز الطبيعي
24.00	24.00	h	ساعات التشغيل
34%	37%	الوحدة	% الكفاءة
44%		المركب	% الكفاءة

Table 5: Daily Report for Thursday, 16/02/2023

الشركة العامة للكهرباء
الإدارة العـــامة للإنتـــاج
محطة كهرباء الزاوية المزدوجة
التقرير اليومي

الخميس	التقرير اليومي ليوم
16/02/2023	الموافق

مركب 1			
GT12	GT11		البيان
تعمل	تعمل		حالة الوحدة
120	170	MW	المتاح
125	173	MW	أقصى حمل
61	126	MW	أدنى حمل
125	166	MW	حمل الذروة
2,389	0	MWh	الطاقةالمنتجة بالخفيف
0	3,700	MWh	الطاقة المنتجة بالغاز
*****		MWh	الطاقة المنتجة بدون وقود
2,389	**3,700**	**MWh**	**إجمالي الطاقة المنتجة**
13	6	MWh	الطاقة المستهلكة
820	0	m³	إستهلاك الوقود الخفيف
0	949200	m³	إستهلاك الغاز الطبيعي
0	34	m. feet³	إستهلاك الغاز الطبيعي
24.00	24.00	h	ساعات التشغيل
27%	35%	الوحدة	% الكفاءة
39%		المركب	% الكفاءة

Table 6: Daily Report for Thursday, 16/03/2023

الشركة العامة للكهرباء
الإدارة العـــــامة للإنتـــــــــاج
محطة كهرباء الزاوية المزدوجة
التقرير اليومي

الخميس	التقرير اليومي ليوم
16/03/2023	الموافق

مركب 1			البيان
GT12	GT11		
تعمل	تعمل		حالة الوحدة
120	170	MW	المتاح
123	164	MW	أقصى حمل
52	120	MW	أدنى حمل
56	163	MW	حمل الذروة
1,429	0	MWh	الطاقةالمنتجة بالخفيف
0	3,427	MWh	الطاقة المنتجة بالغاز
*****		MWh	الطاقة المنتجة بدون وقود
1,429	3,427	**MWh**	**إجمالي الطاقة المنتجة**
13	6	MWh	الطاقة المستهلكة
610	0	m³	إستهلاك الوقود الخفيف
0	870480	m³	إستهلاك الغاز الطبيعي
0	31	m. feet³	
24.00	24.00	h	ساعات التشغيل
22%	35%	الوحدة	الكفاءة %
39%		المركب	

Table 7: Daily Report for Sunday, 16/04/2023

الشركة العامة للكهرباء
الإدارة العـــــامة للإنتـــــــــاج
محطة كهرباء الزاوية المزدوجة
التقرير اليومي

الاحد	التقرير اليومي ليوم
16/04/2023	الموافق

مركب 1			البيان
GT12	GT11		
تعمل	تعمل		حالة الوحدة
122	165	MW	المتاح
123	169	MW	أقصى حمل
61	53	MW	أدنى حمل
122	167	MW	حمل الذروة
1,979	0	MWh	الطاقةالمنتجة بالخفيف
0	3,392	MWh	الطاقة المنتجة بالغاز
*****		MWh	الطاقة المنتجة بدون وقود
1,979	3,392	**MWh**	**إجمالي الطاقة المنتجة**
14	6	MWh	الطاقة المستهلكة
710	0	m³	إستهلاك الوقود الخفيف
0	883190	m³	إستهلاك الغاز الطبيعي
0	31	m. feet³	
24.00	24.00	h	ساعات التشغيل
26%	35%	الوحدة	الكفاءة %
31%		المركب	

Table 8: Daily Report for Tuesday, 16/05/2023

الشركة العامة للكهرباء
الإدارة العـــــامة للإنتـــــــــاج
محطة كهرباء الزاوية المزدوجة
التقرير اليومي

الثلاثاء	التقرير اليومي ليوم
16/05/2023	الموافق

مركب 1			البيان
GT12	GT11		
تعمل	تعمل		حالة الوحدة
125	165	MW	المتاح
120	61	MW	أقصى حمل
54	60	MW	أدنى حمل
120	60	MW	حمل الذروة
2,297	1,457	MWh	الطاقةالمنتجة بالخفيف
0	0	MWh	الطاقة المنتجة بالغاز
*****		MWh	الطاقة المنتجة بدون وقود
2,297	1,457	**MWh**	**إجمالي الطاقة المنتجة**
13	14	MWh	الطاقة المستهلكة
760	715	m³	إستهلاك الوقود الخفيف
0	0	m³	إستهلاك الغاز الطبيعي
0	0	m. feet³	
24.00	24.00	h	ساعات التشغيل
28%	19%	الوحدة	الكفاءة %
24%		المركب	

Table 9: Daily Report for Friday, 16/06/2023

الشركة العامة للكهرباء
الإدارة العـــــامة للإنتـــــــــاج
محطة كهرباء الزاوية المزدوجة
التقرير اليومي

الجمعة	التقرير اليومي ليوم
16/06/2023	الموافق

مركب 1			البيان
GT12	GT11		
تعمل	تعمل		حالة الوحدة
125	165	MW	المتاح
122	130	MW	أقصى حمل
105	104	MW	أدنى حمل
101	126	MW	حمل الذروة
2,519	0	MWh	الطاقةالمنتجة بالخفيف
0	2,786	MWh	الطاقة المنتجة بالغاز
*****		MWh	الطاقة المنتجة بدون وقود
2,519	2,786	**MWh**	**إجمالي الطاقة المنتجة**
14	6	MWh	الطاقة المستهلكة
840	0	m³	إستهلاك الوقود الخفيف
0	861376	m³	إستهلاك الغاز الطبيعي
0	30	m. feet³	
24.00	24.00	h	ساعات التشغيل
28%	29%	الوحدة	الكفاءة %
46%		المركب	

From the tables of the daily report (4, 5, 6, 7, 8, 9) for the operation of the gas turbine (GT12) in the power station, which recorded the efficiency data for the turbine (GT12) as in table (10).

Table 10: Shows the .recorded efficiency and total energy produced.

Date of unit (GT12) operation	Recorded efficiency of unit (GT12)	Total produced energy (GT12)
Monday - 16/1/2023	34 %	2868 MWh
Thursday - 16/2/2023	27 %	2389 MWh
Thursday - 16/3/2023	22 %	1427 MWh
Sunday - 16/4/2023	26 %	1979 MWh
Tuesday - 16/5/2023	28 %	2297 MWh
Friday - 16/5/2023	28 %	2519 MWh

From the data in Table (10) and using the arithmetic mean, we find that the average efficiency of turbine (GT12) is (27.5%).

Result 5: The operational efficiency value (27.5%) of the design efficiency (35%).

We find that:

Result 6: **35-27.5=7.5%**

By comparing result (4), in which the decrease in efficiency calculated using equation (1) was equal to (7.4%) and from result (6), we find that the decrease in the calculated efficiency using the operation section of the control section for turbine (GT12) which was (7.5%), from this we find that the two results are very close.

VI. Discussion of the Results.

After completing all calculations, the final results can be divided into two sections: theoretical results and practical results

1. Theoretical Results: The total theoretical calculations for the decrease in efficiency that were previously reached and included in table (11)

Table 11: Shows the efficiency data for each turbine (GT12) and power loss(MWh)

Turbine (GT12) Efficiency	Produced Power MWh	Loss in Produced Electrical Power MWh
Design Efficiency 35%	3960	0
Operational Efficiency in Winter 32.9%	3130	830
Operational Efficiency in Summer 22.3%	1330	2630
Average Annual Efficiency 27.7	3134	826

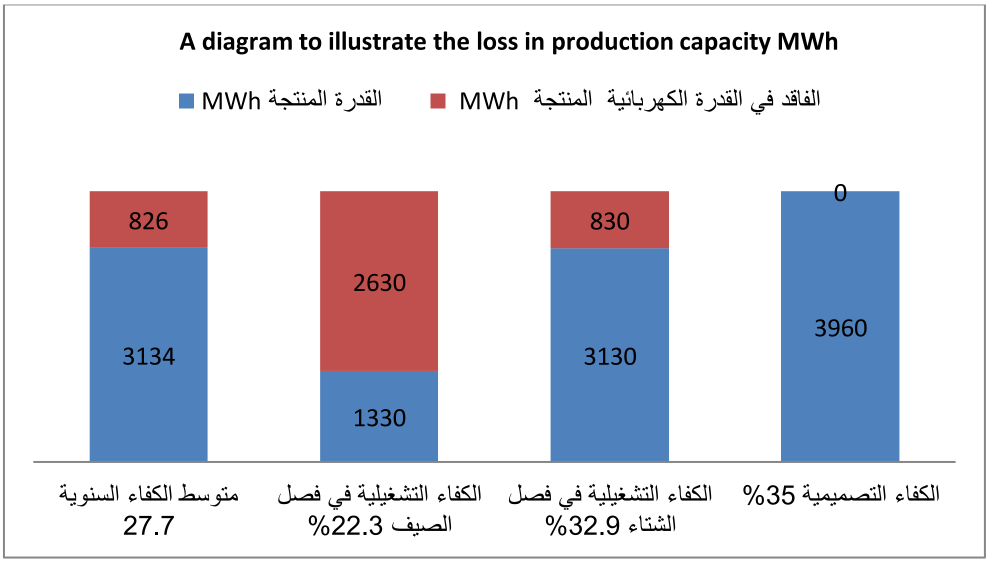


Figure 6: Shows the loss in efficiency for each operating hour for turbine (MWh)

All results obtained from the theoretical calculations that were compiled in Table (11) are represented in the graph illustrated in Figure (6), where Figure (14) shows the extent of the impact of the decrease in efficiency, as the average annual decrease in the electrical output per hour of operation reached (826 MWh).

the 2. Practical Results: The dual cycle of the power station was analyzed through the practical calculations that were conducted and from the daily report tables for the gas turbine (GT12) included in Tables (4, 5, 6, 7, 8, 9), which recorded the efficiency data for the (GT12) turbine. From the results that were compiled in Table (11) and illustrated in graphical representations, the relationship between the operational efficiency and the practical output of the (GT12) turbine is shown in Figure (6) which indicates the operational efficiency (35%) that produces an output of (MWh 3941) with the operational efficiency for a period of 6 months from January to June, which ranged between 22% to 34% as shown in Table (12).

Table 12: Shows the efficiency % with total produced energy and the energy loss in produced energy MWh

Recorded Unit Efficiency (GT12) **From Jan to Jun/2023**	**Total Produced Energy (GT12)** **From Jan to Jun/2023**	**Loss in Production Energy MWh** **From Jan to Jun/2023**
35% Design Efficiency for the whole year	3941 MWh	0
34 %	2868 MWh	1073
27 %	2389 MWh	1552
22 %	1427 MWh	2512
26 %	1979 MWh	1962
28 %	2297 MWh	1644
28 %	2519 MWh	1422

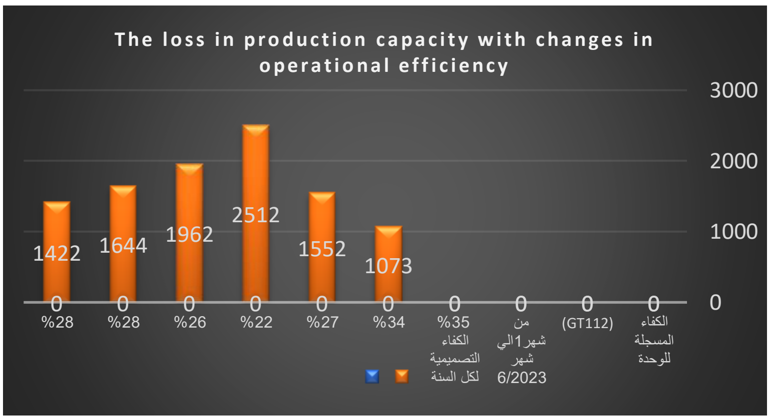


Figure 7: Shows the efficiency % with total energy produced and the energy loss in produced energy MWh

Table (12) illustrating the difference in the energy produced per hour with the change in the operational efficiency of the turbine. The amount of change and decrease in the energy produced per hour with the change in the operational efficiency of the (GT112) turbine, which ranged between 34% to 22%, resulted in a decrease of 12%, leading to a reduction in the energy produced by (2512) MWh for each hour of operation from the productive value of the efficiency, which is equal to 35%.

Table 13: Shows the difference in energy produced per hour with the change in operational efficiency of the turbine

Recorded Unit Efficiency (GT12) From Jan to Jun/2023		Total Produced Energy (GT12) From Jan to Jun/2023
January	34 %	3941 MWh
February	27 %	2868 MWh
March	22 %	2389 MWh
April	26 %	1427 MWh
May	28 %	1979 MWh
June	28 %	2297 MWh
Average Efficiency %27.5		2154 MWh Average Production Capacity

The average productivity in **Figure (8)** below can show the clear change in the columns which represent the energy produced with the change in the productivity efficiency of the turbine (GT112).

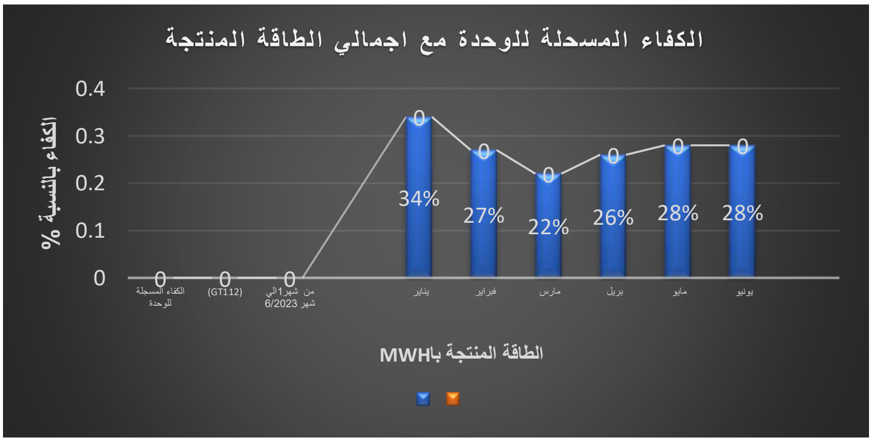


Figure 8: Shows the energy produced with the change in the productivity efficiency of the unit (GT112)

Table (14) shows the relationship between the change in efficiency for the unit GT12 and the electrical energy consumed by the unit during operation, as well as the amount of light fuel consumed during the operation of the unit in cubic meters.

Table 14: Shows the amount of energy consumed by the unit and the fuel consumed with the change in unit efficiency for the unit.

Recorded Unit Efficiency (GT12) From Jan to Jun/2023	Total Energy Consumed by Unit (GT12) MWh From Jan to Jun/2023	Light Fuel Consumption in Cubic Meters From Jan to Jun/2023
34%	14 MWh	800 M^3
27 %	13 MWh	820 M^3
22 %	13 MWh	610 M^3
26 %	14 MWh	710 M^3
28 %	13 MWh	760 M^3
28 %	14 MWh	840 M^3

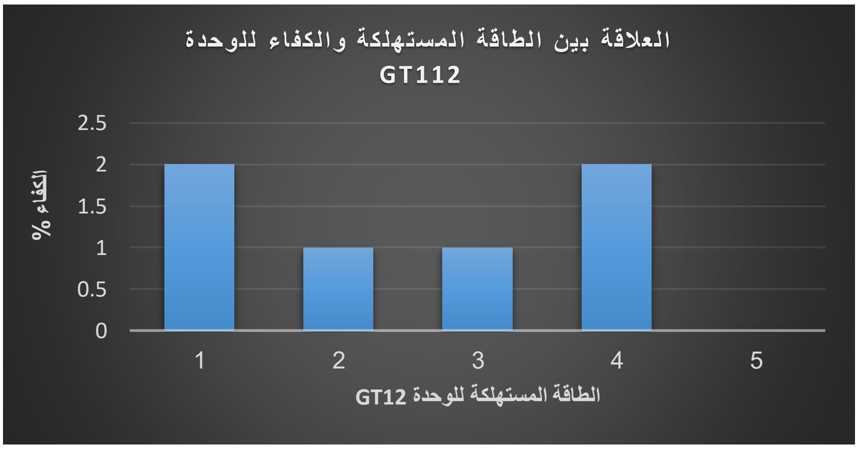


Figure 9: Shows the relationship between the energy consumed by the unit and the efficiency of unit GT112

Figure 9 illustrates the relationship between the electrical energy consumption of the unit during operation and the efficiency, as well as with the amount of light fuel consumed by the unit (GT12) during operation. From the analysis of the chart (9) and also table (14), it is shown that there is no clear relationship between the change in efficiency % and the fuel in cubic meters consumed, and the energy consumed by the unit MWh.

From the analysis and discussion of the theoretical results using equation (1) used in calculating the efficiency of the dual-fuel generation at the electricity station, and after substituting in the equation with the data found in table (2) which was recorded in winter, the efficiency value was 9.32% as shown in result (1). By applying the same equation with the data found in table (3) which was recorded in summer, the efficiency value was 22.3% according to result (2).

From result (1), the decrease in efficiency was by 2.1 %, and in result (2) the amount of decrease in efficiency was 12.7% from the design value of 35%. In result (3), the average decrease in efficiency was 7.4%. According to result (4), the average efficiency throughout the year was equal to 27.7%. This decrease in efficiency leads to a decrease in the productivity of the unit GT12 from MWh 165 to 127MWh.

The amount of decrease during the operation of the unit for 24 hours will be 912 MWh. If we apply this result for the deficiency in efficiency on the six units of the dual-fuel electricity generation station, the result of the efficiency loss would be 5472 MWh for every 24 hours of operation. The average efficiency over the six months was 27.5, and the average total productivity amount equals 2154 MWh, meaning that the amount of deficiency and decrease in efficiency led to a decrease in productivity by 1806 MWh during 24 hours of operation. If we apply this result for the deficiency in efficiency on the six dual-fuel units for electricity generation, the result of the loss in efficiency for the station would be 10837MWh for every 24 hours of operation.

Using the arithmetic average of the theoretical result and the practical result :

$$5472+10837=16309 \text{ MWh}$$

$$16309 \div 2= 8104.5 \text{ MWh}$$

This loss is very significant for each working day of the dual-fuel electricity generation station, and we will summarize a set of reasons for this deficiency and loss in productivity in the conclusion.

It is also noted that the operational efficiency of the gas unit (GT12) indicates that the results of this dual-fuel station witnessed a significant decrease compared to the design efficiency of 35%. The average operational efficiency during the period was 27.6% with a decrease rate of 7.4%.

The productivity has decreased, as this decline has negatively reflected on the capacity from (165 MWh) to (127 MWh) per unit, causing a deficit of (912 MWh). From the six turbines operating at the station, it is clear that the loss, when measured against the total productivity, reaches more than 8100 MWh daily, which is a significant amount affecting the stability of the electrical network in Libya.

The reasons for the annual delays in maintenance schedules and the failure to complete maintenance work are primarily due to the absence of commitment to the periodic maintenance, in addition to the lack of original spare parts, as well as external factors related to the network such as frequency fluctuations and difficulties in connection. The results showed that the fuel used represents a significant factor in efficiency, where operating with natural gas achieves higher efficiency compared to liquid fuel with a difference of up to (4.5%).

VII. Recommendations

Based on the above, the study confirms the necessity of adopting effective strategies for preventive maintenance and building a system that ensures periodic commitments, in addition to improving the operational efficiency and enhancing the stability of the national electricity system.

According to these calculations, which proved that the rate of decline in efficiency negatively affects the productivity of the gas turbines, we recommend the necessity of addressing the causes of the decline in efficiency, the most important of which are:

1. Implementing protection tests for the periodic systems and pumps and conducting the necessary tests.
2. Ensuring the availability of appropriate spare parts for the periodic maintenance of the station according to the plan.
3. Implementing training programs for engineers and technicians at the station on maintenance and operation processes.
4. Supporting the control and operation department with advanced equipment to manage and control the variables in the public network that affect the operation and efficiency of the station.

Also, based on the results of this research, which indicate that the type of fuel used in operating the gas turbines has an impact on increasing the produced capacity and efficiency for the unit that exceeds the efficiency of liquid fuel, we recommend operating the turbines with gas fuel.

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