Chapter

Assessment of Power Plants in the Western Region of Libya during a Period of Insecurity

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Abstract

After the uprising in Libya in 2011, several outages and blackouts occurred in the electrical grid. The western region of Libya is the most affected part especially after the civil war in Tripoli 2014. This chapter focus on the assessment of energy production by Al-Zawia Combined Cycle Power Plant "Al-Zawia CCPP" and Western Mountain Power Plant during the period of blackouts and insecurity. In addition, to figure out the main causes of the frequent blackouts and outages in order to find practical solutions to ease the severity of the problem. This research is done based on the data are collected from the recorded data in Al-Zawia CCPP and Western Mountain power plant during the last two years 2019–2020. The data shows the instability of the annual energy produced from Al- Zawiya PPCC and Western Mountain Power Plant in 2019, also illustrates the improvement in the total produced energy by the six gas units of the Western Mountain power plant after the end of the war on Tripoli in 2020. However, the data shows the deficiency of the Western Mountain power plant to operate at its full capacity, especially in August 2020 due to the lack of maintenance.

Keywords: Assessment, blackout, Western Mountain power plant, Al-Zawia CCPP, outages, western region of Libya

1. Introduction

Power plants, transformers, transmission lines, and distribution stations are the main parts of the power system network [1]. Failure in any part of those could lead to blackout or outages. The European Network of Transmission System Operators expresses the blackout as "the interruption of electricity generation, transmission, distribution, and consumption processes, when operation of transmission system or a part is terminated" [2, 3]. In the last decade, the Libyan power grid faced numerous blackouts and outages and the consequences of these blackouts and outages were costly [4]. Therefore, more studies have to be done to reduce the effect of these problems. Some reasons for the continuous interruptions and load shedding are; the armed conflicts, postpone of overhaul units of the power plants. In this chapter, field study on the causes of power outages and blackout in Western Mountain power plant & Al-Zawia CCPP is presented. As well as, an assessment of the generation power units in both power plants during the period of the outages and blackouts 2019–2020. In order to suggest practical solutions.

1.1 Research questions

- What are the main reasons of the current outages?
- Does the GECOL,“ the General Electricity Company of Libya power system” able to solve these problems?
- Is there an improvement in the energy supply to the consumers in 2021 or will it be worse?
- Is there a possibility for the electricity company to invest in alternative energies such as the solar and wind energy to cover the deficit in energy production?
- Is there a possibility to reconnect the network with the countries of the Maghreb Arabic and the European Union, or are there technical reasons that prevent this?
- to what extent it is possible to address these issues or find effective solutions to them to alleviate the suffering of the citizen in the difficult conditions of the country?

1.2 Relevance and important of research

The idea of the research is to investigate the real causes of the blackouts and frequent outages in energy supply to consumers in Western region of Libyan power system grid. It is possible to achieve this goal by analyzing the performance of the power plants in Western region of Libya. Which are Alzawia Combined Cycle Power Plant“ Alzawia CCPP” with a total installed capacity of 1440 MW and Western Mountain power plant with a total installed capacity of 600 MW [4]. These power plants represent more than a quarter of the energy produced in Libya. Therefore, focusing the study on these stations may help find suitable solutions for the electric company.

1.3 Literature review

The major industrial continents of North America, Europe, Asia, and Australia have faced the same causes of blackouts since 1965 [1]. In September 2003, due to cascade tripping in the transmission line (380 kV 220) linking Italy and northern Europe, which resulted in the largest blackout that Italy has witnessed, affecting more than 55 million people [2]. In 2010, there were many blackouts in the supply of electrical energy to consumers, which caused millions of customers to lose energy for long hours. September 2011, due to a blackout in the southwestern ocean, which led to a loss of energy for more than 12 hours, and about 2.7 million people have affected in some southwestern states in North America, such as residents of San Diego, California, Arizona, and Mexico. The main reason for the occurrence of blackout is an increase in the load during the peak period on a major transmission line, which caused the collapse of the electrical network system [3]. In 2019, there was a study on the performance of the Zawia CCPP during the blackouts and normal operation conditions [4]. Therefore, when a blackout or power outage takes place, the consequences can be costly. It can cause the loss of life of intensive care patients and children where childbirth needs a nursery, in addition to financial and industrial losses. There are several reasons that lead to blackout and power outages in power system grid such as; faults in transmission lines, increase of load demand, failure in protection system, poor maintenance of the equipment, human error, over frequency, cyber-attacks, voltage fluctuation, a short circuit, lighting strike, severe weather, and ice storms [3, 5].

2. Causes of outages and blackouts in Libya

Since the 2011 uprising, the Libyan power grid has suffered from several operating and infrastructure problems. Most of the maintenance projects have stopped due to security and political problems of the country. Among the most prominent of these problems are; the repeated attacks on GECOL's assets and on workers, stealing of electrical equipment such as copper wires, transformers, and electrical transmission towers. Which caused the GECOL to be unable to perform some of the necessary periodic maintenance for most of the power plants. These problems resulted in a decline in the performance of the electricity network and a severe deficiency in the production capacity of the generating stations, long outages, and blackouts in most areas in the country [6].

2.1 A brief overview of power plants in Libya

The GECOL owns about 26 electric power plants. These power plants contain 85 generating units of different ages, sizes, and operating technology. These units are mostly concentrated on the sea in the North [6]. The official installed capacity by the GECOL until 2017 is 10.238 GW, while the energy available to consumers only 5.53 GW until the date of this study, which represents 52% of the total capacity of the GECOL. Besides, 19 units of the GECOL units are must be discontinued due to the end of their useful life and the futility of their continued operation [6]. In short that, there is a deficit in the power production of the GECOL at a rate of approximately 25% of the average production, compared to the maximum value of the energy demand, which is 7.5 GW [7].

2.2 Overview of control department in GECOL

The control infrastructure in the GECOL consists of several levels. At the top of the system, is the National Control Center (NCC), as shown in **Figure 1**. Its mission

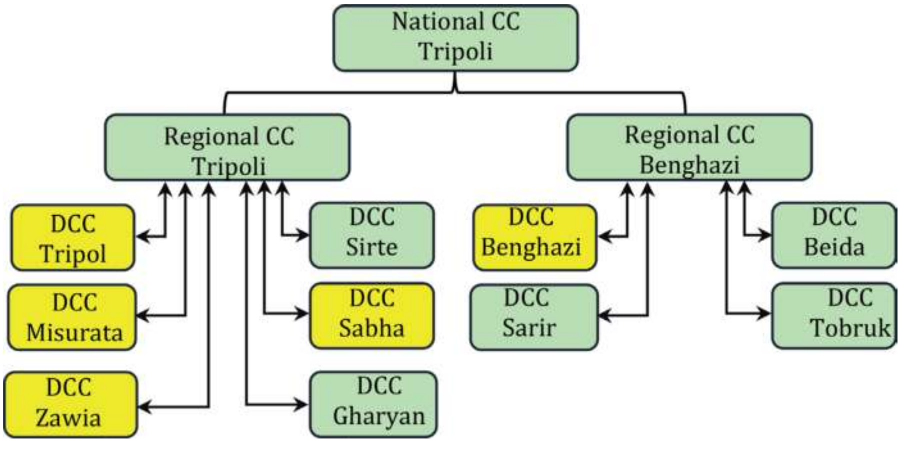

Figure 1.
Distribution control system of GECOL precedence DCC's in yellow [6].

is to supervise, coordinate and control the power plants. The main transmission network is 400 KV, whereas 220 KV is the subnet that linking between Egypt in the east and Tunisia in the west [6].

Libya's control system is divided into two parts: the Tripoli Regional Control Center (TRCC) in the Western part and the Benghazi Regional Control Center (BRCC) in the East, both parts responsible for controlling and operating the substation 220 kV. In addition, the Distribution Control Center is responsible for the medium and low voltage network lines of 66 kV, 30 kV and 11 kV. Whereas NCC, TRCC and BRCC are supervised by the General Control Department. The Distribution Control Center (DCC) is under the control of the General Distribution department and the Medium Voltage General Department. These control centers are linked to the generation stations and substations and are controlled by a fiber optic system. This system consists of ground cables, Optic Ground Wires (OPGW) transmission towers, and some old power carriers and microwave connections [6].

After the uprising in 2011, the transmission lines were mostly damaged due to the civil war, which results in losing communication links one by one and a huge loss in each fiber optic-based data and voice communications links between the power plants and network substation.

The mentioned problems in the communication links and some Remote Terminal Units (RTUs) in the stations, led to a loss of 80% of the data compared to the year 2011, where there is only a 2% loss. The NCC and TRCC computer system only controls 20% of the data that covers main points in the network, which provides a partial picture to the control engineers [6]. Some lost data is covered by Supervisory Control and Data Acquisition (SCADA) and the rest of the data is manually entered to give a fair picture of the network. Consequence, NCC is completely dependent on the operators in all stations and on voice communications linked with the operators to effectively control the network [6].

Through investigations and studies for the GECOL Control General Department, it was established that the four causes of the blackouts in 2017 were for the following reasons; firstly, the interruption of some transmission lines has shaking the operative reliability of the electrical power grid. Secondly, outages in some transmission lines, which weakened the operational capacity of GECOL power system. Thirdly, all blackouts were due to in faults in the transmission network and as a result the loss of some generation units. Fourth, the southern region suffers from voltage instability, which caused the network frequency to rise, followed by a transmission failure, following the initial transmission fault clearance. Finally, the recorded data of frequency and voltage response after the fault is removed, indicates the possibility of a "Fault-induced delayed voltage recovery" (FIDVR), causing an increase in frequency and loss of generation. This phenomenon has been observed to occur in the electrical power grid with large loads of inductive motors, specifically the loads of air conditioners. The Libyan electrical power grid is full and saturated with air conditioner loads, which is easy to assure that at the end of the summer and with temperate temperatures, particularly in a two-week period of September 2017, peak loads decreased by 2 GW because consumers did not need to use their air conditioners. So there is no sure solution to this problem, which requires more research and studies to solve the problem and avoid the consequences resulting from it [6].

3. The construction of Al-Zawia combined cycle power plant and its connection with the power system grid

Al-Zawia CCPP contains of three steam turbines and 6 gas turbines, beside two auxiliary motor turbines. The six gas turbines are known as (GT11, GT12, GT13, GT14, GT15 and GT16), whereas, the steam turbines are called (ST10, ST20 and ST30). The auxiliary motor turbines named (TM05 & TM10). The nine units of steam and gas are divided to three compounds, each compound contains two gas turbines coupled with steam turbine [4].

Al-Zawia CCPP is connected to the general power system grid through eight electric circuits to transfer the produced energy. There are two main transmission lines 400 KV and the rest are 220 KV. Four transmission lines are linked to Western Tripoli power plant. The 400 KV transmission lines need to reduce the transferred energy to 220 KV using step-down transformer 400KV/220 KV, and the other two 220 KV transmission lines are linked directly to the Bus-Western Tripoli 1 &2 respectively. The fifth and sixth transmission lines 220 KV are connected to Al-Harsha substation through Bus Al-Harsha 1 &2. The last two transmission lines 220 KV are joined with Zahra Gas Turbine power plant.

From **Figure 2**. it can be noticed that the annual energy produced from Al-Zawiya PPCC for the year 2019 is fluctuating and not constant in all months of the year. The best performance for Al- Zawiya PPCC was in the winter season, specifically in January, where it reached 884274 MWh, then it declined by 19.30% In February, where it reached 731551 MWh. August 2019 was the most difficult period of the year for the power plant in a matter of production. Due to the increased energy demand, in the summer season, with the rise of temperatures, the power plant production decreases as well as its efficiency by 55.3% compared to January. Only 394,491 MWh were produced by the power plant during this month which means a very sharp drop in the power plant's production, which is expressed by the plant's inability to produce steadily and continuously. One of the main reasons that led to deficiency production of power plant in August, the worst at all, is the frequent blackouts. There were eight blackouts during this month, in particular, from 02 to 08 to 12–08-201. 4th -August was the worst day ever, where three blackouts took place within a 24-hour. In the following figures (**Figures 3**–**5**), there are more details on the power plant's performance in some of these days [8].

The daily report of Al-Zawia CCPP shows the status of the nine units on the day of blackout, as following; the GT11 and GT12 were tripped at 10:17 on 02/08/2019 due to a shake in the grid. The GT11, GT13, and GT12 were restored at 12:51, 13:16, and 14:05 consequently. The GT13 tripped at 14:07 due to a shake in the grid and it was restored at 14:29, then, it tripped again at 15:39 for the same previous reasons. The GT12 tripped again at 15:39 due to a shake in the grid. The

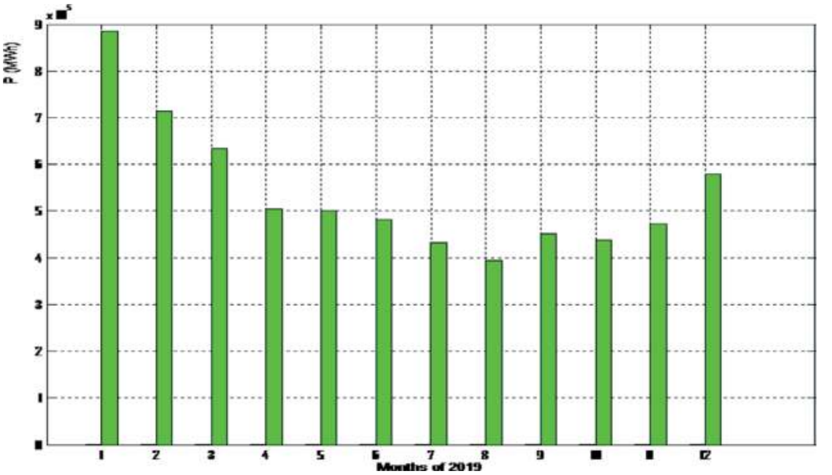

Figure 2.
The total produced energy by Al-Zawia CCPP in 2019.

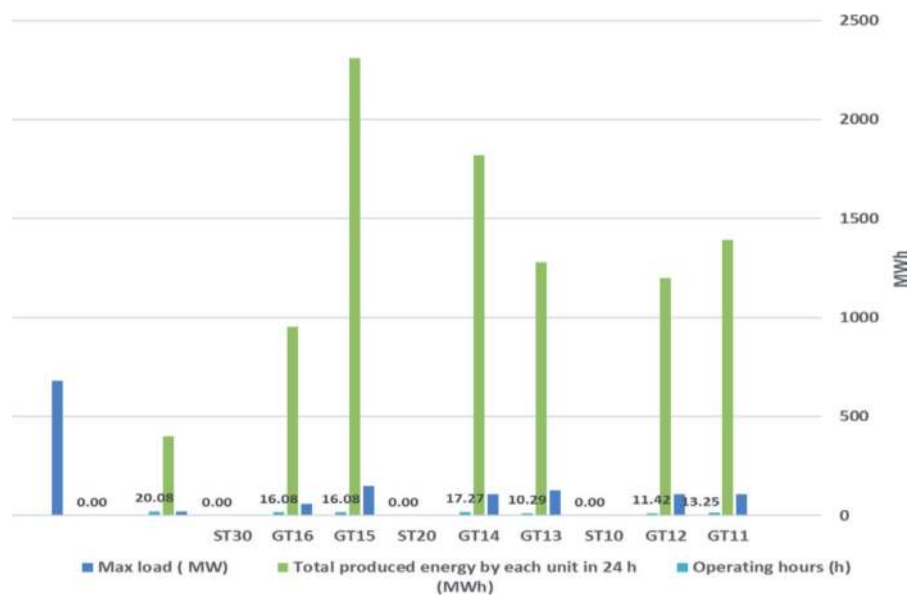

Figure 3.
The produced energy by Al-Zawia CCPP on 02-08-2019.

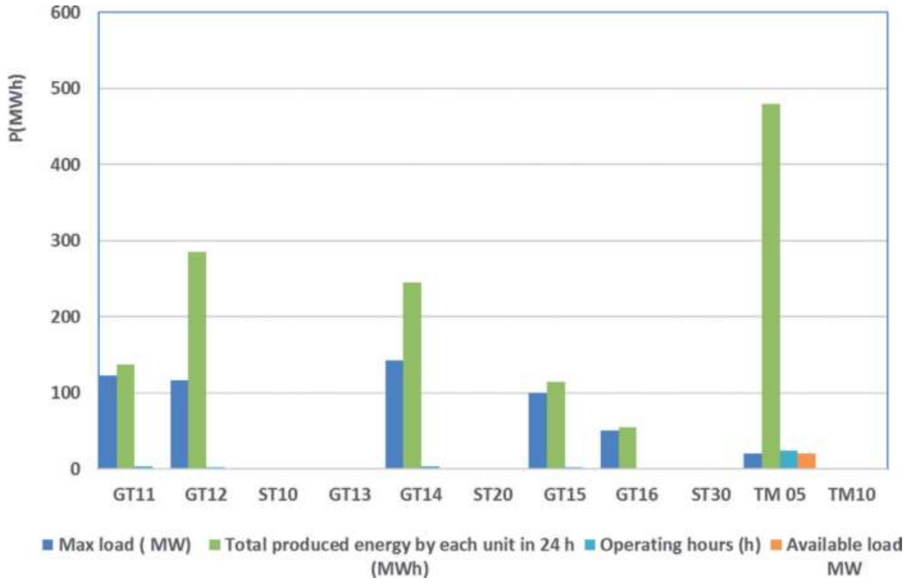

Figure 4.
The statu of the nine units on the day of blackout 03-08-2019.

GT11, GT15, and GT16 tripped because of a shake in the grid, which let to blackout at 16:52. TM 05 and the GT14 were restored at 21:00, 21:59 respectively. Once again, a complete Blackout At 22:34, and TM 05 stayed disconnected.

As result of the repeated blackouts, it can be shown in **Figures 3–6** the sharp decline of the daily produced energy by the six gas units, and not to mention that the three steam units were all out of service.

On the day after 03-08-2019, the scenario of the blackout continued until, the gas units were started up one by one as following; GT14 at 18:12, GT15 at 18: 18, GT11 at 18:35, GT16 at 18:56, and GT12 at 19:38. On the day after 03-08-2019, the scenario of the blackout continued until, the gas units were started up one by one as following; GT14 at 18:12, GT15 at 18: 18, GT11

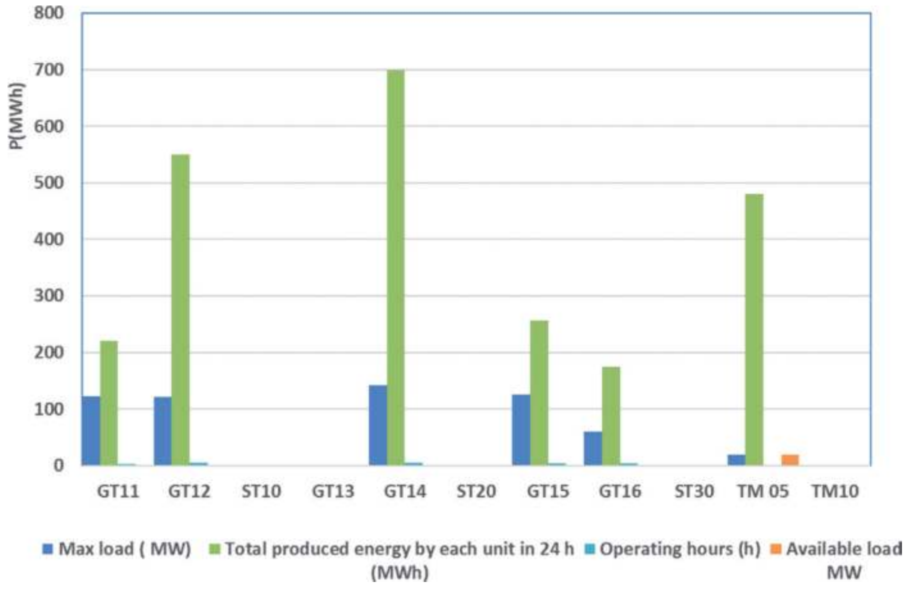

Figure 5.
The produced energy by the units of Al-Zawia CCPP on of the day of the blackout 4-8-2019.

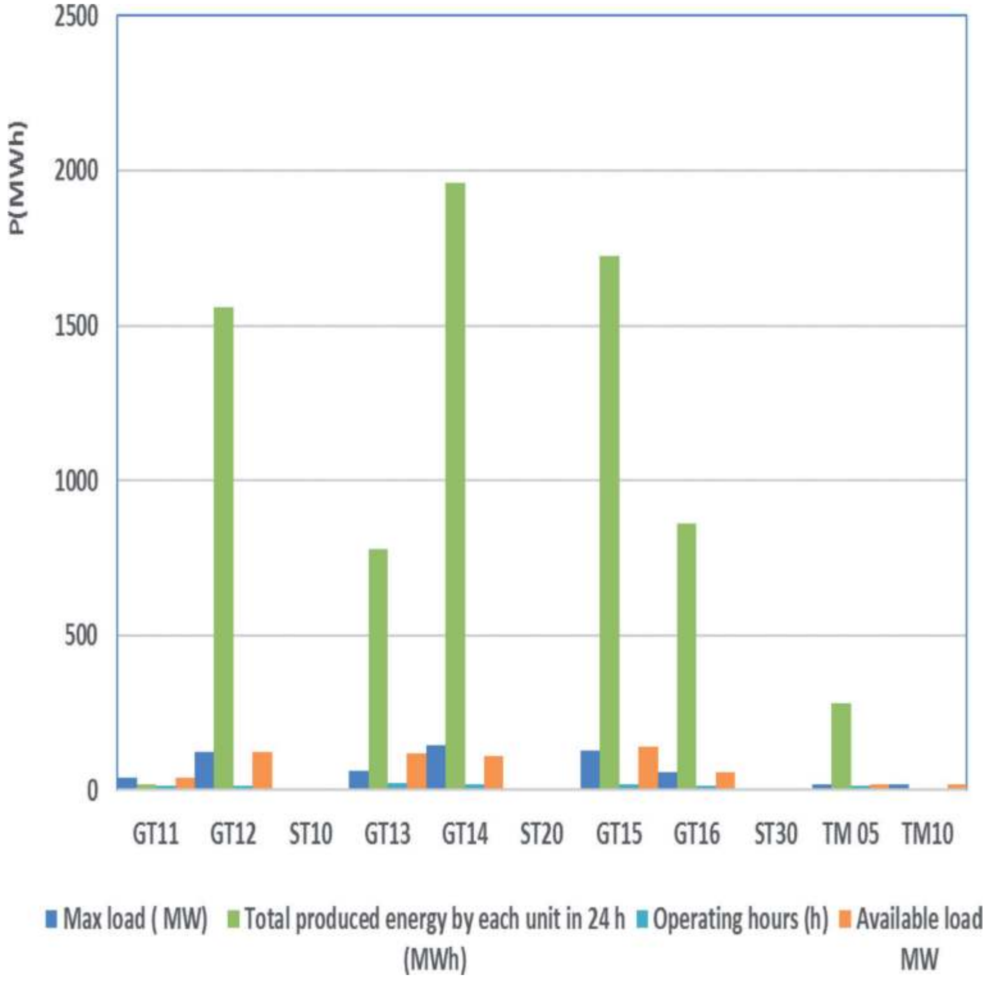

Figure 6.
The performance of gas units of Al-Zawia CCPP on one day of the blackouts 07-08-2019.

at 18:35, GT16 at 18:56, and GT12 at 19:38. At the same day, at 20:20 another blackout was occurred. The gas units were started up in order GT12 22:08, GT11 at 22:43, GT14 at 23:04, GT15 23:59 and GT16 00:17. In the third day in row,

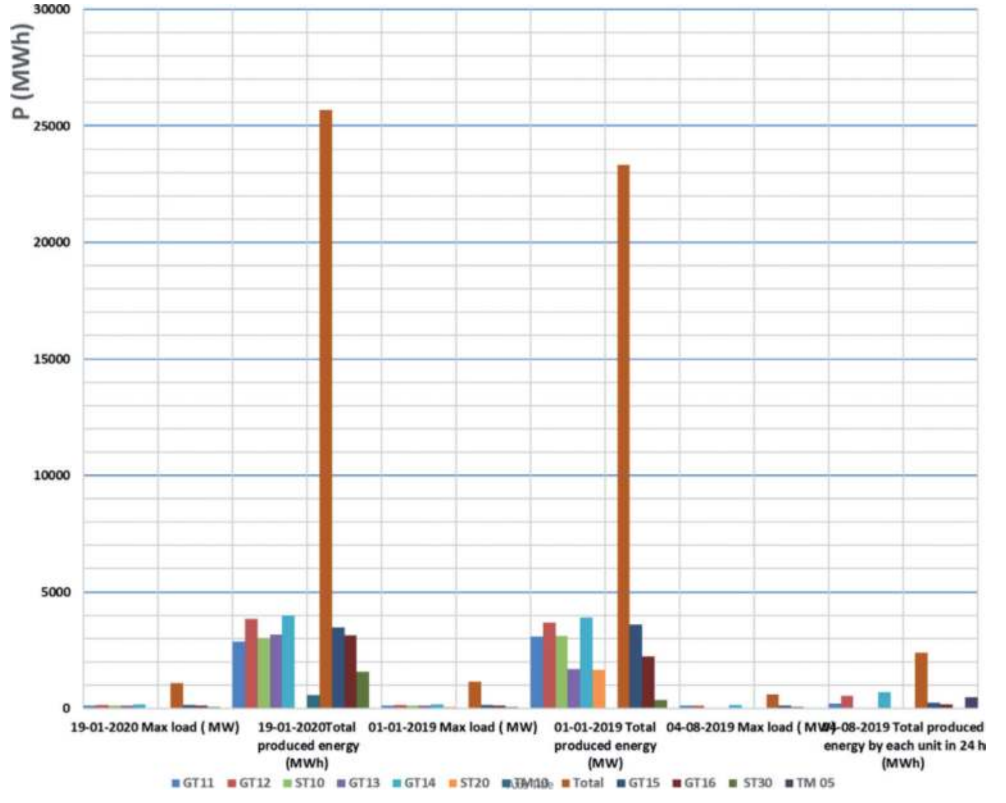

Figure 7.
Comparative of the total produced energy on normal operation day and on the days of the blackouts.

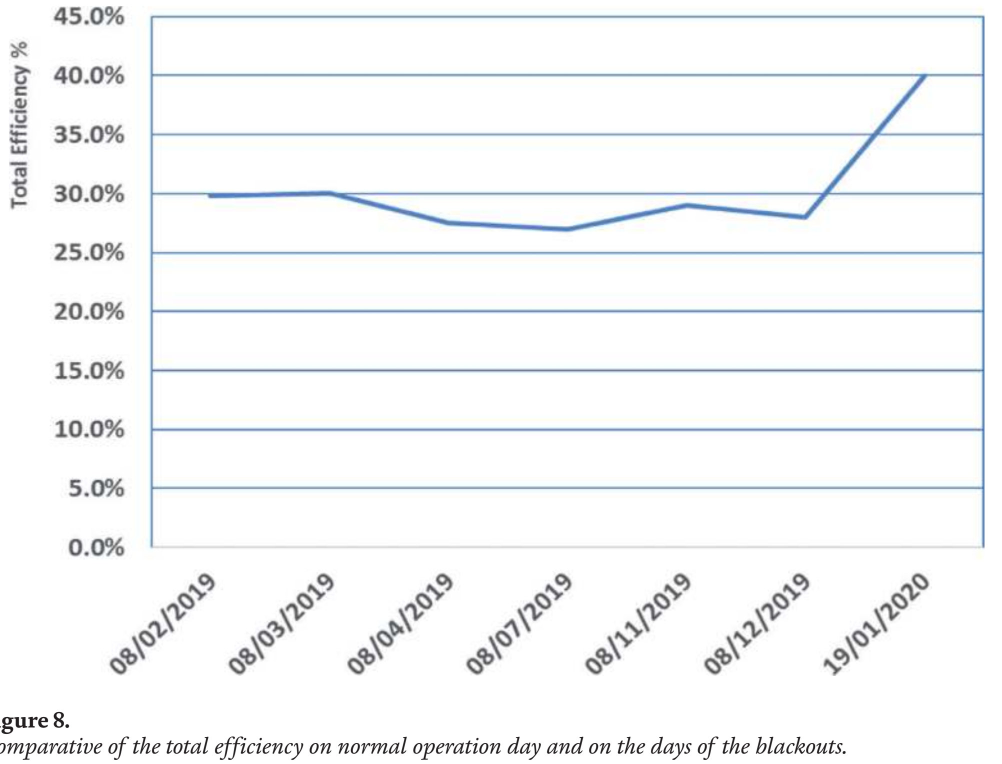

Figure 8.
Comparative of the total efficiency on normal operation day and on the days of the blackouts.

on 04-08-2019 at 02:32 all gas units were shut down again which means blackout again.

After a long exhausting night of continuous and tedious work from the plant's engineers and operators to restore the units to the network, they succeeded to restore four out of six respectively, GT14 at 11:45, GT12 at 12:10, GT15 at 12:30 and GT16 at 12:50 on 04-08-2019. After 1.16 h, the restored units went blackout again. In the evening, the four gas units were successfully restored within 1.10 h, as following, GT12 at 20:45, GT14 at 20:55, the GT16 at 21:30, and GT15 at 21:55″. Within 24 hours, the third blackout occurred at 22:28. On 05-08-2019, On 05-08-2019, the swinging four units were restored and connected to the power system grid again in order, the GT16 at 01:05, GT14 at 01:15, GT15 at 1:37, and GT12 at 03:40. In the morning at 09:07, a blackout took place again.

On 07-08-2019 at 13:56 another blackout occurred. 03:31 hours later, four gas units were restored in sequence GT14 at 17:25, GT15 at 19:08, GT16 at 17:34, and GT11 at18:06.

From next **Figures 7** and **8** it can be noticed the following; the increase of the daily total produced energy by Al-Zawia CCPP at the beginning of the year 2020 compared to the year before. The sharp decrease in operating efficiency in the days of blackouts compared to the normal operation days.

4. Western Mountain power plant

Western Mountain Power Plant (Ruwais) is located southwest of the capital Tripoli, with an estimated distance of about 250 km. It depends on natural gas to produce electricity as the main fuel, and on diesel as fuel in case of emergency. It consists of four units as a basic project and two units as an expansion project, meaning the total is six units, each unit produces 156 MW, which means 936 MW total. There is a Central Control Room (CCR) through which all units can be controlled, and each unit can also be controlled through Power Control Center (PCC) sub-controller.

For the connection with GECOL power system, there are six units (GT11, GT12, GT13, GT14, GT15 and GT16). The first four units GT1- GT4 are connected to transmission lines 220 KV through step-up transformers. There are five transmission lines 220 KV, the first and second lines are connected to Shakshuk substation and known as "Shakshuk1 and Shakshuk2". The third and fourth lines are linked to Al-Rabeta, Zahra substations respectively, and the last line is connected to Tataouine – Tunisia photovoltaic 10 MW. The fifth and sixth units (GT5, GT6) are connected to a 400 kV high voltage line via step-up transformer and linked with Ghadames substation.

Figure 9 shows the total produced energy from natural gas by the six units of the Western Mountain power plant, the consumed energy from natural gas, and the total available loads in 2019. It can be seen the variation of the six units in the amount of annual production energy. It can be noticed that the sixth and second units are considered the best in terms of performance. They produced 945001.25 MW and 861 103.80 MW respectively. While the fourth and first units are the worst in terms of the amount of electrical energy production, the reasons behind are; the units exceeded the equivalent operating hours for overhaul and that the last one for GT14 was on 5 July 2016, as well as, the number of scheduled stopping hours were 2288.23 hours as shown in **Table 1**. As for the first unit GT11, the last overhaul was on 23 November 2015, and the hours of sudden stop were 2990.6 hours, which explains the reason for the low amount of energy production compared to other units [9].

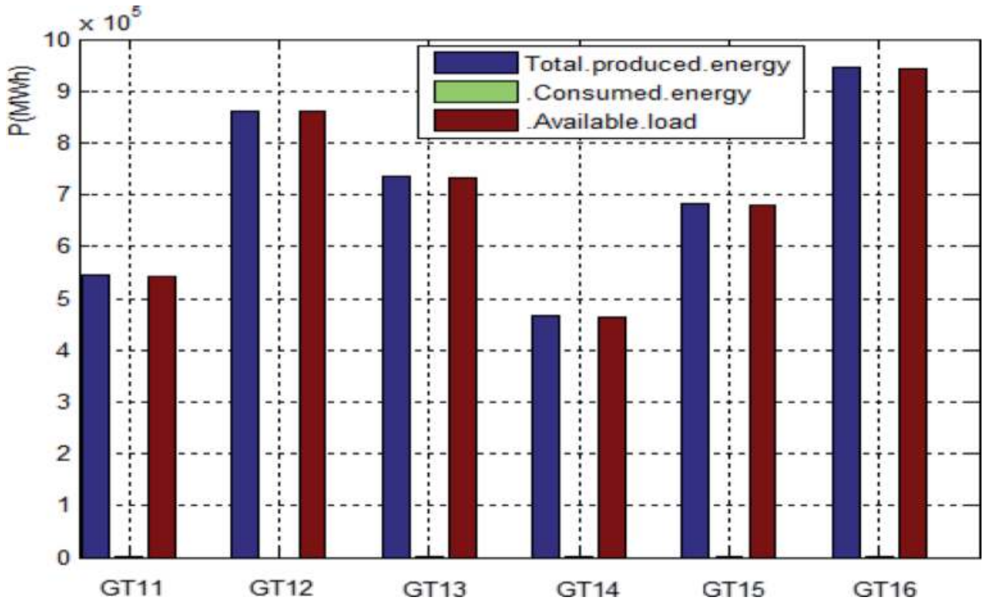

Figure 9.
The total produced energy by the six units of the Western Mountain power plant in 2019.

Data	GT11	GT12	GT13	GT14	GT15	GT16
Number of actual operating hours (h)	5598.02	8399.9	8282.71	6447.01	8164.76	8094.43
The number of equivalent operating hours (h)	6524.64	30156.76	9046.76	195511.86	9080.38	9080.8
The number of scheduled stoppage hours	171.37	226.48	415.01	2288.23	475.3	571.99
The number of hours of forced stoppage	0	0	0	0	0	0
The number of hours sudden stoppage	2990.6	133.61	62.28	24.76	120.03	93.58
The number of run times	16	25	15	17	19	11

Table 1.
Annual report on the number of operating hours of the Western Mountain power plant in 2019.

Figure 10 shows the total energy produced from the six units of the Western Mountain power plant for the year 2020. There is a significant increase for production of the GT11 compared to the year 2019, which reached 35% from its production. The same applies to GT14 and GT15 whose performance improves by 21.5% and 20.01%, respectively. There is a slight decrease in the production quantity of the GT16. The rise of energy production by GT11 goes to the increase of the number of actual operating hours from 5598.02 in 2019 to 8394.45 in 2020, as well as the decrease in the number of scheduled stoppage hours from 171.1 in 2019 to 67.11 in 2020, as shown in **Tables 1** and **2**.

Figure 11 shows the significant improvement in the performance of the Western Mountain power plant through the increase in energy production and the amount of

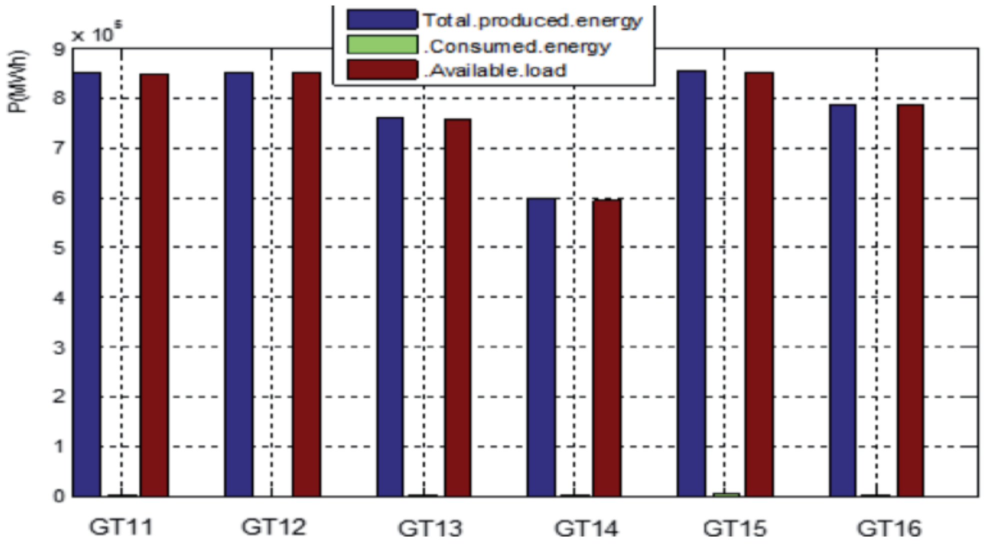

Figure 10.
The total produced energy by the six units of the Western Mountain power plant in 2020.

Data	GT11	GT12	GT13	GT14	GT15	GT16
Number of actual operating hours (h)	8394.45	8602.6	8541.78	8464.1	8474.25	6208.71
The number of equivalent operating hours (h)	12082.2	12336.03	11443.46	9364.01	9957.83	8205.9
The number of scheduled stoppage hours	67.11	209.84	103.24	210.39	225.77	473.83
The number of hours of forced stoppage	0	0	0	0	0	0
The number of hours sudden stoppage	322.44	69.69	139.02	109.51	83.98	2100.9
The number of run times	35	44	32	23	26	24

Table 2.
Annual report on the number of operating hours of the Western Mountain power plant in 2020.

energy sent to consumers in 2020 compared to the year before. This improvement has achieved because of; in the first quarter of 2020, the civil war stopped in the capital, Tripoli, where the National Control Center Tripoli of GECOL, some main transmission lines, substations, and Tripoli South Power plant are on the armed conflict area "south of Tripoli". This puts this equipment under the risk of destruction, damage, and cutting off some main transmission lines. As result, these risks effect on the stability of the power system grid and cause of frequent outages and blackouts.

Due to the high temperatures in summer season, specifically in August, which causes an increase of electricity demand by customers. Those conditions, put the power plants under the pressure to cover the increase of energy demand. This month was chosen to study the performance of the six units of the Western Mountain power plant under these conditions. **Figures 12–17** show the performance of the six units GT11, GT12, GT13, GT14, GT15 and TG16 in terms of maximum, minimum and average loads.

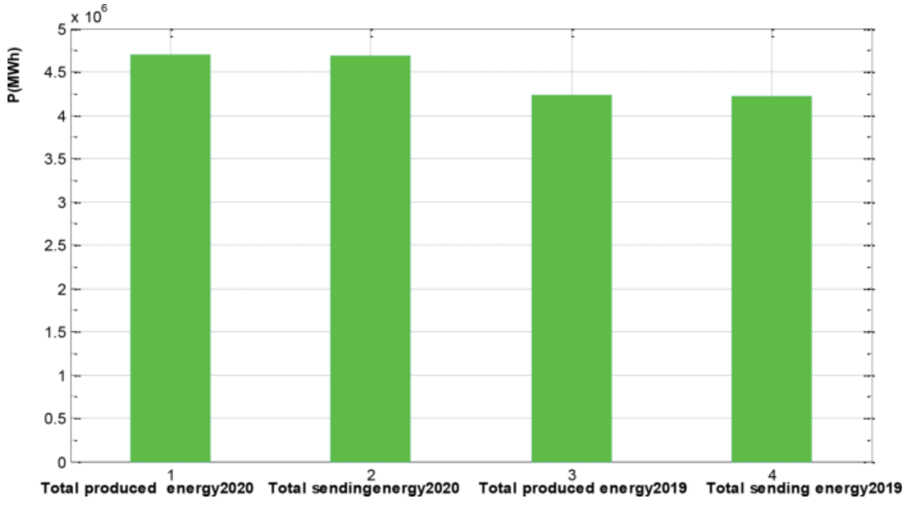

Figure 11.
Comparative of Western Mountain power plant production between 2019 & 2020.

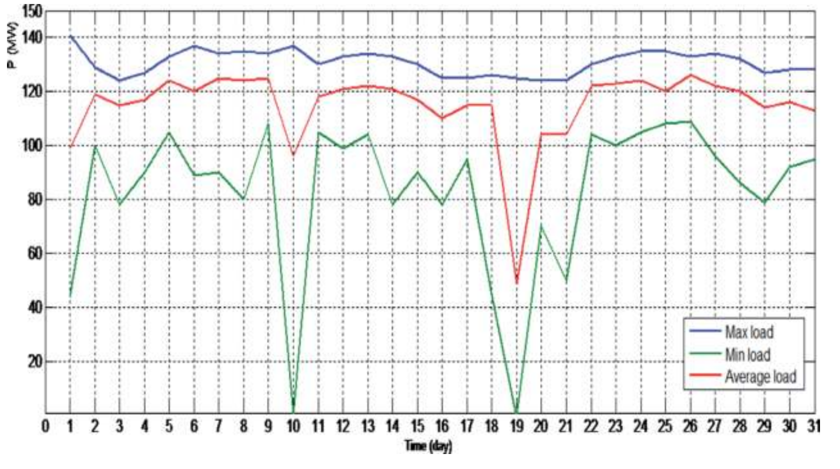

Figure 12.
The performance of GT11 in Aug-2020.

From **Figure 12**, it can be seen that the minimum loads in GT11 decreased sharply twice in August, the first one was on 10-Aug-2020 due to over frequency as reported on the recorded data, which led to the trip of GT11 0.5 h. The second sharp decline was on 19-Aug-2020 for the same reason and caused an outage of 1.9 h.

The minimum loads of GT12 decline suddenly to zero four times as shown in **Figure 13**. Which means four outages, the first sudden decline was on 03-August −2020 because of a trip of GT12 due to surge protection. The second and third decline was on 10 & 19 -Oct led to a trip of GT12 due to over frequency. Tripped of GT12 on 29- Aug due to the high temperature of the turbine outlet caused the last sharp decline.

There were sharp decreases in the remaining four units GT13 and GT16, as shown in **Figures 14–17**. The units GT13 &GT15 declined to zero minimum loads three times in Aug- 2020, which mean three interruptions, while the GT14 was the worst among the six units s in terms of performance and quantity of production. The minimum loads of GT14 decreased to zero six times in a period 9–26 Aug, which shows the clear effect of lack of maintenance. The GT16 was the best performance compared to the other units even, the minimum loads reduced zero twice in the same period.

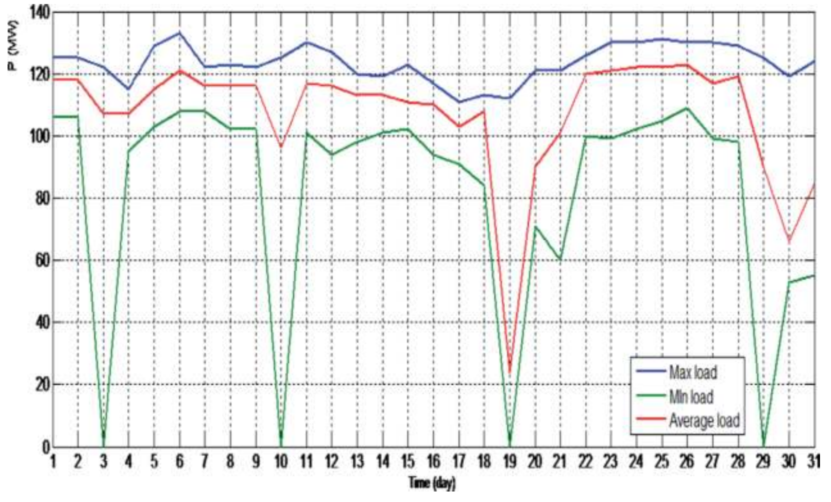

Figure 13.
The performance of GT12 in Aug-2020.

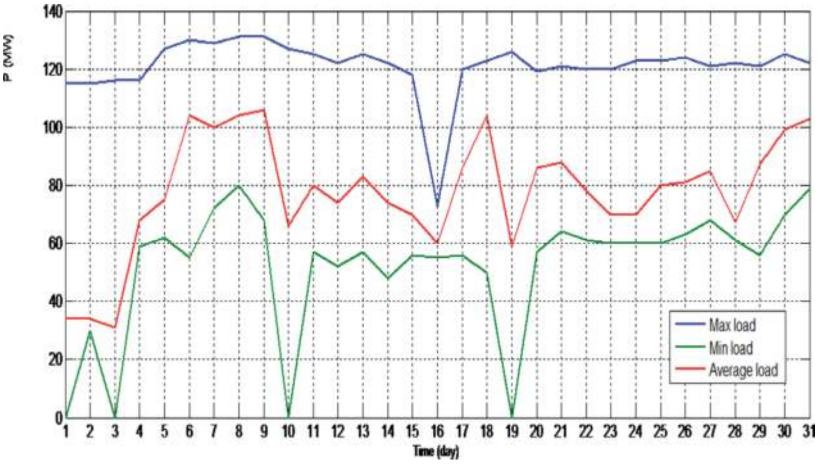

Figure 14.
The performance of GT13 in Aug-2020.

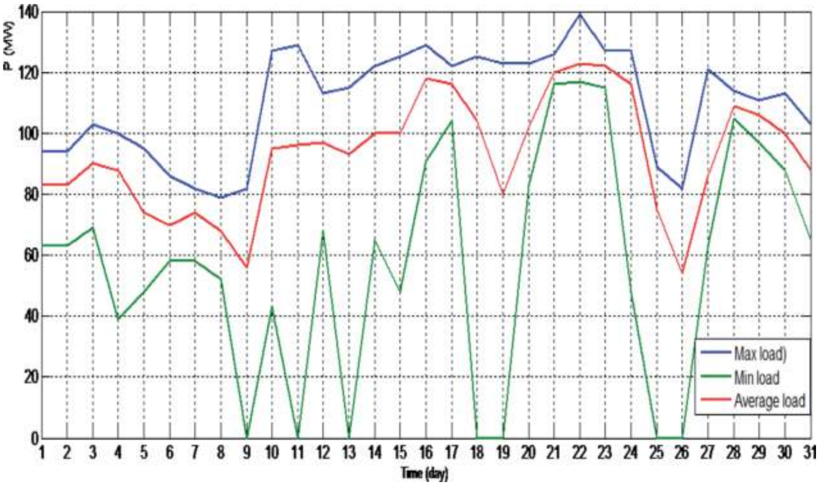

Figure 15.
The performance of GT14 in Aug-2020.

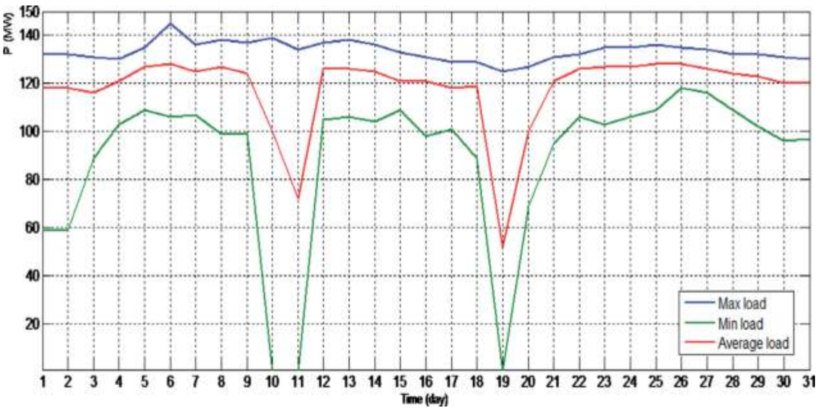

Figure 16.
The performance of GT15 in Aug-2020.

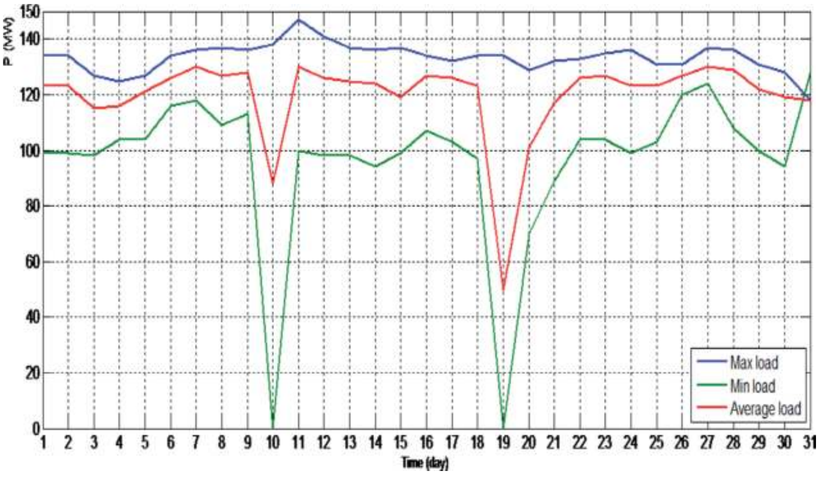

Figure 17.
The performance of GT16 in Aug-2020.

The cause of interruptions in GT14 is due to the following: four interruptions to increased frequency, the fifth programmed for maintenance, and the sixth interruption because of repairing air leakage. The units GT15 &GT16 were tripped twice on 10 &19 – Aug, due to over frequency. From all **Figures 12–17**, it can be noticed that all units were tripped on 10 & 19 -Aug, except, GT14 due to over frequency and shake in the power system grid.

5. Conclusion

In this chapter, outages and blackouts that occurred in the general electrical grid in 2019–2020 have been discussed in detail as follows; from the point of the annual energy produced by Al- Zawiya PPCC in 2019 and during the period of blackouts 02–07 Aug –2019. Also, Comparative of the annual energy produced by Western Mountain Power Plant in 2019 & 2020. In addition, an assessment of the performance of the six gas units of Western Mountain Power Plant during the peak load demand on Aug-2020. From the presented data, the main causes of outages and blackouts are as follows; the inability of the two power plants to operate at their full capacity during the peak load to cover the load demand, the exit of foreign experts for security reasons caused the delay in the maintenance and overhaul of the units, the deliberate sabotage of the control room of the Western power plant by armed militias, the division of the power system grid into several parts as well as the loss of the main transmission line 400 KV that linked the Western region to the East is leaving the network very weak, the NCC and TRCC computer systems only control 20% of the data that covers the main points in the network, all faults in the transmission network led to the loss of some generation units. The SCADA only covers some lost data and the rest is manually entered to give a fair picture of the network. Finally, the civil war and political division make the maintenance work very difficult to repair the broken equipment near the conflict zone.

The proposed solutions to overcome the outages and blackout are protecting power plants, transmission lines, and the equipment of the electric company from theft and deliberate destruction. Moreover, reconnecting the main transmission line 400 kV that linking East region with the West, re-activate the automatic operation of the National Control Center for remote generation stations, update Scada system, maintenance of protection relays for the main transmission lines and activation of the deactivated automatic connection and disconnection system. Furthermore, maintenance of all broken generation units and overhaul of the operating units on time, reconnecting the main transmission line 400 KV linking between Tunisia, Libya, and Egypt to increase the stability of the network. Finally, in war zones and conflict areas, where the transmission lines power system equipment is under the threat of deliberate destructions and stealing, using renewable energies, smart grid and smart metering to supply the customers with power and to compensate the voltage drop for increasing network stability are the best solutions.

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