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Optimization and Increase Production and Efficiency of Gas Turbines GE-F9 Using Media Evaporative Cooler in Fars Combined Cycle Power Plant

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Abstract

Gas turbines play an important role in supplying power for the country especially in peak electricity load. The main disadvantages are the turbines, they produce large changes are a result of climate change. However, in times of peak electricity grid and at the same time warm months, can produce gas turbines under the effect of ambient temperature, the amount of reduced considerably. The methods adopted for the turbine compressor inlet air cooling and recovery of their power optimization is necessary. In this paper, different methods of cooling the inlet air to gas turbines for Fars power plants weather conditions and eventually introduced various schemes to install combined cycle gas turbine inlet air cooling system of the plant, good design, Media evaporative air cooler system have been selected according to technical and economic evaluation. Media evaporative air cooler by an external contractor blueprint designed, constructed and installed in the plant. Performance tests are conducted at the site, 11 MW equivalent to 14.5 percent for gas units and 1.2 MW (6.2%) for steam combined cycle unit to the circuit after the Media cooling system in the summer show.

Keywords: Increased power; Gas turbine; Inlet air cooling; Evaporative cooling; Media system.

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1. Introduction

Gas turbines are due to benefits play an important role in supplying power for the country, especially during peak load is responsible. The main disadvantages turbines, large changes in productivity and efficiency is due to changes in environmental conditions. Studies and experience show that by increasing the ambient temperature by one degree Celsius, up 1% decrease in turbine power output and thermal efficiency will also be low [4,5,6,7,8,16,22].

Thus, in peak time grid and at the same time increasing energy demand during the warm months of the year, production potential under the effect of ambient temperature gas turbines are significantly reduced, the simultaneous production cuts by increasing energy demand, negative effects it will be doubled. Therefore, the adoption of effective methods for cooling turbine compressor inlet air and recovery of power they are necessary to optimize production. Studied changes in productivity and efficiency gas units study area (Fars Power Plant) is also perceptible changes of production (see Figure 1) and efficiency (Figure 2) of the effects of climate change in different months of the year, so that the least capable of producing and The efficiency of these units in the hottest months (July and August) and the highest power and efficiency in the coldest months (January and February) will be.

2. The gas turbine intake air evaporative cooling methods

A) The method of evaporative cooling media

Media pages generally of cell-like honeycomb and corrugated to be built and together constitute a media evaporative air cooler. By spraying water on them wet cells can be by way of evaporation, cooling the air. The weather surfaces are higher, faster, and more evaporation will occur. Select the cells to form a spiral and a hornet's nest, precisely in order to increase the contact area between water and air is taken.

B) The Fogg

In Fogg water nozzles, a high pressure compressor inlet air is sprayed. These nozzles, generally in less than twenty-micron diameter water droplets lead the public to reach the compressor blades are evaporation and erosion of compressor blades are not acquired. These droplets with a diameter very low, because of the large surface to volume ratio of the particle, the rapid evaporation and increase the intake air humidity and temperature are reduced. In this way, the moisture content of the incoming air can be saturated or supersaturated, and the pressure of the system is very low and negligible.

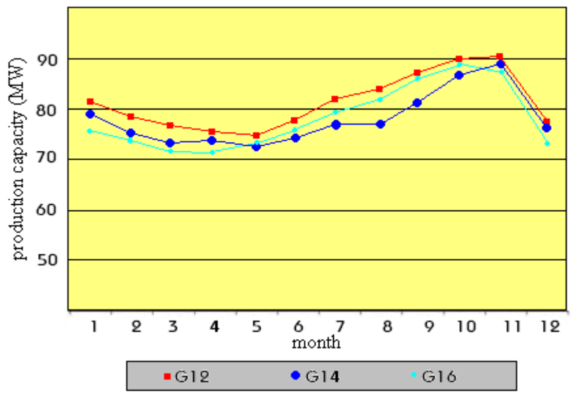


Fig. 1. Changes in production capacity gas power plant units in Fars Power Plant

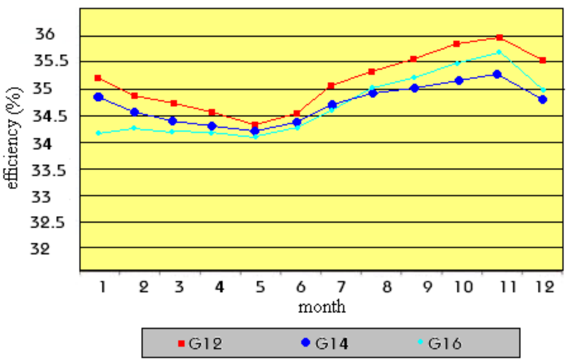


Fig. 2. Changes in plant efficiency gas power plant units in Fars Power Plant

3. The Effect of Temperature on The Parameters of The Gas Turbine

By changing the ambient air temperature, air density will change. Since the cycle gas turbine, air is assumed to be complete gas. (At normal ambient temperature and pressure 10 MPa compressibility factor in the equation of state for air about (1) will be.) If the temperature of Ti1 to Ti2 be reduced to an equation of state for air can be written as follows [1]:

$$PV = mRT \Rightarrow \frac{P_{i1}V_{i1}}{m_{i1}T_{i1}} = \frac{P_{i2}V_{i2}}{m_{i2}T_{i2}} \quad (1)$$

Such as gas turbines operate at a fixed speed and shape of the compressor inlet air is rigid and fixed volume. (Air pressure at i1 and i2 are the same.) The change of Mass Flow Rate, a function of its density and by reducing the inlet air temperature to the compressor, its density increases and mass flow rate of air through the following increases:

$$m^{\bullet}_{i2} = \left(\frac{T_{i1}}{T_{i2}}\right) m^{\bullet}_{i1} \quad (2)$$

Increasing the intake air mass flow to the combustion chamber allows us to be more fuel injection and combustion products passing through the turbine will increase the mass flow rate. Because the hot gas mass flow through the gas turbine, the direct impact on production capacity turbine, therefore decreasing temperature and increasing the compressor inlet air mass flow, increase production capacity turbines will be as follows [1]:

$$W_{net} = m^{\bullet}(q_H - q_L) = m^{\bullet}(w_t - |w_c|) \quad (3)$$

In combined cycle units, increasing the gas turbine exhaust gas mass flow rate, allows us to produce more steam in the boiler and steam turbine will be produced in this way will increase [9.16].

Reduce the temperature of the air entering the compressor reduces the compressor used to compress the incoming air (for a given pressure ratio) will be as follows:

1) Input compressor
2) Compressor output

$$w_{comp.} = \frac{C_p T_1 \left(\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1\right)}{\eta_c} \quad (4)$$

Reducing the compressor intake, increased net operating cycles and consequently will increase efficiency [1]:

$$w_{net} = w_t - |w_c| \text{ و } \eta_{th} = \frac{w_{net}}{q_H} \quad (5)$$

Cycle gas turbine thermal efficiency, which is expressed as the following equation shows that reducing compressor inlet air temperature and increasing the pressure ratio compressor cycle will increase thermal efficiency [1]:

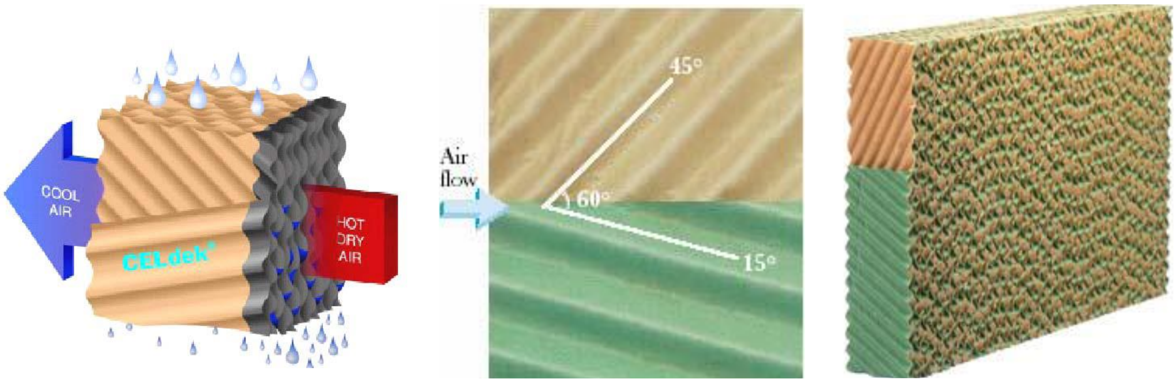
$$\eta_{th} = 1 - \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{K}{(K-1)}}} = 1 - \frac{T_1}{T_2} \quad (6)$$

4. The Cooling System Media

This system is used to evaporate water from a media matter. The gas turbines are widely used, especially in arid regions is hot. This system is the basis for the functioning of the water evaporates about Kj / Kg 2698 the consumption of thermal energy. (Latent heat of evaporation) and this process is a dry ambient temperature.

A) Media pages:

Pages with media made of cellulose fiber and corrugated are made. A set of plates together as shown in Figure (3), form a media evaporative cooler are in the form of honeycomb. This property of similar properties in the vacuum cord fluid and water in the Media player, and cause the ratio of surface area per unit volume of media evaporation and cooling of the air is better. In order to prevent the decay of the pages they are covered by special chemicals, it should be noted that because cellulose media pages are highly flammable. (Note that the media pages are made of fiberglass is not the case.)



(A) (B) (C)

Fig. 3. A) a set of plates together cellulose, B;C) Position the media pages for a specified angle to maximize the area of contact between air and water

Each of these pages determinate angles together form a Media cooler, the pages one at angles between 15 and 45 degrees from horizontal are connected together to the contact surface air with the water in the pages of and more. In this way the air flow direction in parallel with the horizon is shown in Figure (3).

B) Absorbent or the eliminator (Mist Eliminator)

It generally placed in the later part of the media pages. The device, water droplets in the air separates out of the cooler. Last drop droplets with diameters larger than 100 microns should be removed, the separation efficiency of the droplets of 100 microns and above shall be 99.9%. [3].

C) Monitor water flow

A warning device to prevent water from certain pages and embedded Media in the continuity of the flow of cooling water if a problem occurs, the operator is warned. The impact of Media on the rate of cooling evaporative air cooler inlet air to gas turbine compressor capacity by reducing the inlet air temperature of the cooling system increases the output power of the media can be as follows:

1. Reduce the compressor inlet air temperature increases air density and mass flow rate of the gas turbine power output increases and thereby increase.

2. Reduced compressor inlet air temperature decreases the power required for air compression and power requirements of the compressor with intake air temperature has a direct relationship of the net receipts from the gas turbine to be increased. Reduce the temperature of the exhaust gas turbine inlet air temperature decreases. Therefore turbine control system is used to reduce the error signal caused by the exhaust temperature and set point, the action and the high flow rate of fuel consumption. Increase the fuel flow rate, increasing the power output of the gas turbines will bring. The exact amount of increase in gas turbine power output with this method depends on the type of gas turbine, site altitude and ambient air conditions there. Evaporative system, according to the diagram (4) as the main limiting factor in the decrease of temperature, is moisture in the air. These systems in air with high humidity almost lose its effectiveness. Normally, the Media system in hot weather with low humidity, the turbine output of approximately 15 to 20 percent and 10 percent increases in high humidity.

D) Water consumption

The manufacturers of evaporative cooling to install cooling systems with more than 1.5 meters height, water flow rate between 1-2 Gal / min per square foot of surface area for cooling distribution cushion with height higher than 4 meters, 1.25-3 Gal / min are recommended. Experience has shown that about one gallon per minute flow rate per unit area distribution system cooling pads taller than 1.5 meters to operate satisfactorily. Similarly, the cooling rate of 2 to 3.5 meters 1.25 is recommended. Higher flow rate, has the advantage that the rate of deposition on the surface of at least the Media Fig(5). But lower than the likelihood of the water flow rate (Carry Over) to a minimum. In practice, you should consider the effect, optimized flow rate. Typically for such, the mass flow rate of gas turbines 90.9 Kg / s ratio of about 200 to 800 gallons per hour (which is a function of ambient air humidity) is.

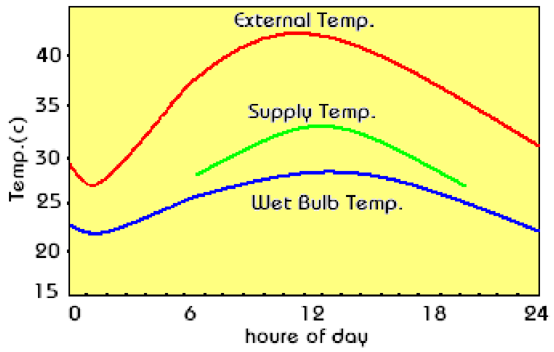


Fig. 4. The main limiting factor in the reduction of temperature, humidity is in the air.

E) *Water quality system requirements Media*

As mentioned, normally for industrial gas turbines mass flow rate of about 90.9 Kg / s, about 200 to 800 gallons of water per hour is evaporated. Therefore, the water quality is very important. Therefore continuously percentage of blow down water of water storage tank and its concentration is controlled. The quality of water required parameters such as hardness, alkalinity, dissolved substances and PH should be considered to be within a certain range. If in relation to the quality of water sufficient accuracy is not, on the pages of Media layers of sediment will be formed, (but this long and about 2 years occurs), as a result of the failure, the failure of the Media, to penetrate sediment air and damage to the compressor and turbine rotating parts and reduce the efficiency of the system will bring [6].

5. System Installation Media

The place of Media evaporative coolers installed is also very important. This place according to the manufacturer's design before or after the filter is dry.

Cooler installed before the filter is recommended for the following reasons: The filter acts like coolers and about 87% of all particles with a diameter greater than 10 microns will be absorbed. As a result of increased dry filter service life and reduced maintenance costs. Installation of mechanical equipment investment is lower. The disadvantages of this method of controlling air velocity are Media system. But manufacturers of evaporative coolers suitable place for installing the cooler dry air filter after proposed. The reasons are as follows [7]: Easy to install, own and exclusive designs for the cooler and does not require welding operations for the installation, the widespread use of electric and electronic control and reduction of mechanical means low pressure drop in the intake air, about 0.3 - 0.4 or 0.5 - 0.6 inch water column according to Media type used of parts and equipment made of stainless materials. Generally, in a gas turbine intake air evaporative cooling is recommended after the filter intake air is not before it, this type of installation Media from pollutants in the air to keep the other. Media evaporative cooling type filtering has not been tested for efficiency, but it is known that they can take a significant amount of particles in the air.

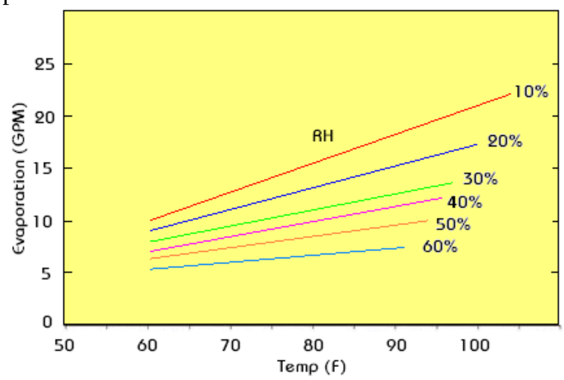


Fig. 5. The effect of temperature on water purity

The quality of these water-based studies as follows [6]:

Table.1.
Water Quality system uses Media

Between 7 to 9	**PH water**	**50-400 µs / cm**	**Water Vrsanayy guidance**
less than 500 ppm	Chlorine content	45-170 ppm	hardness
less than 5 ppm	suspended solids	45-170 ppm	dissolved substances
****	****	less than 50 ppm	alkalinity

The results of the media on the unit cooling system G12, G14, G16 Fars power plant units each rated capacity 123.4 at ISO conditions in the 1995 installation. Plant height of 1530 meters above sea level, and the power output of the units at the site of the 99.3 to 109 MW with gas and diesel fuel is 97 to 107. The need for network and power shortages in recent years to optimize these units was considered. In order to compensate for lost capacity units mentioned in the warm seasons inlet air cooling system design installation Media by the Fars Power Plant units were implemented. Also, according to statistics provided by the meteorological temperature and relative humidity in summer and dry in the Fars power plant cooling system design conditions of 35 ° C and 20%, respectively parameters are taken into account.

6. Economic and Technical Assessment of Inlet Air Cooling System Media

Operational system evaporative cooling is done over the air, air cooling is only humidifying. This is a Adybatyk change. During this process the temperature of the moist air remains constant. This process schematic diagram shows the Psychrometric diagram.

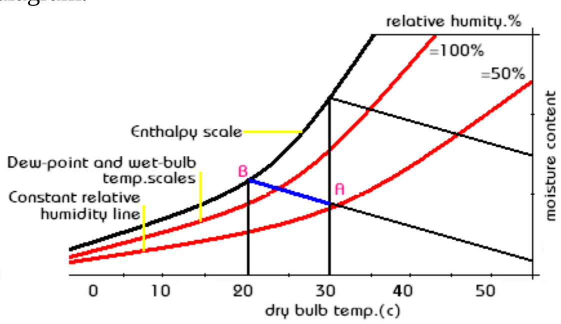


Fig. 6. Diagram Psychrometric

1. The initial conditions TDB2 <TDB1
2. The final conditions W2> W1 and Rm2> Rm1
3. Saturation an Adiabatic conditions h2 = h3

Efficiency humidification system is defined by the following equation:

$$\eta_{humidifying} = \frac{T_{DB1} - T_{DB2}}{T_{DB1} - T_{WB}} = \frac{w_2 - w_1}{w_3 - w_1} \quad (7)$$

Where TDB is drying air temperature, TWB is moist air temperature and humidity W for air. The water requirement of the system is obtained from the following equation:

$$\dot{m}_{water} = \dot{m}_{air} \times (w_2 - w_1) \quad (8)$$

Regarding in the Fars power plant site designed to maximize recycling can be obtained under the TDB = 35 C temperature and relative humidity φ1= 20% moisture content for the W1 = 0.008464 Kg/Kg dry air will be. In the best situations, assuming maximum efficiency for cooling evaporation system, the lowest temperature attainable temperature wet bulb environment, so TDB = TWb = 17.86 C and relative humidity φ1= 100 %, the amount of moisture for it to W2 = 0.015568 Kg/Kg dry air will , so ΔW = 0.007104 Kg/Kg dry air Since the compressor inlet air mass flow in the design of 406 Kg/s [10], the required water flow rate: M water = 0.007104 × 406 = 2.88 Kg/s will be.

Since the Fars power plant site at an altitude of 1530 meters above sea level, and for the tables to correct altitude and graph output based on input temperature in the Fars power plant amount of power available to unit GE-F9 recovery to be defined as [8]:

The power output of the gas turbine design point MW1= 79.13 MW and MW2= 90.18 MW system will then come to the circuit, so the Media can be recovered up to the terms of 79.13 - 90.18 = 11.05 MW and from to per cent against (11.05/79.13) × 100 = 13.96 is.
One of the important factors that should be considered in the feasibility of a project is its economy. The gas turbine inlet air cooling project should be economically analyzed. The Media systems assessed amount of initial investment for each kW of net power through the use of recycled cooling system shows 50 to 55 $. The costs of maintenance (O & M) of about 3 to 5 percent of the initial cost [8].

Design conditions (35 ° C dry bulb and wet bulb 86/17 C for the environment) Assuming 90% efficiency for the cooling process of increasing MW of about 56/12 percent. Investment cost of about 55 $/KW consider. Thus, for each unit of 10 MW power plant in Iran with respect to output power, in terms of initial investment of 10000×55=550,000 $ and maintenance is 27,500 $.

As the hours of operation of the cooling system in summer and warm air will be in high demand, the amount of time the system is turned on within 24 hours about 4 hours is considered. Given the function of the device is 4 months warm year (May to September) the number of hours of operation of the system for a year for 4 × 30 × 4 = 480 h/year and the amount of electricity generated annually by the application of this system to 10 × 1000 × 480 = 4800000 KWh/year is. Sales of electricity production would back the capital cost will be within a short time. It should be noted that this calculation is considered the highest limits and so values listed show their extreme value and depending on the circumstances, the pay-back period will be less of. Figure (7) return for the return on investment of various amounts of electricity sold to the grid and taking into account operating costs, respectively. Referring to this figure indicates that the average selling price 6 Cent/KWh time return on investment within 2 years.

7. Performance Testing and Analysis

Since testing the performance of the system is one of the more important is the implementation of a project, the evaporative cooling system installed in the Fars plant units function tests for G12, G14, G16 was conducted in August. The test parameters were considered in increasing the power output of the units, as well as the ambient temperature and humidity environment as well as the input to the compressor, which according to them were identified measurement points. Since the correct operation of sensors installed on the PLC and the accuracy of the test must be deployed, moisture and air temperature data measured with a multi-function machine delta and were compared with PLC. Testing process is as follows:

- commissioning of test Fars plant gas units and putting control in automatic mode
- Consider getting units to full load and no load, most of them
- Registration required parameters function test
- Turn on evaporative air cooler system and wait 10 minutes to stabilize conditions
- control and parameters

Table (2) and (3) and (4) attached function test results showed that the test subjects. The results show that the data obtained from test performance is very close to the values related to computing.

The calculations are based on 80% efficiency evaporative cooler system and according to the curve for the power plant site condition have been corrected, were conducted. The difference between the amounts of computing performance test may be due to changes in operating conditions of the gas turbine performance curves primary difference between the efficiency of the cooling system is installed for the calculation of. Based on the graph (8) it can be seen that with increasing temperature and decreasing relative humidity, the compressor inlet temperature drop increases. For example, at ambient temperature of 38 ° C and a relative humidity of 8% based on test calculations using water-cooled compressor inlet air temperature to the media at least 17 ° C is reduced. Based on the chart (9), increasing in power output of 11 MW. The power output of the above conditions in the graph (10) for the unit G12 is shown.

8. Conclusion

The results show that Media evaporative coolers system installation on gas turbine units under test Fares combined cycle power plant increased about 11 MW averages of 14.5 per cent. Technical and economic results above show that the installation of these systems from the installation of a new gas turbine to produce more power, and are much cheaper to areas such as Fars, Yazd, and so the weather with high temperatures and moisture to continually during the day, very convenient. Also, the initial investment is low compared to the return on investment and payback period of the plant will be about 2 years.

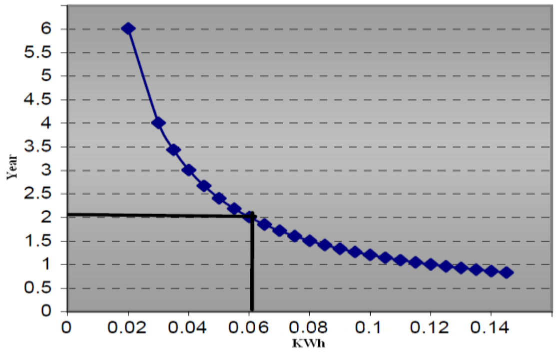


Fig. 7. About the return on investment for the installation of Media evaporative cooling systems for Fars power plants, for different value of electricity price

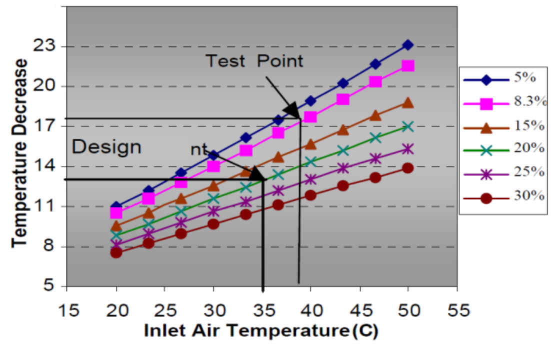


Fig. 8. Reduction of compressor inlet air temperature by Media evaporative cooler in different climatic conditions

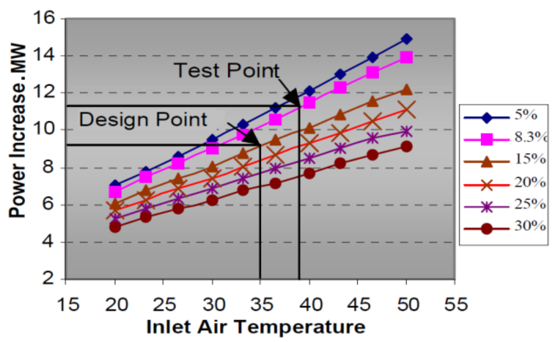


Fig. 9. The rate of increase power output in gas turbine of Media evaporative cooler in different climatic conditions

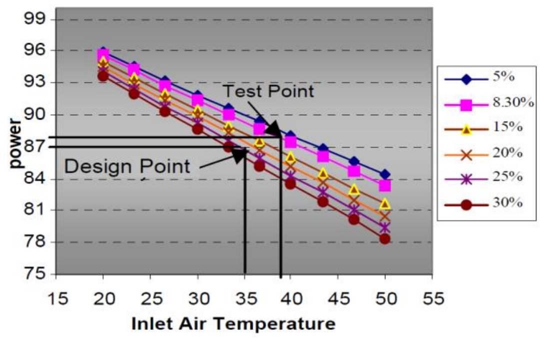


Fig. 10. The power output of the gas turbine unit Media evaporative air cooler G12 in different climatic conditions

Table.1.
Media evaporative system performance test results on various parameters of the gas turbine Fars power plant G12

Percentage Changes	**Changes**	**After Media**			**Parameter**
0.271	0.103	38.27	38.17	**C**	**Ambient temperature**
-1	-0.08	8.2	8.3	**%**	**Relative humidity**
-0.028	-0.023	83.82	83.85	**KPa**	**Ambient pressure**
-44.17	-17.93	22.66	40.6	**C**	**Compressor inlet air temperature**
-6.47	-24	347	371	**C**	**Temperature of the exhaust air from the compressor**
8.49	0.69	8.92	8.23	**Bar**	**The output of the compressor air pressure**
-1.90	-10.66	549	559.6	**C**	**Temperature exhaust**
14.50	11.11	87.71	76.6	**Mw**	**Output**

Table.2.
Media evaporative system performance test results on various parameters of the gas turbine Fars power plant G14

Percentage Changes	**Changes**	**After Media**			**Parameter**
0.62	0.23	38.60	38.37	**C**	**Ambient temperature**
3.73	0.3	8.23	8.03	**%**	**Relative humidity**
-0.06	-0.05	83.90	83.95	**KPa**	**Ambient pressure**
-43.75	-18	20	38	**C**	**Compressor inlet air temperature**
-6.69	-25	348.66	273.66	**C**	**Temperature of the exhaust air from the compressor**
7.45	0.65	9.42	8.76	**Bar**	**The output of the compressor air pressure**
-1.99	-11	540	551	**C**	**Temperature exhaust**
13.27	10.81	92.29	81.48	**Mw**	**Output**

Table.3.
Media evaporative system performance test results on various parameters of the gas turbine Fars power plant G16

Percentage Changes	**Changes**	**After Media**			**Parameter**
0.58	0.79	36.85	36.06	**C**	**Ambient temperature**
0.08	0.20	8.25	8.05	**%**	**Relative humidity**
-0.015	-0.02	83.90	83.92	**KPa**	**Ambient pressure**
-45.47	-18	21	39	**C**	**Compressor inlet air temperature**
-6.57	24.13	249.87	274	**C**	**Temperature of the exhaust air from the compressor**
7.84	0.8	9.35	8.55	**Bar**	**The output of the compressor air pressure**
-1.96	-11.9	541.8	553.7	**C**	**Temperature exhaust**
14.20	9.75	85.45	75.7	**Mw**	**Output**

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