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Improvement Thermal Efficiency of Al-Rumaila Gas Turbine Power Plant in Basrah by Upstream Inlet Air Cooling System

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Abstract

The efficiency of gas turbine units is highly affected by the variation of ambient temperature. Increasing the ambient temperature decreasing the efficiency of gas turbine. Cooling the inlet air to the compressor of the gas turbine units is an essential and economical technique for improving its efficiency. Al-Rumaila gas turbine power plant was located in Basrah city, Iraq, which is characterized by its hot climates for more than six months during the year. A novel upstream inlet air cooling system was applied and tested for Rumaila gas turbine power plant. This article represents a thermo-economic evaluation of applying upstream inlet air cooling system. The analysis is based on the test results for operating single unit of Rumaila gas turbine power plant using upstream inlet air system for cooling. The test was performed during July of 2019 for 90 minutes of operation period with ambient temperature of 45 °C. The evaluation analysis shows that, the power output increased from 217.71 MW to 250.11 MW during the period test with percentage increase in power by 15%. This increase in power output led to net economic gains is approximately 1000 $/h.

1. Introduction

Although gas turbine power plants are considered one of the plants that are rapidly spreading because the low capital cost and short time required for their construction, also the time required to operate and reach the rated load is small compared to other stations, but the gas turbine power output is greatly affected by the temperature of the external environment, where the capacity decreases by 20% when the ambient temperature rises more than 40 °C. Because of the increased demand for electrical energy in the summer, especially in Iraq, and the decrease in energy output due to high temperatures, it is necessary to search for ways to cool the air temperature inter to the turbine. Many researchers have investigated various cooling methods (systems) to enhance the gas turbine plants performance operating at high climate temperatures. Abdalla and Adam [1] presented feasibility technical and economic study of turbine inlet air cooling and its impact on gas turbine performance in Khartoum County. They investigated three options (cooling, fogging, and evaporative cooling with wetted media), where cooling with coolant had the lowest air inlet temperature but was costly. AL-Salman et al. [2] parametrically studied the air inlet cooling system with fog for a power plant gas turbine in order to reduce the ambient air temperature. The ambient temperature, humidity, firing temperature, and pressure effects on the output of the gas turbine were investigated. Results revealed decreased in the output power and efficiency as the ambient temperature increased. Bagabir et al. [3] investigated two techniques to rise the gas turbines output power (cooling intake air and using an intercooler between two compressors). The power enhancement of a microturbine test unit 4 kW using evaporative and coil cooling systems was investigated experimentally. A parameter study was conducted to investigate the climate air conditions effects (temperature, humidity, and pressure) for the gas turbine cycling with evaporative and coil cooling. Results shown that the performance of gas turbine cycles can be improved by lowering the inlet air temperature. The application of an intercooler between two compressors to enhance the gas turbine performance was also studied theoretically. They concluded that the method can improve turbine performance, notably at a high value of expansion ratio. Ibrahim et al. [4] studied several cycles (single cycle gas turbine, two-shaft gas turbine, gas turbine with intercooler and renovation gas turbine). Simulation results indicated that the influence of climate temperature and compression ratio had significantly affects the performance of a combined cycle gas turbine power plant for different gas turbine configurations. Santos and Andrade [5] conducted a thermodynamic analysis for performance of gas turbine to estimate the heat rate, output power and efficiency at different inlet temperatures and relative humidity. They computationally implemented three cooling techniques and solved for different inlet conditions. Under different cooling methods gas turbine was tested at two Brazilian locations. The comparison between the cooling systems (mechanical chiller and absorption chiller) demonstrated that the absorption chiller introduced the highest increase in the annual energy production at a lower cost per unit. Evaporative cooling, additionally, offered the lowest energy cost per unit but was associated with limited cooling potential. Kodituwakku et al. [6] investigated the performance of a gas turbine plant in Kelanitissa (GE MS5001 R) as a function of changes in ambient temperature. Two approaches were used to investigate this phenomenon. First, the performance parameters were calculated using actual data from the operating history of the power plant. Second, the power was analyzed using thermodynamic principles. The results showed that the performance was very poor due to the prevailing high ambient air temperatures. Originally designed for 25.8% efficiency, the maximum efficiency at 33 °C was only 21.2%. Ünver et al. [7] investigated the performance of the ice thermal storage system (ITES) for operated gas turbine in Bursa / Turkey 239 MW under full load conditions. The energy and exergy analysis were performed using the meteorological climate weather data of the last decade. Results shown that the use of the ITES system increased the net power generation by up to 12.60%. Sultan [8] conducted a thermal and economic analysis for Rumaila gas turbine power plant in Basrah (Southern Iraq). The results shown that the maximum power reduction due to the increase in climate air temperature which reached 22.97% in the month of July, power reduction due to supply cooling air increased with the increase in climate temperature. Elberry et al. [9] developed a thermodynamic model to simulate the combined cycle before and after integration of the proposed Li-Br single-stage and H_2O absorption cooling system. The results showed that cooling the inlet air by 10 °C caused an improvement in the annual power generation by 6.4% and enhance the heat rate of the combined cycle by 0.3%. The decrease in heat rate means a significant drop in CO_2 emissions 30 kton/year and improves the performance of the plant. Lyu et al. [10] performed calculations and analysis using thermodynamic and economic methods. For the propose a specific quantitative indicator that can be simply measured to determine the usefulness of an evaporative cooling system, they established effective criteria for the quantitative estimation of the feasibility of an evaporative cooling system for CCPP. Al Essa et al. [11] designed a LiBr-water absorption cooling system to enhance the performance of power plant (gas turbine) by cooling the air inlet to the compressor. They performed analysis for different exhaust gas turbine temperatures 150-220 °C. The results show a visible enhancement in the thermal efficiency for the gas turbine, and cooling capacity which increased by up to 5 °C colder air for ambient temperature 35 °C. Radchenko et al. [12] analyzed the cooling ambient air efficiency at the inlet of gas turbines in climatic conditions to improving its through deep cooling. By the simplest numerical simulation, they synthesize of logical analysis of the actual efficiency of gas turbine with air cooling systems. The result shows that a new trend in cooling the inlet air to 7 or 10 °C in climate conditions by cooling of two-stage in combined chillers that provides annual fuel savings of practically 50%. Alnasur and Furaiji [13] conducted a simulation analysis for gas turbine unit operated with a fogging system at climate temperature ranged 25-55 ℃ in the southern Baghdad station. Results show that the effective power, thermal efficiency and effective efficiency of the gas turbine unit can be significantly increased while reducing the specific air flow rate. Hamedani et al. [14] investigated combined systems for cooling inlet air Indirect Evaporative Cooling System (IECS) and absorption chiller that used for a 157 MW gas power plant in Asalouyeh, southern of Iran. Results showed that the thermo-economic and performance annual electricity generation can be 62090 MW, the net revenue from increasing electricity sales reached $3,851,000 for 60% of the year, during payback period of one year and six months. They found that compared to a direct evaporative cooling system (DEC), increasing electricity revenue as a result of the use of a direct evaporative cooling system (DEC) was 12290 MW and the revenue generated by increasing electricity sales was $116,899 for a 60% of the year period, while the payback period was about eight months. Tolba et al. [15] designed a combined air-cooling system with a cooling system upstream of the mist cooling system to decrease its size and enhance the performance of gas turbine. They also created a theoretical model using Engineering Equation Solver (EES) software to calculate exergy dissipation, net power output, and all efficiencies. gas turbine performance was comparable with and without the use of a multi-stage cooling system. Maximum power output was increased by 14.3% at the maximum climate temperature 40 °C. In reviewing previous studies, we found that there is no sufficient study on the upstream cooling air system, although it offers advantages over the other systems. Therefore, the focus in this study is on this type of cooling system and investigating the performance of the process.

According to our review, there is no available studies on the present upstream inlet air cooling system. The present study represents a novel real evaluation of upstream inlet air cooling system. The aims of the present study are to perform thermo-economic evaluation based on the real operation test results of using upstream cooling air system for Rumaila gas turbine power plant in south of Iraq.

2. Upstream cooling air system for Rumaila power plant

A simple system manufactured by Siemens company and consists of a group of pumps (pump skid) as shown in Fig. 1, number of mesh grid and nozzles shown in Fig. 2 in addition to the pipes. Table 1 show the system specification and technical data.

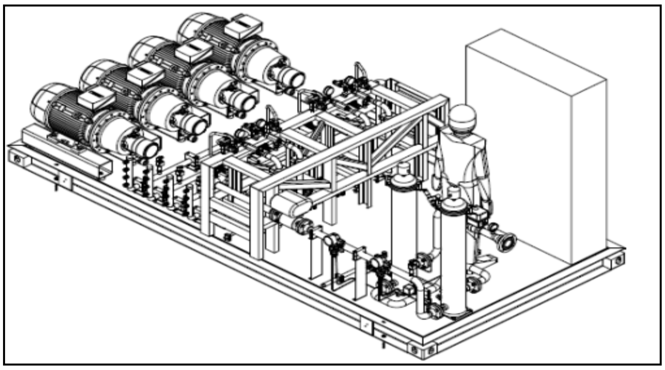

Fig. 1 Pumps skid [18].

Table 1. specifications of upstream cooling system for Rumaila power plant [19].

Parameters	Value	Unit
Turbine type	SGT5 400F	-
Turbine output (ISO)	292	MW
Air volume flow (ISO)	548	m^3/s
Ambient temperature (ISO)	15	°C
Humidity (ISO)	60	%
Min temperature	5	°C
Max temperature	50	°C
Number of nozzles	2112	-
Regulated nozzle pre-pressure	140	bar
Max water requirement	7.22	kg/s
Max. electric power consumption approx.	167	KW

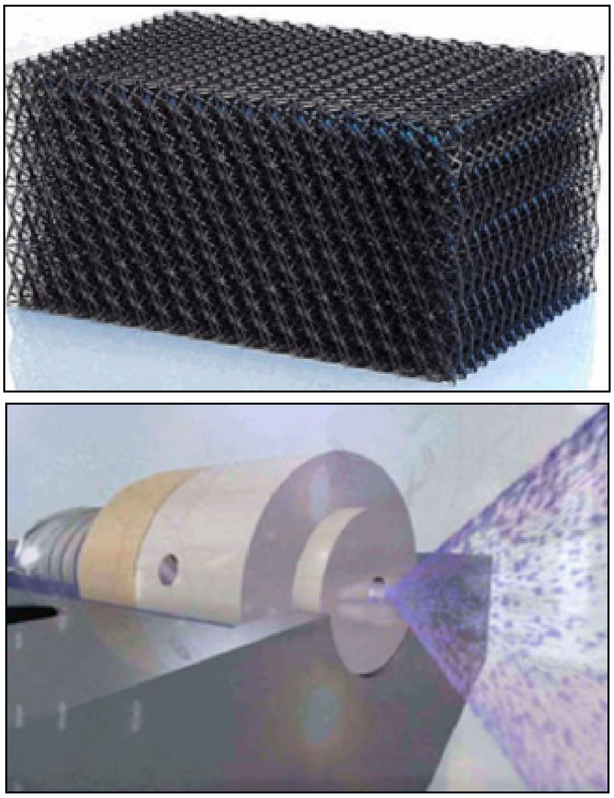

Fig. 2 Grid mesh and Nozzle [17].

3. Upstream cooling system test

The test results of using upstream cooling system for Al-Rumaila gas turbine power plant is given in Table 2. Period of test is 90 minute (this time is required for upstream cooling system to reach its full load of operation) and the data recorded are ambient temperature T_{amb}, inlet and outlet air temperature for compressor are T_1 and T_2 respectively, turbine outlet temperature T_4, relative humidity before and after the upstream system, ambient pressure P_{amb}, pressure at compressor outlet P_2, cooling water flow rate for upstream system nozzles and the power output.

4. Performance evaluation

According to the test results given in Table 2 the variation of the main performance parameters with time and for different percentage of upstream cooling load cooling water flow rate M_w (l/s) / maximum cooling water flow rate M_w (l/s) = 7.03 l/s will be viewed and discussed in the following figures. Figure 3, demonstrates the variation of compressor inlet air temperature T_1 with time and for different percentage of upstream system cooling load. The figure indicates that, the inlet temperature for the compressor decreases with time with increasing the percentage of upstream system cooling load. While without using the upstream system the inlet temperature was nearly constant temperature that is ambient temperature which give a low performance with respect to the first case.

Table 2. contain the test results of using upstream cooling system for Al-Rumaila gas turbine power plant [19].

Date	Time (min)	T_1 (°C) Inlet compressor temp.	T_4 (°C) outlet turbine temp.	Cooling water flow rate M_w (l/s)	upstream load %	H % Before	H % After	P_{amb} (mbar)	Power (MW)	P_2 (bar) outlet compressor Pressure	T_2 (°C) outlet compressor temp.	T_{amb} (°C)
7/13/2019	0	44.25	569.04	0.00	0.00	9.41	10.10	995.06	217.71	16.18	465.04	44.97
7/13/2019	5	41.59	568.55	2.26	32.15	9.65	15.07	995.06	221.92	16.32	462.62	45.10
7/13/2019	10	33.28	568.85	5.34	76.05	9.64	25.95	995.06	237.76	16.82	452.39	44.98
7/13/2019	15	31.66	568.94	5.34	76.00	9.40	30.00	995.06	241.47	16.95	448.69	45.14
7/13/2019	20	31.31	568.92	5.35	76.13	9.16	29.98	995.06	243.61	17.09	448.81	45.14
7/13/2019	25	31.30	568.99	5.35	76.21	9.02	31.26	995.06	245.26	17.18	449.86	45.10
7/13/2019	30	31.10	569.01	5.36	76.25	8.88	30.33	995.06	245.40	17.17	450.10	45.32
7/13/2019	35	31.14	569.00	5.29	75.30	9.34	29.99	994.89	244.68	17.12	449.50	45.27
7/13/2019	40	30.63	568.94	6.48	92.30	9.24	30.98	994.87	245.83	17.18	449.26	45.39
7/13/2019	45	29.47	568.99	7.03	100.00	8.91	31.56	994.87	248.31	17.30	448.42	45.29
7/13/2019	50	29.25	569.02	7.01	99.77	8.66	31.16	994.87	248.46	17.26	447.94	45.16
7/13/2019	55	29.22	569.14	7.00	99.61	8.78	31.28	994.85	244.88	17.00	445.73	45.57
7/13/2019	60	29.00	568.80	6.97	99.21	9.04	32.29	994.73	241.86	16.84	441.68	44.75
7/13/2019	65	28.90	569.02	7.00	99.59	8.81	32.50	994.51	246.27	17.12	443.96	44.50
7/13/2019	70	28.83	569.18	6.96	99.13	8.64	31.60	994.84	241.74	16.75	442.37	45.24
7/13/2019	75	28.95	568.73	6.93	98.58	8.79	31.52	994.84	238.38	16.65	438.85	45.45
7/13/2019	80	29.17	568.96	7.02	99.94	8.44	32.24	994.82	247.59	17.23	444.28	45.37
7/13/2019	85	29.19	568.95	7.03	100.00	8.47	31.30	994.44	249.45	17.35	446.07	45.05
7/13/2019	90	29.37	569.03	7.03	100.00	8.35	33.09	994.76	250.11	17.42	447.39	45.16

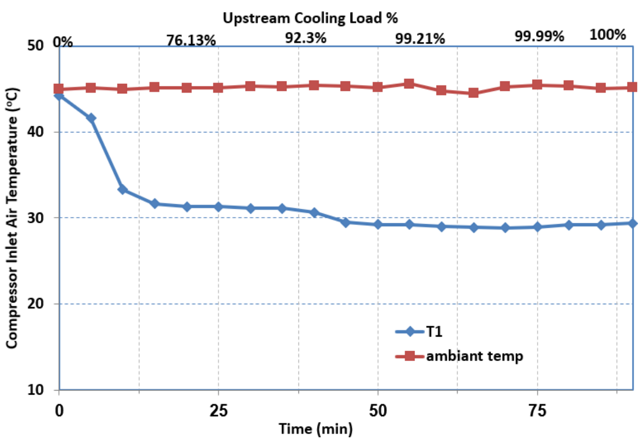

Fig. 3 Compressor inlet air temperature against the time.

Figure 4 shows the relative humidity variation at compressor inlet with time and for different percentage of upstream system cooling load. The figure indicates that, the relative humidity of air increase with time with increasing the percentage of upstream system cooling load. The maximum relative humidity is 33% and corresponding to the full load upstream system cooling load at cooling water flow rate of 7.03 l/s. The increase in the relative humidity is still below the relative humidity of air at ISO conditions so this increase will not effect on the compressor blade. While without using the upstream system the humidity was equal or less than 10% due to bad cooling process.

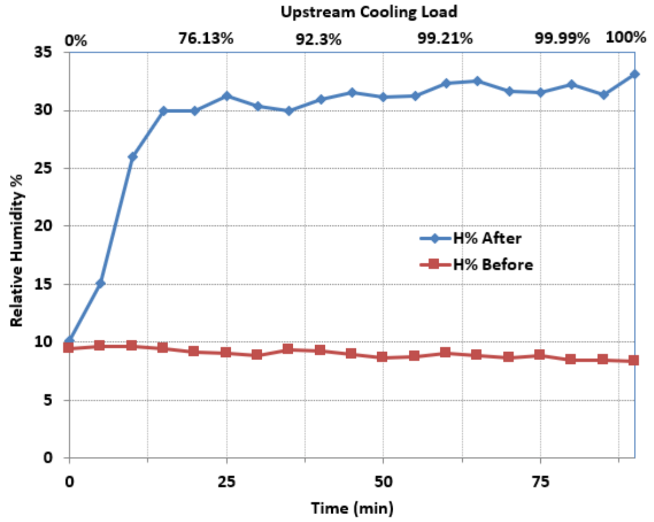

Fig. 4 Relative humidity variation with time.

Figure 5 shows the output power variation with time for different percentage of upstream system cooling load. The figure indicates that, the power output increase with time with increasing the percentage of upstream system cooling load, that happened due to the affect cooling process that increasing with increase mass flow rate of cooling system with time. The maximum power is 250 MW and corresponding to the full load upstream system cooling load at cooling water flow rate of 7.03 l/s.

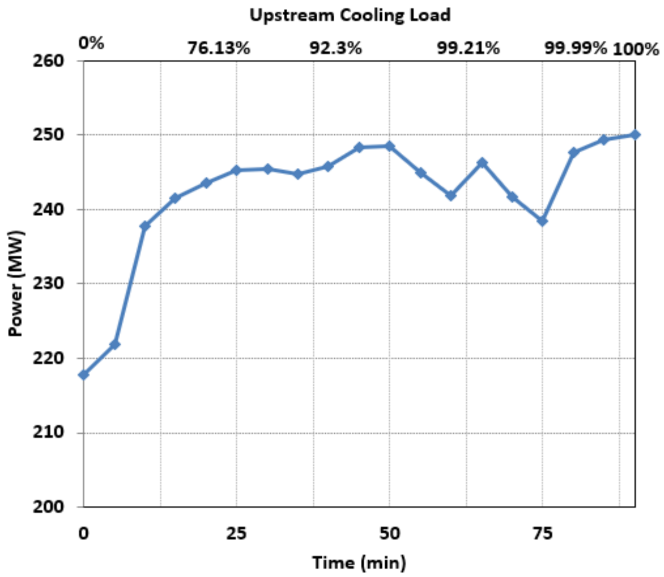

Fig. 5 Variation of power with time.

Figure 6 shows the compressor outlet air temperature variation with time and for different percentage of upstream system cooling load. The figure indicates that, the outlet temperature for the compressor decreases with time with increasing the percentage of upstream system cooling load. As a results of increase of cooling temperature and the relative humidity by increasing mass flow rate of the air inlet to the compressor. The minimum inlet temperature is 447 °C and corresponding to the full load upstream system cooling load at cooling water flow rate of 7.03 l/s.

Figure 7 shows the thermal efficiency variation with time and for different percentage of upstream system cooling load. The figure indicates that, the thermal efficiency increasing with time with increasing the percentage of upstream system cooling load. That may be happened due to enhancement in the cooling process by increasing the flow rate of the coolant. The maximum efficiency is corresponding to the full load upstream system cooling load at cooling water flow rate of 7.03 l/s.

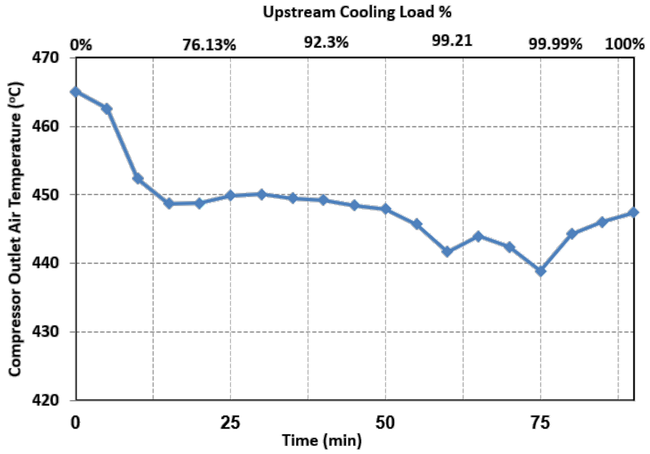

Fig. 6 Compressor outlet air temperature variation with time.

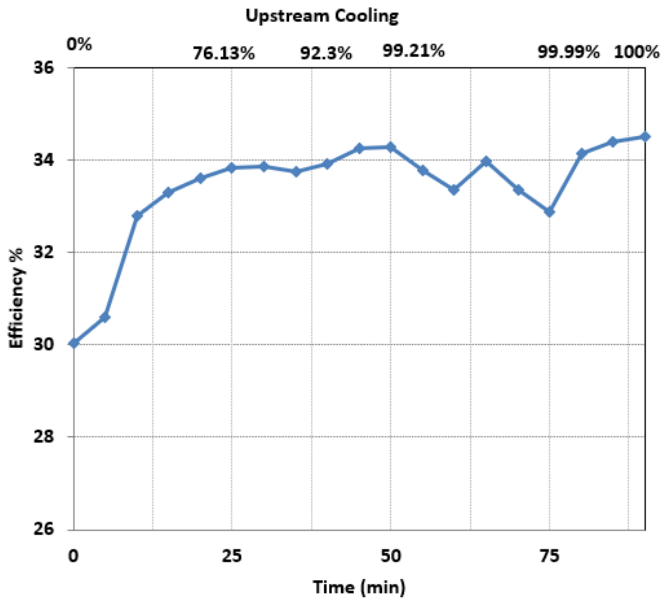

Fig. 7 Efficiency variation with time.

5. Economic evaluation

The economic evaluation for using upstream inlet air cooling system for Al-Rumaila power plant working with gas turbine will be explained in this section.

Firstly, the net saving in power is calculated by the following relation [8].

Net saving in power in (MW.h) = output power with upstream cooling – (output power without upstream cooling + power consumption by upstream cooling system) (1)

Secondly, the net economic gains (benefits) for the saving in power is calculated by the following relation.

Net Economic gains in ($) = net saving in power in (MW.h) × cost of electricity unit ($/MW.h) – (cost the consumption water $/($m^3$/h) × consumption water (m^3/h)) (2)

Figure 8 shows the variation of net economic gains for using the upstream cooling system. It is clear from the figure that, the net economic gains increase with increasing the percentage of the upstream system cooling load. The maximum net economic gains are approximately 1000 $/h and corresponding to the full load upstream system cooling load at cooling water flow rate of 7.03 l/s.

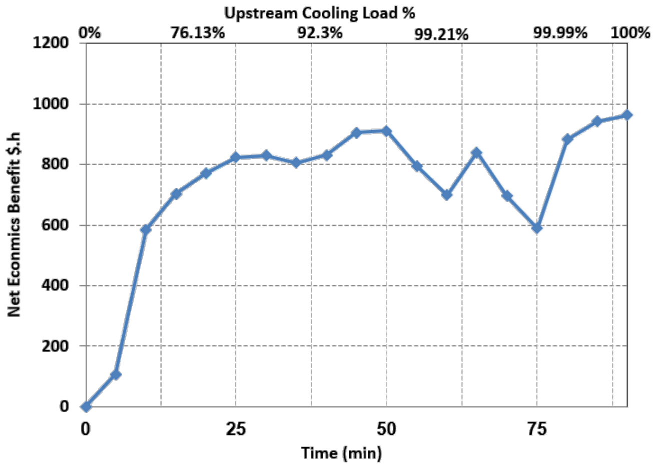

Fig. 8 Variation of net economic benefit $.h with time.

6. Conclusions

The thermo-economic evaluation analysis revealed that the upstream inlet air cooling system improve the efficiency of the power plant with good economic gains. The increase in power output for the period test is 15% with net economic gain of 1000 $/h.

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