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Analysis of the Cooling Tower Methods and their Integration with the Condenser and it's Influence on the Net Power Output of Power Stations

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Abstract — In this paper, the effect of both condensate cooling methods on the net power generated by the solar electrical station was studied using the cooling tower or the alternative method of cooling using the air-cooled condenser, and through sequential steps the number of air-cooled condensing units needed to accomplish the task was determined, where it was found that the best performance of the plant commensurate with the method of cooling the condenser, because the condensation temperature of the water in the condenser and the process of converting saturated steam into water is determined by the air wet bulb temperature . It has been found that the net power produced from the solar power plant in the case of the use of evaporative condensation or the so-called cooling tower is higher than if it used the air-cooled condenser and this is due to the high energy needed to operate the fans. This study was conducted for a specific geographical area, which is the city of Baghdad in Iraq. The station's performance has been tested for both condenser cooling methods and for two cases using energy heat storage and without heat storage. For the case without heat storage, the net power reduction when using an air-cooled condenser is 4.13% compared to using a cooling tower, while for the case with heat storage under the same conditions, this value is 3.43%.

Keywords* — *Cooling Tower ; Power Stations; Heat Transfer Fluid; Heat Loss; Condenser.

I. INTRODUCTION

Cooling towers are widely used in industrial processes to remove excess heat. There are two types of cooling towers: natural draft and mechanical (forced) draft. In this work, an analysis of the cooling tower with mechanical traction with air and water in countercurrent was carried out. Hot water from the condenser is sprayed into the tower to create a large surface of water droplets and jets in the ambient air. Due to the low humidity of the air entering the cooling tower in Iraq, part of the falling water evaporates [1,2,3], creating irreversible losses. The cooling tower operation results in a decrease in the cooling water temperature (Figure 4.9). Another factor in the "cooling tower approach" (Figure 4.9) is the difference between the cold water leaving the cooling tower and the ambient wet bulb temperature [4,5,6]. For a minimum value of this factor, it is recommended to maintain a certain temperature difference equal to -15 °C, since the size of the cooling tower varies widely depending on this temperature [7,8]. Wet bulb temperature is an important variable in the design of cooling towers, since the pressure in the condenser is a direct function of the temperature of cold water.

II. MATHEMATICAL MODEL

For a given set of design conditions, there is an optimal cooling tower design. Optimal design conditions related to the minimum cost of building and operating costs. The optimum air temperature at the outlet of the cooling tower is determined by the formula [9,10]:

$$T_{air,o} = \frac{T_{cw3} + T_{cw2}}{2} \qquad (1)$$

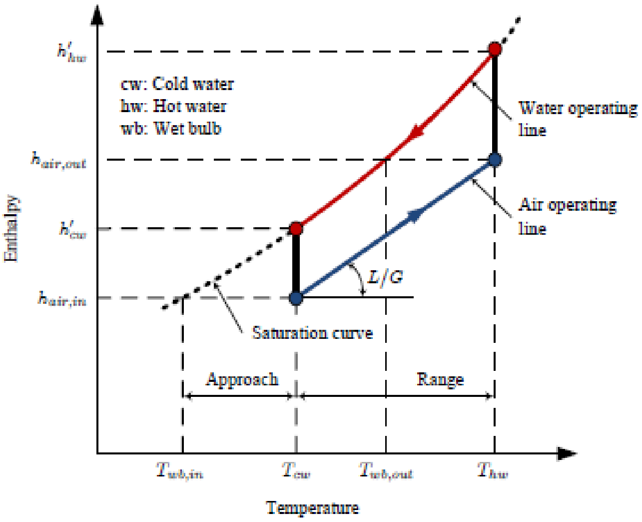


Figure 1 - Thermal process of a cooling tower [4]

As shown in Figure 2, the chilled water leaving the cooling tower is directed to the condenser. An increase in temperature in the circulation pump can be neglected [11,12], which means $T_{cw2} \approx T_{cw1}$. The inlet and outlet water temperature is determined by the formula:

$$T_{cw3} = T_{sat@p=p1} - \Delta T_{pinch,c} \qquad (2)$$

$$T_{cw1} = T_{wb,in} + \Delta T_{approach} \qquad (3)$$

where $\Delta T_{pinch,c}$ is the temperature difference between the steam and cooling water in the condenser; $T_{wb,in}$ - calculated wet bulb temperature, °C.

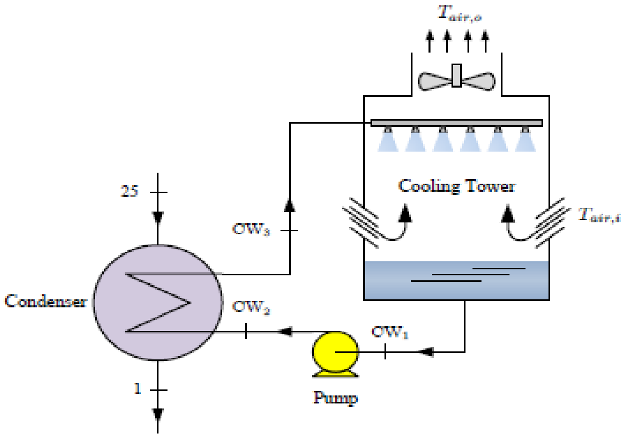


Figure 2 - Scheme of a cooling tower

The pump power is determined by the following formula:

$$W_{CT,pump}\,(к\text{Вт}) = \frac{\rho_w\, g\, L_w H_p}{1000\,\eta_{ct,pump}} \quad ,(4)$$

where ρ_w is the density of water, kg/m^3; L_w is the mass flow rate of water per unit cross-sectional area of the tower, kg/(h m^2); H_p - pump head, m; $\eta_{ct,pump}$ - the efficiency of the cooling tower pump.

The approximate pump head is calculated as follows [9]:

$$H_p(m) = Z_{tower} + 3\ , \quad (5)$$

where is the required filling height of the cooling tower, m.

The power consumption of the fan is calculated on the basis of an empirical ratio, which assumes that for every 226.5 m^3 of air passing per minute through the fan, one horsepower is required (hp≈0.75 kW) [13,14]. Air consumption is determined by the formula:

$$F = \frac{G}{60\,\rho_{air,o}}\ , \qquad (6)$$

where $\rho_{air,o}$ is the air density, kg/m^3, calculated for the outlet air flow; G - is the mass air flow per unit of the cooling tower cross-sectional area, kg/(h m^2).

The fan power is calculated as:

$$\dot{W}_{CT,fan}(\text{кW}) = \frac{F\ (m^3/min)}{226{,}5}\ 0{,}75 \quad (7)$$

NTU$_c$ (number of transfer units) and heat transfer efficiency, ε_c, are calculated as shown below. The heat removed from the condenser is determined by the formula:

$$\dot{Q}_c = L_w C_{p,w}(T_{CW3} - T_{CW2}) \quad , \qquad (8)$$

$C_{p,w}$ - specific heat capacity of water, kJ/(kg.K). The maximum heat transfer in the condenser is determined by the formula:

$$\dot{Q}_{c,max} = C_{min,c}(T_1 - T_{CW2}) \qquad (9)$$

The value obtained for cooling water and dimensionless capacity ratio C_c= 0, where C_{min} is defined as:

$$C_{min,c} = L_w C_{p,w} \qquad (10)$$

The heat transfer efficiency is defined as [15,16]:

$$\varepsilon_c = 1 - \exp(-NTU_c) \qquad (11)$$

NTU$_c$ calculated as:

$$NTU_c = \frac{(UA)'_c}{C_{min,c}} \qquad (12)$$

Under variable load conditions, the result of the general ratio of the heat transfer coefficient, U_c and the heat transfer area, A_c, has the form [17]:

$$(UA)'_c = (UA)_c\left(\frac{L'_w}{L_w}\right)^{0,8} \quad , \qquad (13)$$

where $(UA)_c$ is the new result of the overall ratio of the heat transfer coefficient and the heat transfer area of the condenser, calculated for the new mass flow rate L_w'.

III. RESULTS AND DISCUSSION

The paper analyzed the effect of the alternative condensation method (air-cooled condenser) on the performance of a solar power plant. Initially, the number of air-cooled condenser units was determined. The obtained results are shown in Figure 3, the best performance corresponds to the evaporative method, since the minimum water condensation temperature is limited by the air wet bulb temperature. In the case of an air-cooled condenser, the net power is lower than for an evaporative condenser cooled by a cooling tower due to the high power consumption of the fans.

As shown in Figure 3, the condenser performance air-cooled condenser has an optimal number of blocks, that provides a balance between output power and cycle loss own needs. For the city of Baghdad, the optimal number of air-cooled condenser units is chosen equal to 12 according to the condition of maintaining the required pressure in the condenser (0.008 MPa).

Figures 4 and 5, shows the monthly average pressure distribution in the condenser for the two proposed cooling methods. For Baghdad of low relative humidity and high relative temperature are present during most of the year, so the air-cooled condenser gives a slight improvement in pressure, but its high energy requirements reduce the effective power. Air-cooled condensers cause a decrease in cycle performance due to higher condensing pressure and high auxiliary losses due to high air temperatures. The calculation of the air-cooled condenser was carried out for the size of the solar field corresponding to the minimum cost of electricity (LCOE). Table 1 shows the results obtained for condensers with evaporative cooling in a cooling tower and air cooling.

Monthly performance of PTC solar power plant is shown in Figure 6, for two cases: without heat storage and with him. As mentioned earlier, high fan power consumption and high air temperatures reduce the net power, the difference being especially noticeable during summer days.

Figure 7 shows the annual net power obtained for each cooling method for two cases of energy production and storage (without and with heat storage). For the case without heat storage, the net power reduction when using an air-cooled condenser is 4.13% compared to using a cooling tower, while for the case with heat storage under the same conditions, this value is 3.43%. This decrease in net power also affects cost: the increase in LCOE with air cooling is 8.37% and 11.41% for both cases, respectively.

On the other hand, analysis of alternative condensers has shown that although air-cooled condensers are an excellent alternative, the loss of auxiliary power (required power to the fans) and higher condensing pressure, especially in hot areas, make this technology less attractive. If water is available at the power plant site, then cooling towers must be used to cool the condenser. In the Republic of Iraq, there are two rivers (Tigris and Euphrates) where cooling towers can be used.

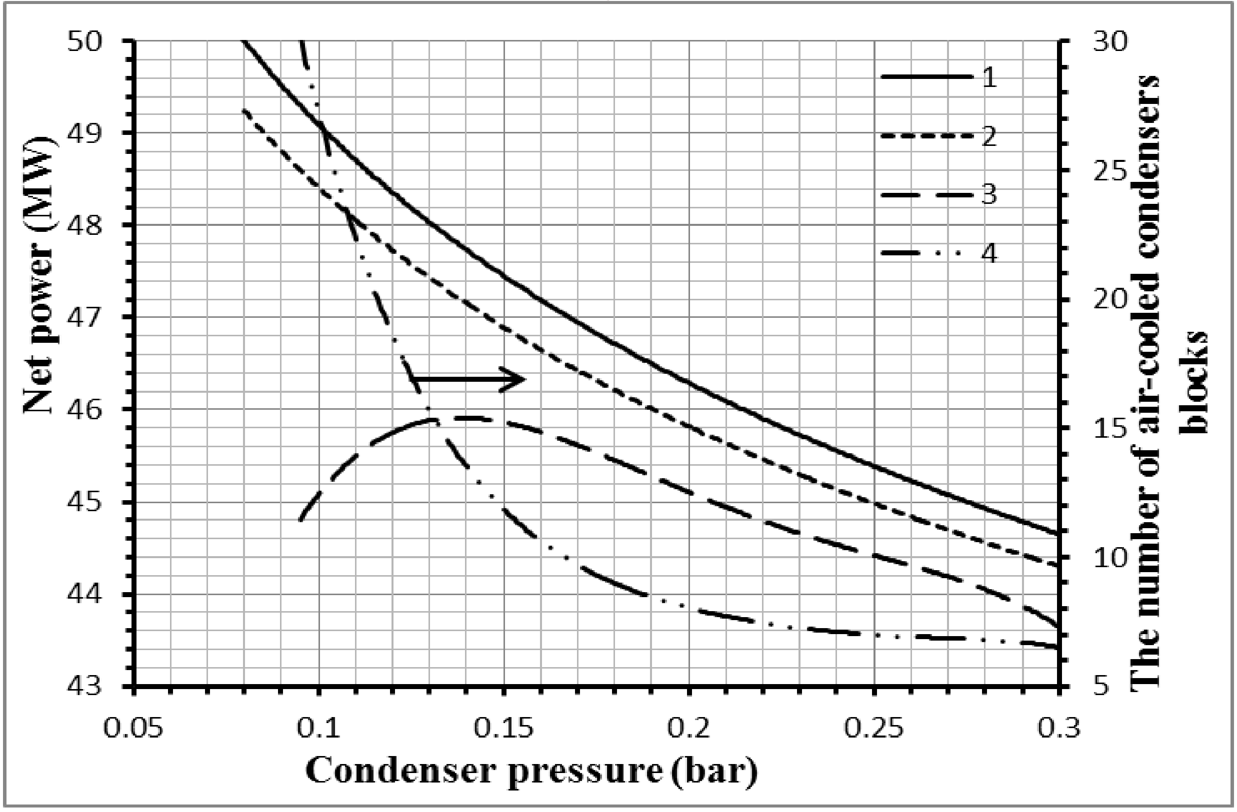


Figure 3 - Influence of the condensation method on the performance of the power cycle: 1- net power without supply of fans in the condenser; 2 - net power with cooling from a cooling tower; 3- number of air-cooled condenser units; 4- net power, air-cooled condenser

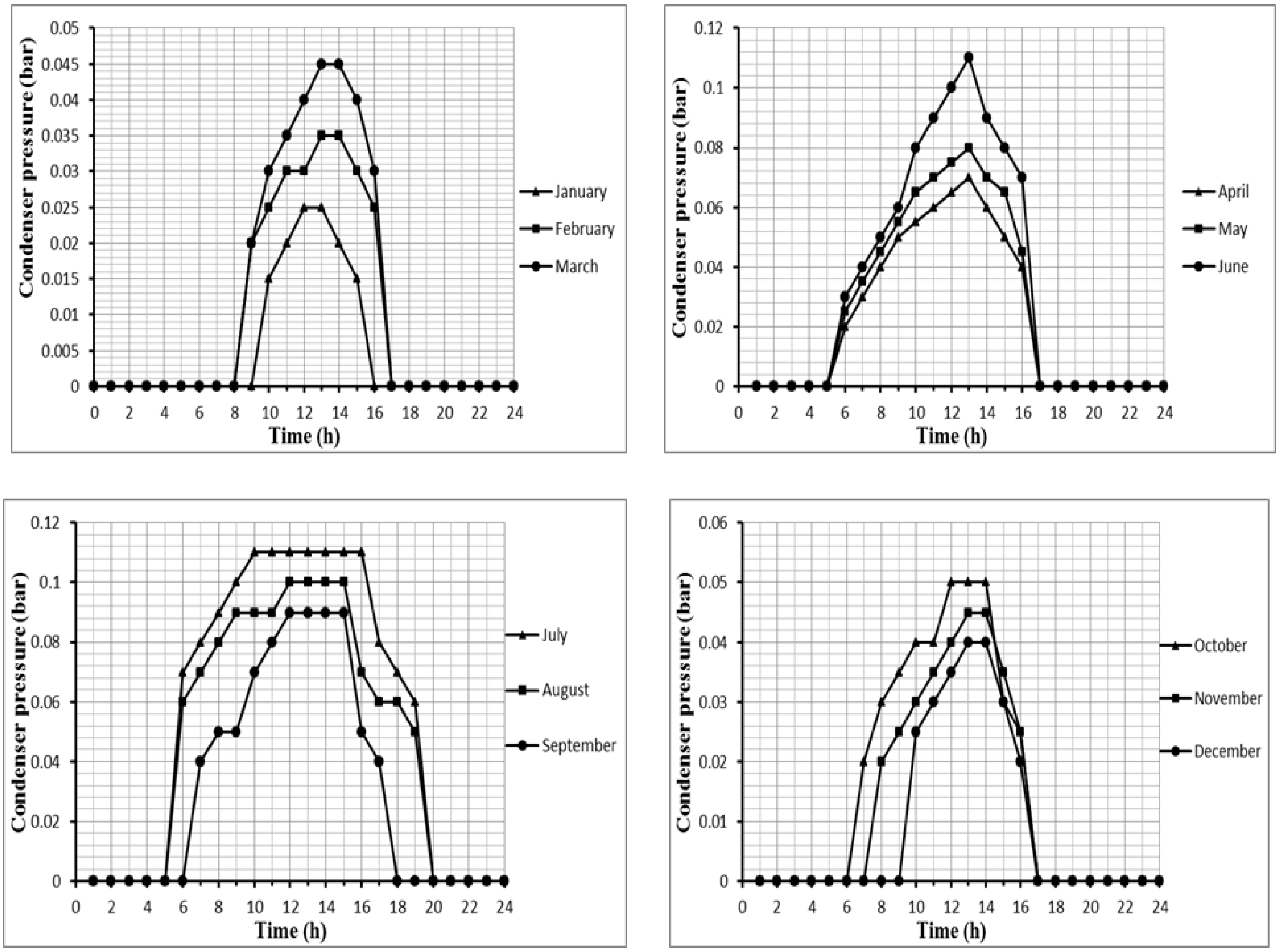


Figure 4 - Average monthly condenser pressures with cooling tower water

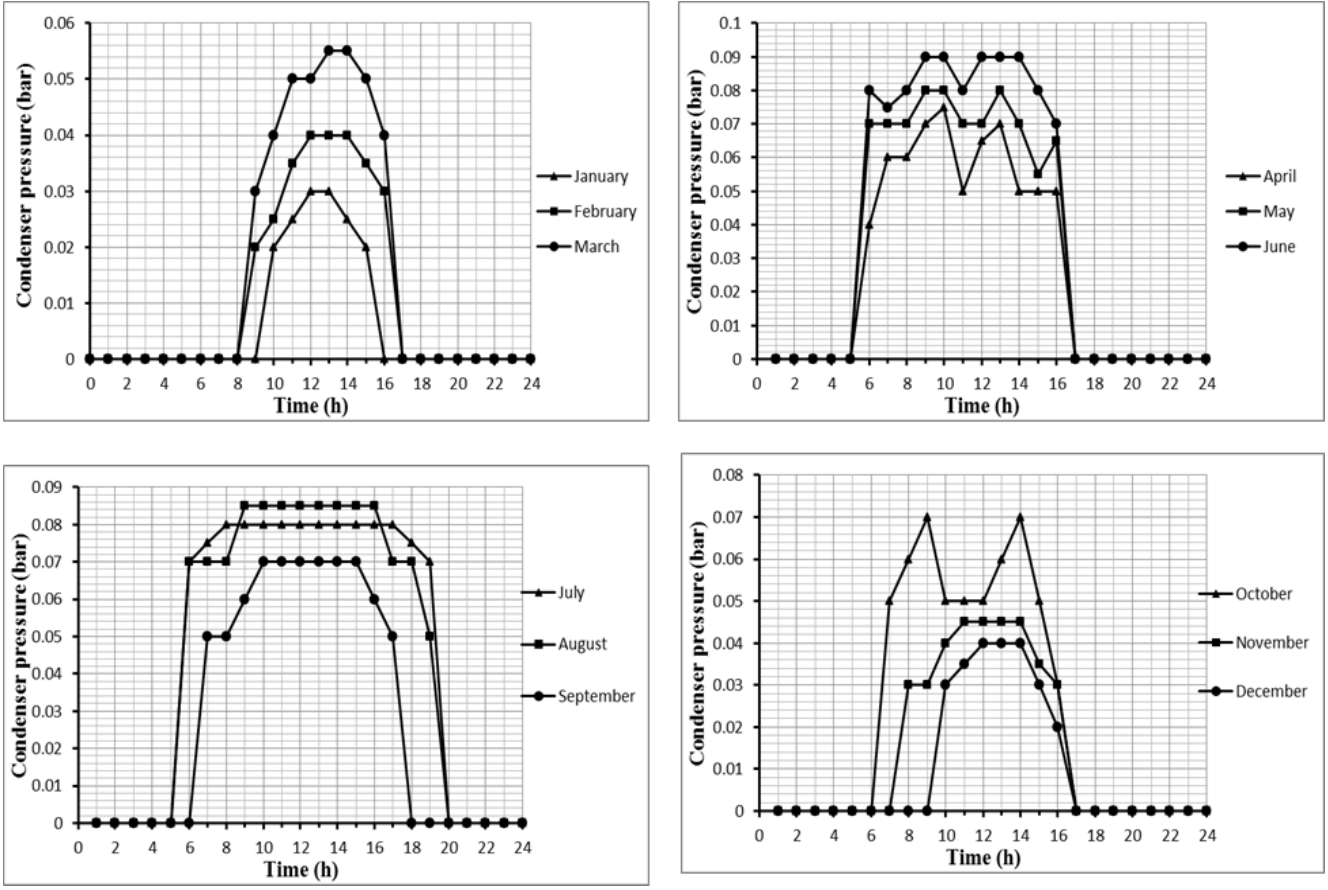
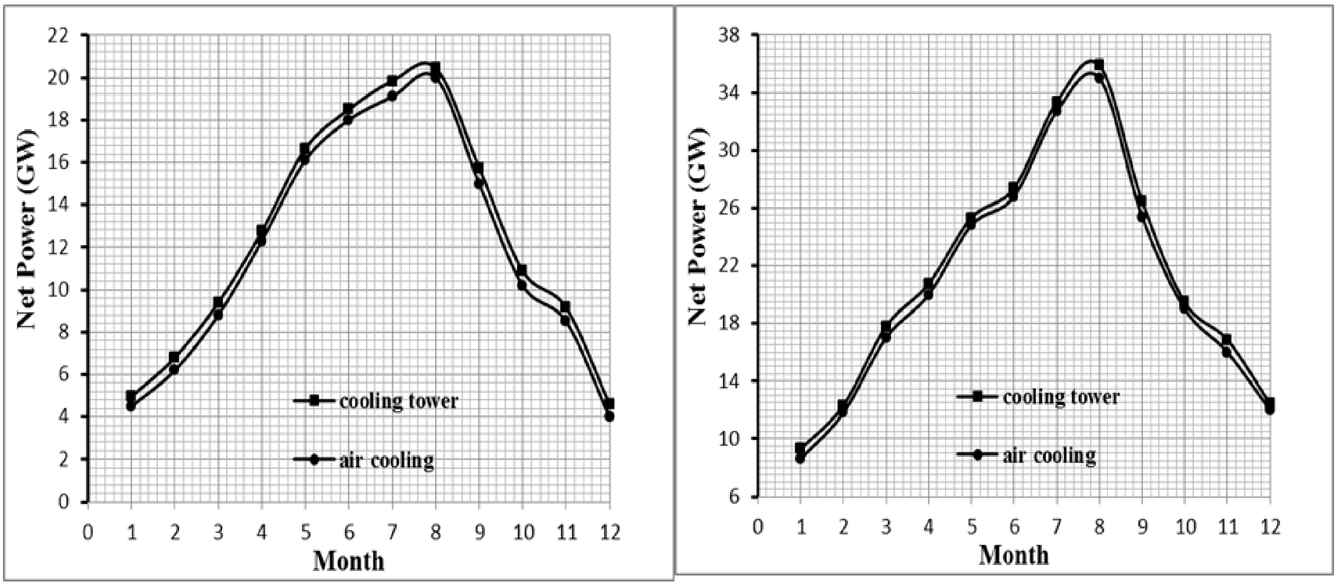


Figure 5 - Average monthly pressures in an air-cooled condenser

Table 1 - Effect of condenser type for annual performance PTC solar power

Parameters					
$W_{net.cycle}$, кW	W_{par}, кW	$LCOE_R$, ¢/кW · h	$LCOE_N$, ¢/кW · h	Net power, GW	
				without accumulation	with accumulation
Cooling tower					
49321,8	3619,3	20,7	25,5	145,7	256,4
Air cooled condenser					
49312,8	5363	22,8	28,1	139,2	247,6



(a) without heat storage

(b) with heat storage

Figure 6 - Influence of the condenser type on the monthly net power

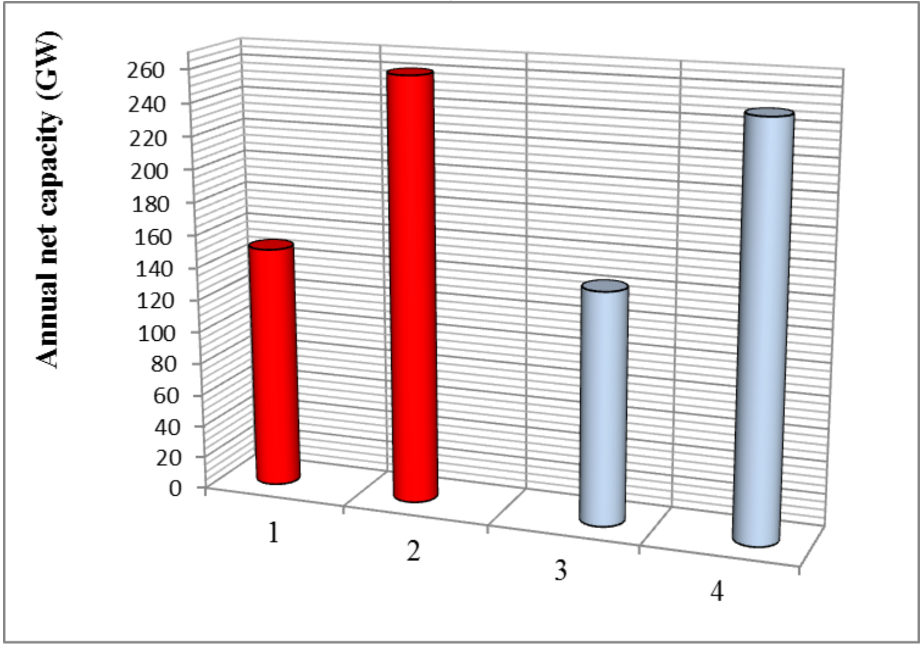


Figure 7 - Annual net capacity of the power plant with cooling tower and air cooled condenser for cases: without heat accumulation: 1 - with a cooling tower, 3 - with air cooling; with heat storage: 2 - with cooling tower, 4 - air-cooled

References

[1] Moran, M.J. Fundamentals of Engineering Thermo-dynamics, 5 ed. / M.J. Moran, H.N. Shapiro //Wiley. - Apr.2004.

[2] Moafaq K.S. Al-Ghezi, “The Global and Scattered Radiation Evaluation for a Horizontal Surface in Baghdad City”, *International Journal Of Computation and Applied Sciences IJOCAAS*, Vol. 3, Issue 1, ISSN:2399-4509, PP: 153-158, August 2017.

[3] Shneen, Salam Waley. “Advanced Optimal for PV system coupled with PMSM.” *Indonesian Journal of Electrical Engineering and Computer Science* 1.3(2016):556-565.

[4] Green, D. Perry’s Chemical Engineers’ Handbook, Eighth Edition, 8 ed / D. Green, R. Perry // McGraw-Hill Professional, Oct.- 2007.

[5] Moafaq K.S. Al-Ghezi, "Simulation Concentrator type of Compound Parabolic Trough Solar Collector in the Solar Thermal Power Plant (STPP) for Conditions of Iraq," *Elixir International Journal, Elixir Thermal Engg***.**121, pp. 51589-51592, August 2018.

[6] Roshen T. A Hamdi, “Dust impact on the photovoltaic outcomes”, Journal of Computation and Applied Sciences IJOCAAS, Vol. 5, Issue 2, ISSN: 2399-4509, PP: 385-390, October 2018.

[7] Fraas, A. Heat exchanger design / A. Fraas // Wiley-Interscience.- 1989.

[8] Moafaq K.S. Al-Ghezi, "Study the Maximum Solar Radiation by Determining the Best Direction of the Solar Collectors," *International Research Journal of Advanced Engineering and Science*, vol.4, Issue 3, pp. 42-44, 2019.

[9] Leeper, S.A. Wet cooling towers: rule-of-thumb design and simulation / S.A. Leeper // Tech. Rep. EGG-GTH-5775, Idaho National Engineering Laboratory, U.S. Department of Energy. – July1981.

[10] Moafaq K.S. Al-Ghezi, " Heat Transfer Model for Thermal Analysis Parabolic Trough Solar Receiver," *International Journal of Trend in Research and Development IJTRD*, vol.6, Issue 4, pp. 155-159, Jul-Aug 2019.

[11] Cengel, Y. Thermodynamics: an engineering approach, Vol. 930. / Y. Cengel, M. Boles, Y. He // McGraw-Hill New York.- 2002.

[12] Moafaq K.S. Al-Ghezi, "Calculate the Reflected Hourly Solar Radiation by Mirror Surfaces of Solar Concentrators Parabolic Trough," *International Journal of Computation and Applied Sciences IJOCAAS*, vol. 3, No. 3, pp. 256-260, 2017.

[13] Mohiuddin, A. Knowledge base for the systematic design of wet cooling towers. Part II: Fill and other design parameters / A. Mohiuddin, K. Kant // International journal of refrigeration. -1996. -№ 1(19) - pp. 52-60.

[14] Moafaq K.S. Al-Ghezi, "Heat Accumulation System for Solar Power Station with Parabolic Trough Solar Collector," *Elixir International Journal, Elixir Renewable Energy* 119, pp.51122-51125, June 2018.

[15] Cengel, Y.A. Heat Transfer: A Practical Approach, 2nd ed. / Y.A. Cengel // McGraw-Hill Companies. –Nov. 2002.

[16] Moafaq K.S. Al-Ghezi, " Effect of the Condenser Pressure and Normalized Steam Mass Flow Rate on the Normalized Net Work Output of the Solar Power Plants," *International Research Journal of Advanced Engineering and Science*, vol.5, Issue 3, pp. 15-20, 2020.

[17] Patnode, A.M. Simulation and performance evaluation of parabolic trough solar power plants / A.M. Patnode // Master’s thesis, University of Wisconsin-Madison., College of Engineering. - 2006.