International Journal of Energetica (IJECA)
https://www.ijeca.info
ISSN: 2543-3717 Volume 6. Issue 2. 2021 *Page 35-43*

4E (Energy-Exergy-Economic-Environmental) performances assessment of different configurations of power cycles

Islem Meriche[1], Adem Chemoul[1], Taqiy Eddine Boukelia[1,2*]

[1] *Mechanical Engineering Department, Jijel University, Jijel, ALGERIA*
[2] *Mechanical and Advanced Materials Laboratory, Polytechnic School of Constantine, Constantine, ALGERIA*

*Email *: taqy25000@hotmail.com*

Abstract – *Steam power plants are alimented by different sources of energy including fossil fuels or renewable ones such as solar thermal, biomass or geothermal. Thus, thermodynamic, economic and environmental analyses of different steam power cycles are highly required for identification and choice of the most effective and viable layout to be adopted in the installation. Consequently, the main aim of the present paper is to compare five different configurations of power cycles in terms of energy and exergy efficiencies, fuel and cooling water consumptions, CO_2 emissions rate, as well as investment and operating costs, and net present value (NPV). The obtained results present relevant differences; the energy and exergy efficiencies of the fifth configuration similar to the one of Achouat power station are the highest with 41.9% and 39.5% respectively. On the other hand, this configuration shows better environmental performances represented by CO_2 emission (46.12 kg/s), and water consumption for cooling (7.42 m^3/s). Economically, there is a clear convergence in the NPV values for configurations with Reheating and Regeneration processes. Moreover, the fourth configuration is the best in terms of net present value (NPV) of 103.1(M€).*

Keywords: *4E, Configuration, Power cycle, Performance, Steam power plant.*

Received: 06/08/2021 – Accepted: 30/10/2021

I. Introduction

The world is witnessing major changes in the energy sector that control the joints of human daily life, and there is no doubt that energy based on fossil fuels such as coal, oil, and gas is the most important source of energy for human development. However, this type of energy is currently facing two main challenges; global climate change and harmful environmental effects. To meet these challenges, any energy conversion system must comply with the environmental laws and respect the emissions limits.

In Algeria, the global demand for electricity has increased, especially during summer season and hot days, when consumption is at its peak. This increase is a direct result of a change in habits consumption and an increase in livelihoods, as well as the impetus given to economic and industrial sectors to meet Algeria's electricity needs. In 2017, the power generation based on steam power plants was about 10074 GWh, which represents a share of 12% of the total installed capacity [1]. Steam power plants have attended remarkable developments in order to improve their energy and exergy performances, and to reduce their economic risks and CO_2 emissions.

Steam power plants are alimented by different sources of energy, either fossil or renewable ones. This last type can be solar thermal, biomass or geothermal. Thus, thermodynamic, economic and environmental analyses of different steam power cycles are highly required for identification and choice of the most effective and viable configuration to be adopted in the installation. In this direction, a large number of studies have been presented to examine this concern. a group of researchers analyzed the thermodynamic performances of a steam power plant with reheating-regenerative technology [2]. The simulations were performed with a CyclePad V2.0 software package. They examined the effects of regeneration on the performance indicators of the steam plant by increasing the number of feed water heater from 1 to 10. The simulation results show that the thermal efficiency of the plant has increased by 8.3%.

Furthermore, another group of researchers analyzed the exergy and exergo-environmental performances of a 660 MW coal-fired supercritical steam power plant located in western India [3]. The study is based on the SPECO (Specific exergy costing) approach, which is followed in this case by exergo-economic analysis. The obtained results prove the possibility of attending a value of 35.54 % for the exergy efficiency; the cooling water and exhaust gases represent the environmental impact rate of 507.173 mPts $s^{-1}$and 676.29 mPts s^{-1} respectively. On the other study [4], the same research team, used MATLAB programming software and performed an economic and exergo-economic analysis of the 660 MW coal-fired supercritical units. The economic analysis is carried out using the net present value method. The results of the economic analysis established that the payback period of the plant is estimated at 4.5 years for 9% of the interest rate. In another numerical study performed a complete thermodynamic analysis of an 82 MW steam power plant. They developed an EES code to assess the energy loss, energy efficiency, exergy efficiency and exergy destruction for each part of the installation, by considering the range of actual values of the operating parameters. It has been observed that the energy and exergy efficiencies of this plant are 35.95% and 33.15% respectively [5]. Moreover, the maximum energy loss occurs in the boiler, (approximately 36.39%). Using the thermodynamic properties of steam, an investigation to show via a code developed under EES environment, the energy and exergy efficiencies of an existing commercial thermal power plant, and values of 38% and 53% respectively have been recorded. In addition, the monetary expenditure, the costs of exergy losses and the exergo-economic factors of the power plant units were calculated, and a maximum cost of exergy losses in the boiler of 758.32 $/h has been obtained [6]. On the other hand, a study concluded conducted technical and economic evaluations of the use or non-use of low- and high-pressure feed water heaters in different situations [7]. In a research lab, they used the pinch analysis method to integrate energy into the steam cycle of a 250 MW steam power plant located in Rajasthan, India [8]. The recovery of the steam cycle is carried out according to six schemes. By using this approach, the generated power is increased by 0.55%, and the demand for demineralised water is reduced by 57.6%. Furthermore, the exergy analysis shows that the boiler has maximum exergy destruction with a share of 89% of the whole steam power plant. An investigation used TRNSYS programming software to design a numerical model of a thermal power plant based on parabolic trough solar technology. The energy performance of the system was compared for two cases, the Rankine cycle with and without a solar field [9]. a fairly recent study performed a techno-economic analysis of deploying an aero-condenser in a concentrating solar power (CSP) plant with two configurations; the first is based on thermic oil as the working fluid, and the second is utilizing molten salt[10].

However, according to our knowledge, a 4E comparative study (Energy-Exergy-Economic-Environmental) between different layouts of Steam Rankine power cycle is not found in the literature. Consequently, the main aim of the present work is to compare five different configurations of this type of power cycles in terms of energy and exergy efficiencies, consumed fuel, CO_2 emissions, cooling water consumption, as well as investment and operating costs, net present value (NPV) and depreciated payback period (DPP).

II. DATA AND METHODOLOGY

II.1. Studied Configurations

4E (Energy- Exergy-Economic-Environmental) is a comparative study of five different configurations of a power cycle was carried out in order to choose the best configuration to adapt in CSP, geothermal and biomass thermal power plants. These layouts are listed below:

- Basic Rankine Cycle (1);
- Regenerative Rankine Cycle (2);
- Rankine Cycle with Reheating (3);
- Rankine Cycle with Reheating and Regeneration on both turbines (LPT and HPT) (4);
- Similar Rankine Cycle of a real steam power plant (Achouat- Jijel, Algeria) (5).

The five studied configurations have the same net capacity of 210 MW to have a common ground for comparison. However, due to the addition of different processes in each configuration, differences in thermodynamic performances, economic and environmental parameters arise. Therefore, the five configurations are compared in terms of energy and exergy efficiencies, consumed fuel, CO_2 emissions, cooling water consumption, as well as investment & operating costs, net present value (NPV) and depreciated payback period (DPP). The Table 1 summarises the assumptions and the nominal values of the design for the main parameters within the five studied configurations [11].

Table 1. Nominal values for the main parameters in the studied configurations [10,11]

parameters	Value	units
Ambient conditions: Temperature/ Pressure	25/ 1.01325	°C/ bar
HPT input conditions: Temperature/ Pressure	540/ 127.5	°C/ bar
LPT input conditions: Temperature/ Pressure	540/ 23.48	°C/ bar
Isentropic efficiency of turbines	88	%
Mechanical efficiency of turbines	97.5	%
Isentropic efficiency of pumps	87	%
Generator efficiency	98	%
Fuel lower calorific value	28938	kJ/kg
Condensing pressure	0.0527	bar
Outlet temperature of the reheater	540	°C
Power generated by the plant	210	Mw
Number of service hours per year	7000	hr/yr

II.2. Mathematical Modeling

The Cycle-Tempo 5.1 Software has been used to simulate the thermodynamic performances (energetic and exergetic). On the other hand, using MATLAB software [12,13], mathematical codes have been developed to simulate the economic and environmental performances of these investigated configurations.

II.2.1. Thermodynamics modelling

The energy analysis of every sub-system of the installation is based on the conservation of mass and energy (the first law of thermodynamics):

$$\sum \dot{m}_{\text{in}} = \sum \dot{m}_{\text{out}} \tag{1}$$

$$\dot{Q} + \sum \dot{m}_{\text{in}} h_{\text{in}} = \dot{W} + \sum \dot{m}_{\text{out}} h_{\text{out}} \tag{2}$$

On the other hand, the general formula to present the exergy analysis can be formulated as:

$$\dot{E}x_Q + \sum \dot{m}_{\text{in}}\, ex_{\text{in}} = \dot{E}x_W + \sum \dot{m}_{\text{out}}\, ex_{\text{out}} \tag{3}$$

The exergy of a substance can be partitioned into four segments. The two most significant are physical exergy and chemical exergy [14]. In this study, the other two parts; kinetic exergy and potential exergy are negligible.

$$\dot{E}x = \dot{E}x_{Ph} + \dot{E}x_{Chm} \tag{4}$$

$$\dot{E}x_{Ph} = \dot{m}\left(h - h_0\right) - T_0\left(S - S_0\right) \tag{5}$$

$$\dot{E}x_{Chm} = \dot{m} \sum_i^n R_i T_0 \ln\left(\frac{y_i}{y_i^0}\right) \tag{6}$$

Table 2 presents the main equations for each component of the studied configurations.

Table 2. Main equations used to perform the thermodynamic analysis for each component of the configurations

Component		Equation
Boiler	Exergy produced	$\dot{E}x_{prd,Boiler} = \dot{E}x_{steam}^{tm} - \dot{E}x_{water}^{tm}$
	Exergy source	$\dot{E}x_{src,Boiler} = \dot{E}x_{fuel}^{chm}$
Condenser	Exergy produced	$\dot{E}x_{prd,CON} = \dot{E}x_{p,out} - \dot{E}x_{p,in}$
	Exergy source	$\dot{E}x_{src,CON} = \dot{E}x_{s,in} - \dot{E}x_{s,out}$
Turbines	Power	$\dot{W}_{Tub} = \dot{m}_{steam}\,(h_{in} - h_{out})$
	Exergy produced	$\dot{E}x_{prd,Tub} = \dot{W}_{Tub}$
	Exergy source	$\dot{E}x_{src,Tub} = \dot{E}x_{in}^{tm} - \dot{E}x_{out}^{tm}$
Pump	Power	$\dot{W}_{Pum} = \dot{m}_{water}\,(h_{out} - h_{in})$
	Exergy produced	$\dot{E}x_{prd,Pum} = \dot{W}_{Pum}$
	Exergy source	$\dot{E}x_{src,Pum} = \dot{E}x_{out} - \dot{E}x_{in}$
Feed water heater	Exergy produced	$\dot{E}x_{prd,FWH} = \dot{E}x_{p,out} - \dot{E}x_{p,in}$
	Exergy source	$\dot{E}x_{src,FWH} = \dot{E}x_{s,in} - \dot{E}x_{s,out}$
Deaerator	Exergy produced	$\dot{E}x_{prd,DES} = (\dot{m}_p\ ex_{out}) - \dot{E}x_{p,in}$
	Exergy source	$\dot{E}x_{src,DES} = \Sigma\dot{E}x_{s,in} - (ex_{out}\ \Sigma\dot{m}_s)$
Exergy efficiency		$\eta_{EX} = \frac{\dot{E}x_{prd}}{\dot{E}x_{src}}$
Electric power		$\dot{W}_{ele} = \dot{W}_{Tub}\eta_{Gen}$
Net power		$\dot{W}_{net} = \dot{W}_{ele} - \dot{W}_{Pum}$

II.2.2. Economic modelling

In the present study, the economic analysis of the five configurations was carried out on the basis of the initial investment (€), the operating cost (€/year), the annual income obtained (€/year), the net present value (NPV) (€) and depreciated payback period (DPP) (years) [15].

The initial investment can be expressed in terms of the cost of every individual component as follows:

$$I_{Tot} = (C_d + C_{ind}) \tag{7}$$

The total direct plant costs:

$$C_d = (1 + \mu + \sigma + \delta + \varepsilon)\, C_{eqp} \tag{8}$$

Where:

μ, is the factor of direct installation, μ= 0.3.
σ, is the factor of auxiliary services, σ= 0.15.
δ, is the factor of instrumentation and controls, δ=0.1.
ε, is the preparation site factor, ε=0.1.

The total indirect plant costs:

$$C_{ind} = (\partial + \ell)\, C_{eqp} \tag{9}$$

Where:

∂, is the engineering factor, ∂ = 0.12.

ℓ, is the start-up factor, ℓ= 0.1.

The initial cost of equipment:

$$C_{eqp_i} = [a\,(\dot{W})^b]_i \quad (10)$$

The specific coefficients *a* and *b* are given in Table 3.

Table 3. Constants to determine the cost of each component of the plant presented [15].

Components	*a*	*b*
Boiler	1340000	0.694
Turbines	633000	0.398
Condenser	398000	0.333
Condensate extraction pumps	9000	0.4425
Feed pump	35000	0.6107
Pump	28 000	0.5575
Feed water heater	51 000	0.5129
Deaerator	17 100	0.5575
Generator	138300	0.3139

The total annual operating cost (CO_{opr}), is obtained on an annual basis, including the cost of operating labor (CO_{lab}), the cost of purchasing fuel (CO_f), the cost of servicing and maintenance (CO_m), insurance and general costs ($CO_{inscgen}$).

$$C_{opr} = C_{fuel} + C_{lab} C_m + C_{inscgen} + C_m \quad (11)$$

The annual cost of purchasing fuel (CO_f) :

$$C_{fuel} = V\, CG_P\, hr \quad (12)$$

Where CG_p, is the price of fuel (natural gas) on the Algerian market is set by the value 2 €/MWh [16].

The annual cost of operating labor is given by the following formula:

$$C_{lab} = n_{emp}\, C_{Avr,lab} \quad (13)$$

The annual cost of insurance and general costs:

$$C_{inscgen} = 0.025 \times I_{Tot} \quad (14)$$

The insurance costs are considered as 2.5 % of the total fixed cost [15].

The annual cost of maintenance is given by the following formula:

$$C_m = 0.05 \times I_{Tot} \quad (15)$$

The annual cost of maintenance considered as 5 % of the total fixed cost [15].

The annual revenues (R_{ann}) from the generated power:

$$R_{ann} = \xi\, \dot{W}\, hr\, CE_p \quad (16)$$

Where: ξ as 90 %, takes into account the energy needs of auxiliary equipment [15], CE_P is the current price of electricity on the Algerian market is set by the value 33 €/MW [16], while *hr* represent number of service hours per year.

Finally, net present value is formulated as:

$$NPV = \sum_j^N \frac{(R_{ann} - CO_{opr})_j}{(1+r)^j} - I_{Tot} \quad (17)$$

Where: *r* and *N* are the discount rate (9%) and the life of the plant (35 years) respectively [15], [17].

II.2.3. Environmental modeling

This study also examines the environmental impacts including the CO_2 emissions, and the cooling water consumptions. The general expression for the combustion of methane is written based on stochiometric combustion:

$$CH_4 + 2(O_2 + 3.67\,N_2) \longrightarrow CO_2 + 3.67\,N_2 + 2H_2O \quad (18)$$

The cooling water consumption was also investigated by calculating the mass flow rate ($\dot{m}_c$) as:

$$\dot{m}_c = \frac{\dot{m}_h\, L_v}{Cp_c (T_{c,\text{in}} - T_{c,\text{out}})} \quad (19)$$

III. Results and Discussion

III.1. Validation

In order to confirm the credibility of the developed model, its performances are evaluated by comparing the obtained results using the energy model with those of real data given by the manufacturer of Achouat-Jijel plant. Table 4 represents the statistical comparison between the two based on the relative error at some points. The error of the mass flow rate of the steam goes from a minimum value of 0.09% at the inlet of the boiler to a maximum value of 13.92% at the outlet of the condenser. On the other hand, the pressure error varies from a minimum value of 0% at the majority of the main points, to a maximum value of 3.01% at the outlet of HPT. In addition, the maximum temperature error is 2.94% at the outlet of the deaerator.

Table 4. Statistical comparison between the manufacturer's data and the results of the model.

Point	Parameter	Manufacturer data	Model results	Error (%)
Boiler inlet	T (°C)	244	242.9	0.45
	P (bar)	178.5	178.5	0
	ṁ (kg/s)	171.5	171.66	0.09
HPT outlet	T (°C)	329	321.29	2.39
	P (bar)	26.7	27.53	3.01
	ṁ (kg/s)	160.27	165.92	3.4
Condenser outlet	T (°C)	33.5	33.81	0.91
	P (bar)	0.0527	0.0527	0
	ṁ (kg/s)	125.25	145.52	13.92
Deaerator outlet	T (°C)	169.2	164.37	2.94
	P (bar)	6.9	6.9	0
	ṁ (kg/s)	171.5	171.66	0.09

III.2. 4E comparative study between the five configurations

According to the Figures 1-5, it can be noticed that the quality of the steam at the outlet of the LPT is much better in the cycles which include the heating system than in the other cycles (Basic cycle, Regenerative cycle). The quality varies from a minimum value of 85.51% for the simple cycle, to a maximum value of 94.84% for the fourth configuration; this positive variation is due to the reheating system that works to improve the quality of steam at the LPT. On the other hand, it can be noticed that the steam mass flow in the system decreases when using the reheating system, which goes from a value of 173.5 kg/s in the simple cycle to 144.27 kg/s in the reheating cycle, while the value in the presence of regeneration processes is 154.55 kg/s. Furthermore, due to the addition of different processes in each configuration, differences in performance (energy and exergy), and economic and environmental parameters arise. These differences are shown in Table 5. Furthermore, Figure 6 shows the evolution of NPV with the lifetime of the installation with the five layouts.

Table 5. 4E comparative analysis of the five configurations.

Configurations	1	2	3	4	5
Energy efficiency (%)	35.74	37.41	38.31	40.02	41.09
Exergy efficiency (%)	33.7	35.26	36.11	37.73	39.5
Fuel consumption (kg/s)	19.7	18.9	18.32	17.61	16.81
CO_2 Emissions (kg/s)	54.04	51.85	50.26	48.31	46.12
Cooling water usage (m^3/s)	9.64	8.99	8.56	8.01	7.42
Investment cost (M€)	119.87	119.87	121.76	123.24	132.12
Operating cost (M€/yr)	23.26	22.7	22.46	22.23	21.69
NPV (M€)	96	102	102.2	103.1	100
DPP (years)	8.7	8.3	8.4	8.5	9

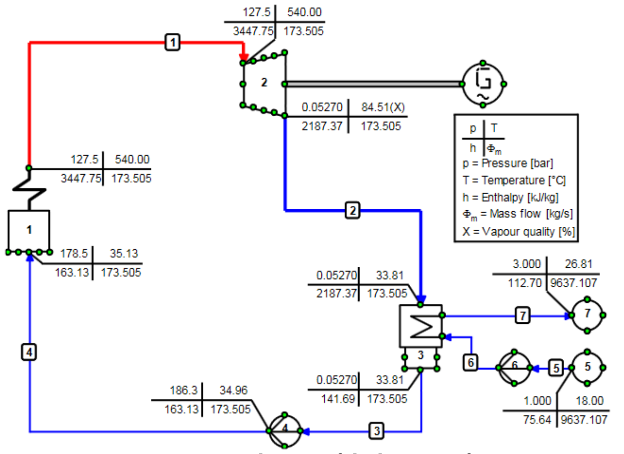

Figure 1. Stream at each point of the basic Configuration.

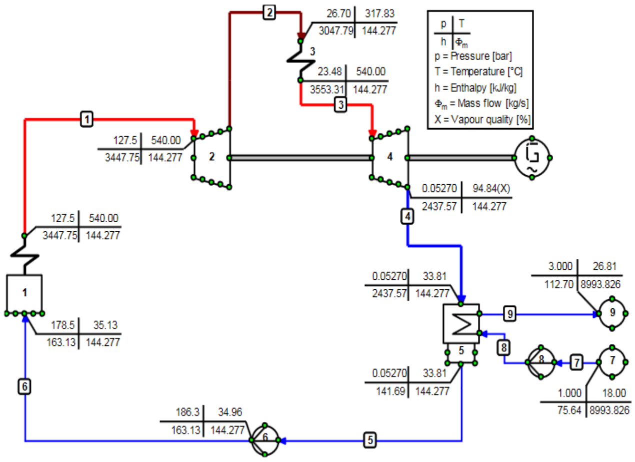

Figure 2. Stream at each point of the Configuration with Reheating.

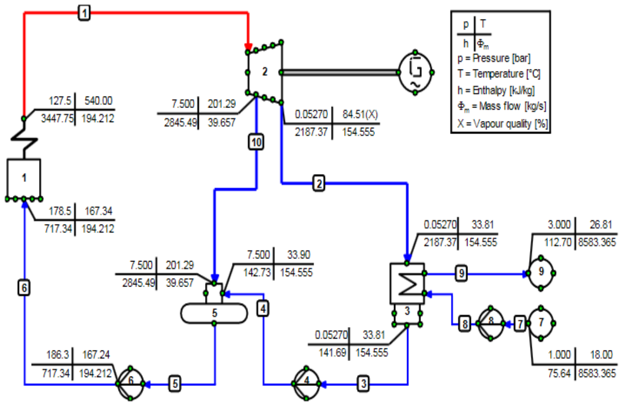

Figure 3. Stream at each point of the Regenerative Configuration.

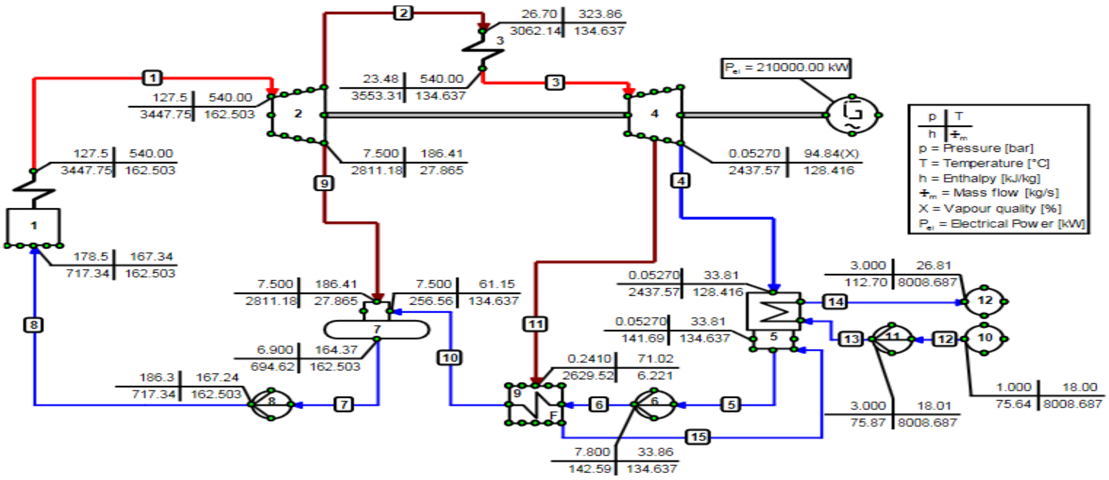

Figure 4. Stream at each point of the configuration with Reheating and Regeneration on both turbines (LPT and HPT).

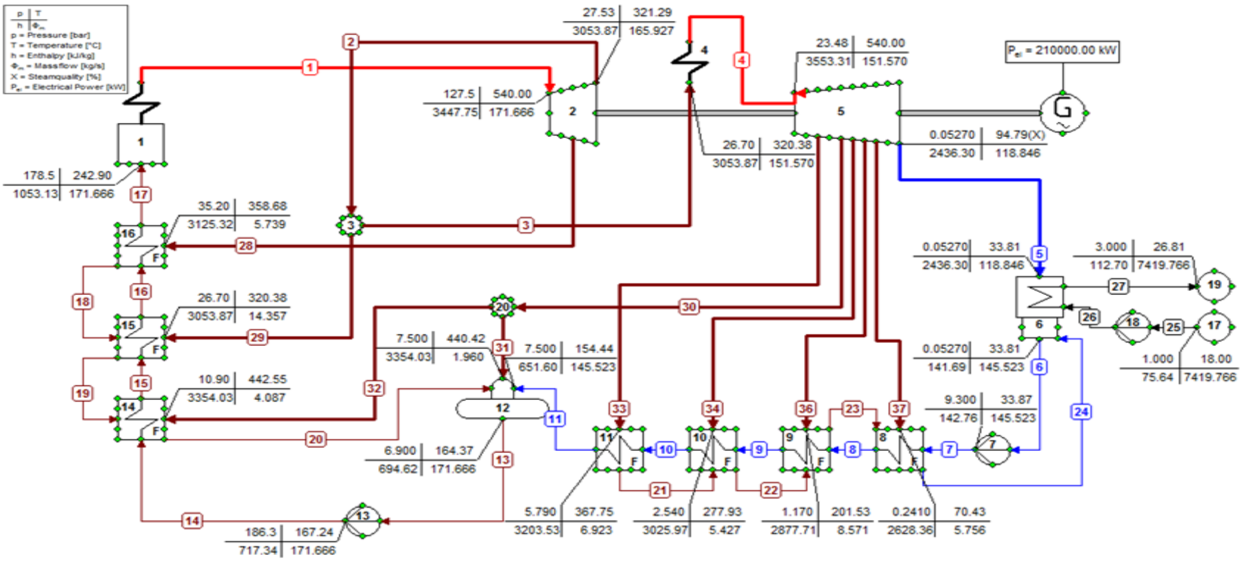

Figure 5. Stream at each point of the fifth configuration.

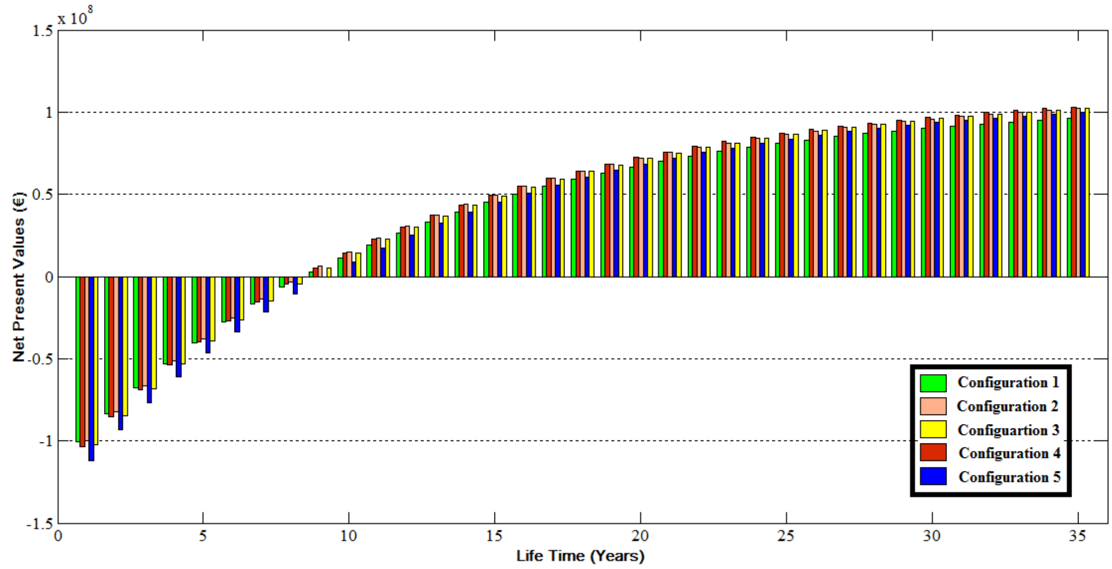

Figure 6. Evolution of NPV with lifetime of the installation with the five layouts.

From Table 5, it seems that the fifth configuration (similar to Achouat plant) has the highest energy and exergy performances, with values of 41.9% and 39.5% respectively, therefore energy and exergy gains of 6.16% and 5.8% respectively are attained compared to the simple cycle (configuration 1). This explains the essential role of regeneration and reheating systems in the process of improving the performances of steam power plants. On the environmental point of view, and according to Table 5, the fifth configuration is always the best, with a fuel consumption of 16.81 kg/s, which refers to a decrease of 2.89 kg/s compared to the first configuration, and 0.8 kg/s compared to the fourth configuration. In addition, the fifth configuration has the lowest rate of CO_2 emissions with a value of 46.12 kg/s, which represents a decrease of 7.93 kg compared to the first configuration, and 2.19 kg compared to the fourth one. On the other hand, the fifth configuration always remains the best configuration in term of water consumption for the cooling process, with the lowest value of 7.42 m^3/s, with a saving of 2.22 m^3/s compared to the simple cycle (first configuration). This difference is due to the decreasing in the mass flow rate of the steam at the outlet of the low-pressure turbine (LPT).

In the economic dimension, there is an increase in the investment cost, when different thermal equipment are added to the plant, with a minimum value of almost 119.9 million Euros (M€) for the simple cycle (configuration 1), and a maximum value of 132.12 million Euros for the fifth configuration, thus, a difference of 12.25 M€ between the two layouts. On the other hand, the annual operating cost improves as the thermal equipment increases with a minimum value of 21.69 M€/year for the fifth configuration and a maximum value of 23.26 M€/year for the first configuration, and this is mainly due to the amount of fuel consumed.

From Figure 6, it can be observed a clear convergence in the NPV in configurations with Reheating and Regeneration. The net present value is 1.07 times greater for the fourth configuration than the first one; with a maximum value in the fourth configuration recorded 103.1 million Euros and the minimum value in the first configuration 96 million Euros. In addition, it is noted the shortest depreciated payback period (DPP) for the second configuration is 8.3 years; this is mainly due to the low investment cost. The longest depreciated payback period (DPP), it goes back to the fifth configuration, 9 years. After this period, the plant begins to make a profit.

IV. Conclusion

In this study, 4E (Energy - Exergy- Economic-Environmental) comparative study of five different configurations of a power cycle was performed. Thus, a validation was carried out to verify the reliability of the developed model compared to real data of Achouat power plant. The results indicate relevant differences; the energy and exergy efficiencies of the Achouat power station are the highest with values of 41.9% and 39.5% respectively, while the worst configuration was that of the basic cycle with the values of 35.74% and 33.7% respectively. On the other hand, Achouat's configuration shows better environmental performance represented by the CO_2 emission rate and the cooling water usage. The net present value is 1.07 times greater for the fourth configuration than the first configuration. In addition, it is noted from the predictions that the shortest depreciated payback period (DPP) for the second configuration is 8.3 years. As for the longest depreciated payback period (DPP), it goes back to the fifth configuration, 9 years. After this period, the plant begins to make a profit.

Nomenclature

C	Cost (€)	$\dot{m}_{out}$	Outlet mass flow rate (kg/s)
$C_{Avr,lab}$	Average labour cost (€)	$\dot{m}_p$	Mass flow rate of a primary fluid (kg/s)
C_d	Direct cost (€)	$\dot{m}_s$	Mass flow rate of a secondary fluid (kg/s)
C_{eqp}	Total cost of equipments (€)	$\dot{m}_{steam}$	Mass flow rate of steam (kg/s)
$C_{eqp\ i}$	Initial cost of equipment (€)	$\dot{m}_{water}$	Mass flow rate of water (kg/s)
C_{ind}	Indirect cost (€)	N	Number (-)
C_{opr}	Operating cost (€)	NPV	Net present value (€)
Cp_c	Heat capacity of cooling water (kJ/K)	n_{emp}	Number of employees (-)
CE_p	Electric price (€)	$\dot{Q}$	Heat quantity (Mw)
CG_p	Gas price (€)	R	Ideal gas constant (kJ/mol.K)
CO_f	Fuel cost (€)	R_{ann}	Annual revenues (€)
$CO_{inscgen}$	Insurance and general costs (€)	r	Discount rate (%)
CO_{lab}	Labor cost (€)	S	Entropy (kJ/K)
CO_m	Maintenance cost (€)	S_0	Specific entropy (kJ/kg. K)
$\dot{E}x$	Exergy (Mw)	T	Temperature (°C)
$\dot{E}x_{Chm}$	Chemical exergy (Mw)	T_0	Ambient temperature (°C)
$\dot{E}x_{in}$	Inlet exergy (Mw)	$T_{c,in}$	Inlet temperature of cooling water (°C)
$\dot{E}x_{Ph}$	Physical exergy (Mw)	$T_{c,out}$	Outlet temperature of cooling water (°C)
$\dot{E}x_{prd}$	Product exergy (Mw)	V	Volume flow rate (m^3/h)
$\dot{E}x_Q$	Heat exergy (Mw)	$\dot{W}$	Power (Mw)
$\dot{E}x_{src}$	Source exergy (Mw)	$\dot{W}_{ele}$	Electrical Power (Mw)
$\dot{E}x^{tm}$	Thermo-mechanical exergy (Mw)	$\dot{W}_{net}$	Net Power (Mw)
$\dot{E}x_W$	Work exergy (Mw)	$\dot{W}_{Pum}$	Pump Power (Mw)
ex	Specific exergy (kJ/kg)	$\dot{W}_{Tub}$	Turbine Power (Mw)
ex_{in}	Specific inlet exergy (kJ/kg)	y	Molar fraction (-)
ex_{out}	Specific outlet exergy (kJ/kg)		**Abbreviation**
h	Enthalpy (kJ/kg)	CON	Condenser
h_0	Specific enthalpy (kJ/kgK)	CSP	Concentrating solar power
h_{in}	Inlet enthalpy (kJ/kg)	DES	Deaerator
h_{out}	Outlet enthalpy (kJ/kg)	DDP	depreciated payback period
hr	Number of service hours per year (Hour/years)	FWH	Feed water heater
I_{Tot}	Total investment cost (€)	HPT	Haut pressure turbine
L_v	Latent heat (kJ/kg)	Gen	Generator
$\dot{m}$	Mass flow rate (kg/s)	LPT	Low pressure turbine
$\dot{m}_c$	Mass flow rate of cooling water (kg/s)	Pum	Pump
$\dot{m}_h$	Mass flow rate of heat fluid (kg/s)	Tot	Total
$\dot{m}_{in}$	Inlet mass flow rate (kg/s)	Tub	Turbine

References

[1] Ministry of Energy (Algeria), https://www.energy.gov.dz/

[2] S.O. Oyedepo et al, "Thermodynamics analysis and performance optimization of a reheat –Regenerative steam turbine power plant with feed water heater", Fuel, Vol. 280, 2020. 118577.

[3] K.C. Nikam, R. Kumar, R. Jilte, "Exergy and exergo-environmental analysis of a 660 MW supercritical coal-fired power plant", J Therm Anal Calorim, 2020.

[4] K.C. Nikam, R. Kumar, R. Jilte, "Economic and exergoeconomic investigation of 660 MW coal-fired power plant", J Therm Anal Calorim, 2020.

[5] V. Kumar, B. Pandya, V. Matawala, "Thermodynamic studies and parametric effects on exergetic performance of a steam power plant", International Journal of Ambient Energy, Vol. 40, Issue 1, 2017, pp. 1- 45.

[6] A. Bolatturk, A. Coskun, C. Geredelioglu, "Thermodynamic and exergoeconomic analysis of Cayırhan thermal power plant", Energy Conversion and Management, Vol. 101, 2015, pp. 371–378.

[7] S.N. Naserabad, A. Mehrpanahi, G. Ahmadi, "Multi-objective optimization of feed-water heater arrangement options in a steam power plant repowering", Journal of cleaner production, Vol. 220, 2019, pp. 253–270.

[8] S.S. Chauhan, S. Khanam, "Enhancement of efficiency for steam cycle of thermal power plants using process integration", Energy, Vol. 173, 2019, pp. 364–373.

[9] A. Remlaoui, M. Benyoucef, D. Assi, D. Nehari, "A TRNSYS dynamic simulation model for a parabolic trough solar thermal power plant", Int. J. Energetica, Vol. 4, Issue 2, 2019, pp. 36-41.

[10] T.E. Boukelia, M.S. Mecibah, A. Laouafi, A. Mekroud, A. Bouraoui, "Potential assessment of using dry cooling

mode in two different solar thermal power plants", Int. J. Energetica, Vol. 2, Issue 2, 2017, pp. 18-24.
[11] Data catalog. Available at Achouat power station.
[12] Asymptote. Cycl-Tempo, http://www.asimptote.nl
[13] MathWorks. MATLAB, https://www.mathworks.com
[14] I. Dincer, " Comprehensive Energy Systems", Elsevier, 1st edition 2018, ISBN 978-0-12-809597-3.
[15] A.C. Caputo, M. Palumbo, P.M. Pelagagge, F Scacchia, "Economics of biomass energy utilization in combustion and gasification plants: Effect of logic variables", Biomass and bio energy, Vol. 28, 2005, pp. 35–51.
[16] Global Petrol Prices, https://fr.globalpetrolprices.com/
[17] R. Kumar, A.K. Sharma, P.C. Tewari, "Cost analysis of a coal-fired power plant using the NPV method", J Ind Eng Int, Vol. 11, 2015, pp. 495–504.