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Energetic modelling of hybrid SOFC-Gas Turbine Power Plant

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***Abstract*—Nowadays, fuel cells and especially solid oxide fuel cells (SOFC) are receiving more attention from researchers because these devices produce clean energy with high efficiency. Noting that in the south of Tunisia power generators suffer from ambient conditions. In the purpose to enhqnce its perfor;qnces q parametric study is performed on an hybrid power plant engendring a gaz turbine cycle GT a fuel cell SOFC. The Tunisian natural gas is used as fuel for the SOFC and the GT cycle. An external pre-reforming system is installed before the SOFC. Heat recovery systems are adopted to valorize the waste heat at the SOFC and GT exhausts. The gas from the SOFC exhaust is also used as additional supply of the combustion chamber.**

The equations governing the electrochemical processes and the energy balances of the power plant components are established. Numerical simulations using EES software are performed. The influences of key operating parameters, such as ambient temperature, pre-reforming fraction and current density on the performance of the SOFC-GT hybrid system are analyzed. The integration of the SOFC enhances the hybrid cycle efficiency of about 50 %. The decrease of the ambient temperature enhances the system efficiencies. While the pre-reforming fraction, has a positive effect on the indicated parameters. The SOFC voltage decreases with increasing current density. The same tendency is obtained for SOFC and SOFC-GT efficiencies.

***Keywords*— gaz turbine, fuel cell, heat recovery, energy efficiency, pre-reforming, energy balance**

Introduction

Nowadays, fuel cells are receiving more attention from researches because these devices produce clean energy with high efficiency. SOFC, among them, presents special advantages which make it suitable for the integration with different power cycles. A high electrical efficiency can be achieved with the integration of SOFC with multi-MW gas turbine engines [1]. Combining solid oxide fuel cells (SOFCs) with gas turbine is widely renowned by the high energy efficiency and the low emission [2, 3]. Adams et al. designed flexible polygeneration integrating the chemicals/fuel production and electricity production to maximize the efficiency. They reported that the feed rate, heating value and composition has an important effect on the power generation [4,5].

A higher efficiency reaching 80% [6, 7] and an important additional power can be obtained with coupling SOFCs thermally or chemically with bottoming power cycles, such as Brayton [8], Rankine [9], Kalina [10] and Stirling [11] cycles, tri-generation systems [12], and renewable energy conversion and storage devices [13].

In order to enhance the capacity and the efficiency of power production, Valerie et al proposed an indirect integration of a standard gas turbine cycle with an internal reforming solid oxide fuel cell (SOFC) system and bottoming organic Rankine cycle (ORC). They investigated this system thermodynamically and economically. They found that toluene is the best working fluid in thermodynamic performance term comparing to benzene, cyclo hexane, cyclo pentane, R123 and R245fa. An energy and exergy efficiencies of approximately 64% and 62%, respectively are obtained with SOFC-GT-ORC system when toluene is used [14]. Eveloy et al. reported that the efficiency of conventional gas cycles used in industrial process plants is limited, mainly at part load and under harsh climatic conditions [15]

Dang Saebea et al. studied the Effect of anode -cathode exhaust gas recirculation on energy recuperation in a solid oxide fuel cell-gas turbine hybrid power system. They found that The SOFC operating parameters has a direct effect on turbine inlet temperature which is higher with increasing the cell temperature and decreasing the fuel utilization factor. They explain the turbine inlet temperature decrease by the decline in the amount of fuel to the combustor with higher fuel utilization.[16] It is noted that fuel type has a great influence on the optimal operational parameters for the SOFC-GT hybrid system and its outputs [17,18]. The majority of SOFC-GT hybrid system configurations can be classified to atmospheric and pressurized SOFC-GT hybrid systems. Gandiglio et al reported that the pressurized hybrid system has 7.3% higher efficiency and a 20% lower rate of destruction exergy than the atmospheric hybrid system [19]. In a pressurized SOFC-GT hybrid system, the working fluid of SOFC is directly supplied for the turbine, which decreasing heat loss from the system.

Xiaojing Lv et al[20] built implemented mathematical models of a hybrid system of an IT-SOFC (intermediate-temperature solid oxide fuel cell) and a GT (gas turbine) fueled by gasified biomass gas they conclude that the F/A ratio has the greatest influence on the performance of the hybrid system and that The efficiency increases from 56.5% to 61.34% when the F/A ratio ranges from 0.27 to 0.43, in addition they noted that an extremely high F/A ratio can cause the turbine to suffer because of excess temperature. Effect of operating parameters on a hybrid system of intermediate temperature solid oxide fuel cell and gas turbine.

M. Gandiglio et al[21] assessed a detailed thermoeconomic analysis of two large solid oxide fuel cell-based power plants operating at atmospheric pressure and 20 bar. It is found that pressurized plant outperforms the atmospheric one, with a (on exergo-economic base) cost of electricity of 47.7 $/MWh instead of 64.2 $/MWh.

Dang et al investigated hybrid systems.[22] They showed that the recirculation of a proportion of the fuel cell exhaust gas raise the system and thermal efficiency.

Nomenclature:
SOFC: solid oxide fuel cell
GT: gas turbine
HE: heat exchanger
V_{ohm}: ohmic polarization (volt)
V_{act}: activation polarization(volt)
V_{conc}: concentration polarization(volt)
I: current density(A/m^2)
R_e :the resistance(ohm)
δ_j: the thickness(m)
ρ_j:the specific electric resistivity of the anode, cathode, electrolyte and interconnect
A_j: the area(m^2)
ε:the porosity coefficient
τ:the tortuosity coefficient
$D_{1,K}$: the knudsen diffusion coefficient
σ_{12}:Collision diameter
Ω_{12}:Collision integral
PR: the pressure ratio
k : the specific heat ratio.
$\dot{m}_a$:the mass of dry air the ratio (kg/s)
$\dot{m}_v$: the mass of vapor (kg/s)
$\dot{m}_f$: the mass of fuel(kg/s)
T_{am}: ambient temperature(°C)
η: energetic efficiency
U_f: utilization factor
V_{SOFC}: SOFC voltage(volt)
X_{reform}: pre-reforming fraction
$\dot{n}_{air}$: air flow (mol/s)
ηc: isentropic efficiency
P_{SOFC}: SOFC power output(MW)
W_{GT}: Gas turbine power output(MW)
W_{aux}: auxiliary power(MW)

I. System Description

Figure 1 presents schematic diagram of the considered power plant. It is principally constituted by compressors, heat exchangers, solid oxide fuel cell, combustion chamber and gas turbine. The input air and fuel streams of fuel cell are preheated by means of heat exchangers using recovered heat from re-circulated gas turbine exhaust mixture. The fuel outlet temperature is controlled by adjusting the mass flow of the stream in order to fulfill the requirement of the SOFC inlet temperature. For the air stream, the air pressure is firstly raised in the air compressor then the air is preheated in a heat exchanger. The needed water is generated in the steam generator where the exhaust heat from HE1 is again utilized to heat the water from the pump. Fuel is firstly partially pre-reformed using the prereformer than it is reformed in the SOFC. The chemical energy is converted to the electrical energy through the electrochemical reaction taking place in the SOFC. Exhaust flow from the cell passes through the combustor chamber where the residual hydrogen and hydrocarbure are burned. The SOFC exhaust heat is utilized before in the recuperator to heat the compressor discharge air flowing to the gas turbine. The main characteristic designs of the SOFC GT hybrid cycle are given on table (1).

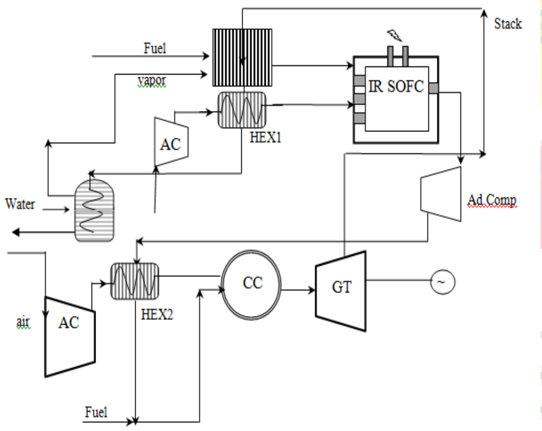

Fig1: schematic diagram of the considered power plant

Table (1): Characteristic designs of the SOFC GT hybrid cycle

Parameters	*Values*
Compressor isentropic efficiency(%)	*90*
Recuperator effectiveness (%)	*90*
GT Pressure ratio	*10*
Turbine isentropic efficiency (%)	*94*
Cell length (cm)	*150*
Cell outside diameter (cm)	*2,2*
Cell voltage (V)	*0,6*
DC–AC Converter efficiency (%)	*95*
Limiting current density (mA/cm²)	*300*

II. Mathematical model

II.1. SOFC:

The fuel cell model developed in this study calculates the stack power and outlet stream parameters. The sizes of the different elements and the material choice are selected according the available data [23].

The proposed system is supplied by Tunisian natural gas. The SOFC can be fueled by hydrogen or directly by hydrocarbon without the need of pre-reforming [24]. It is commonly considered that reforming, shifting and electrochemical reactions are taken place inside the cell.

II.1.1. Electrochemical model

The electrochemical reactions occurring in the anode and the cathode are:

Anode side: $H_2 + O^{2-} \rightarrow H_2O + 2e^-$ (R1)

Cathode side: $\frac{1}{2} O_2 + 2e^- \rightarrow$ O^{2-} (R2)

Overall reaction: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ (R3)

The theoretical open circuit cell voltage E_{th} is calculated using the Nernst equation as:

$$E_{th} = E^{\circ} + \frac{RT_F}{neF} \mathrm{Ln} \frac{P_{H2} P_{O2}^{1/2}}{P_{H2O}} \quad (1)$$

The real cell voltage is less than theoretical one. The losses are mainly due to ohmic over potential, activation over potential and concentration over potential. Therefore, the real voltage of an operating fuel cell is given by:

$$E_r = E_{th} - V_{ohm} - V_{act} - V_{conc} \quad (2)$$

a. Ohmic overpotential

The resistance to charge conduction through the various cell components causes Ohmic losses V_{ohm} .The ohmic losses may be expressed as:

$$V_{ohm} = I.R_e = I.\sum_j \rho_j \delta_j \quad (3)$$

$$\rho_j = A_i \exp\left(\frac{B_i}{T}\right) \quad (4)$$

The values of the constant parameters indicated in this equation are given on table (2)

Table (2): Ohmic polarization constants

Composant	$A(\Omega - m)$	B(K)	$\delta(m)$
Cathode	0.0000811	600	0.0022
Anode	0.0000298	-1392	0.0001
Electrolyte	0.0000294	10350	0.00004
Interconnecteur	0.0012	4690	0.000085

b. Concentration overpotential

This overpotentiel results from changes in the electrolyte concentration due to the passage of current through the electrode/solution interface. It depends on the reduction of dissolved oxygen, since it is usually in low concentration. The concentration polarization V_{conc} is given as follows:

$$Vconc,an = \frac{RTp}{neF} Ln\left(\frac{1-\frac{i}{i_{l,H2}}}{1+\frac{i}{i_{l,H2O}}}\right) \quad (5)$$

$$Vconc,ca = \frac{RTp}{nF} Ln\left(\frac{1}{1-\frac{i}{i_{l,O2}}}\right) \quad (6)$$

$$i_{l,H2} = \frac{neFD_{eff,H2}}{RTp\delta an} P_{H2} \quad (7)$$

$$i_{l,H2O} = \frac{neFD_{eff,H2O}}{RTp\delta an} P_{H2O} \quad (8)$$

$$i_{l,O2} = \frac{neFD_{eff,O2}}{RTp\delta ca} P_2 \quad (9)$$

D_{eff} represents the effective diffusion coefficient and it can be determined by Bosanquet formula :

$$\frac{1}{D_{eff,1}} = \frac{\varepsilon}{\tau}\left(\frac{1}{D_{1,K}} + \frac{1}{D_{1,2}}\right) \quad (10)$$

$D_{1,K}$: the knudsen diffusion coefficient for specie 1 is evaluated using free molecule flow theory:

$$D_{1,K} = \frac{2}{3} r_e \left(\frac{8RT}{\pi M_1}\right)^{\frac{1}{2}} \quad (11)$$

$D_{1,2}$: the diffusion coefficient for gas pairs, it is expressed by Hirschfelder equation as

$$D_{1,2} = \frac{1{,}858 * 10^{-27} * T^{\frac{3}{2}}}{P * \sigma_{12}{}^2 * \Omega_{12}} \left(\frac{1}{M_1} + \frac{1}{M_2}\right)^{1/2} \quad (12)$$

c. Activation overpotential

Chemical reactions, including electrochemical reactions, are characterized by energy barriers which must be overcome by the reacting species. This energy barrier is called “activation energy” and results in activation or charge- transfer polarization, which is due to the transfer of charges between the electronic and the ionic conductors. The activation polarization V_{act} represents the potential necessary to overcome the energy barrier related the electrode reaction. V_{act} is determined using the Bulter-Volmer equation [21] as follows:

$$i = i_0\left[\exp\left(\frac{\beta F n_e V_{act}}{RT_p}\right) - \exp\left(-\frac{(1-\beta) F n_e V_{act}}{RT_p}\right)\right] \quad (13)$$

Where β is usually taken equal to 0.5. That permits to express V_{act} by:

$$V_{act} = \frac{2KT_p}{neF} \sinh^{-1}\left(\frac{i}{2i_0}\right); \quad (14)$$

Where i_0 is the exchange current density, depending on the partial pressure of the reacting gas, compositions and the temperature.

At the anode side the exchange current density is given by:

$$i_{0,an} = \gamma_a \left(\frac{P_{H2}}{P_0}\right)\left(\frac{P_{H2O}}{P_0}\right) exp\left(-\frac{E_a}{RT_p}\right) \quad (15)$$

While at cathode side it is expressed as follows:

$$i_{0,ca} = \gamma_c \left(\frac{P_{O2}}{P_0}\right)^{0.25} exp\left(-\frac{E_a}{RT_p}\right) \quad (16)$$

The values of the different constants in equations (15) and (16) are given on table (2)

Table (2): Activation polarization constants

$E_{act,an}$(kJkmol^{-1})	110000
$E_{act,ca}$(kJkmol^{-1})	155000
$\gamma^{an,ca}$(Am^{-2})	$7*10^9$

II.1.2. Internal reforming and shifting models

SOFC can be fed by several hydrocarbons. The SOFC operating temperature is high enough to enable the direct reformation of natural gas. The hydrogen is electrochemically converted with production of electrical power and high-grade waste heat for recuperation [13].

The reforming and water gas shift reactions occur within the anode as follows:

Steam reforming reaction: $CH_4 + H_2O \rightarrow CO + 3H_2$ (R4)

Shifting reaction: $CO + H_2O \rightarrow CO_2 + H_2$ (R5)

In addition, the carbon monoxide electrochemical oxidation is obtained at the anode according to the following reaction.

$$CO + O^{2-} \rightarrow CO_2 + 2e^- \quad \text{(R6)}$$

But, knowing that its velocity is 2 to 5 times slower than that of hydrogen, this reaction is generally neglected. Consequently, the rapid water gas shift reaction becomes the dominant one.

The equilibrium constants of reforming and shifting reactions can be evaluated by equations (17), (18), (19) and (20) respectively:

$$Kp_r = \frac{p_{H2}^3 p_{CO}}{p_{CH4} p_{H2O}} = \frac{[(CO^0+x-y)/(n_{tot}^0+2x)]\cdot[(H_2^0+3x+y-z)^3/(n_{tot}^0+2x)^3]}{[(CH_4^0-x)/(n_{tot}^0+2x)][(H_2O^0-x-y+z)/(n_{tot}^0+2x)]} p_{cell}^2$$

$$Kp_s = \frac{p_{H2} p_{CO2}}{p_{CO} p_{H2O}} = \frac{[(CO_2{}^0+y)/(n_{tot}^0+2x)]\cdot[(H_2^0+3x+y-z)^3/(n_{tot}^0+2x)^3]}{[(CO^0+x-y)/(n_{tot}^0+2x)][(H_2O^0-x-y+z)/(n_{tot}^0+2x)]}$$

$$z = U_f * (3x + y)$$

$$Log(Kp) = AT^4 + BT^3 + CT^2 + DT + E$$

Where x,y and z are the molar flow rate of CH_4, CO and H_2calculated by solving simultaneously equations (17), (18), (19) and (20). The different constants in equation (d) are given on table 3.

Table 3: Equilibrium constants of reforming and shifting reactions [22].

	Reforming	Shifting
A	$-2.63121*10^{-11}$	$5.47301*10^{-12}$
B	$1.24065*10^{-7}$	$-2.57479*10^{-8}$
C	$-2.25232*10^{-4}$	$4.63742*10^{-5}$
D	$1.95028*10^{-1}$	$-3.91500*10^{-2}$
E	$-6.61395*10^{1}$	$1.32097*10^{1}$

Calculating the temperature of the effluent gas from the SOFC is an important step. The heat generated by the electrochemical reaction is used to supply the required heat of the internal reforming reaction and to heat the SOFC products and residual reactants until the stack temperature. But in real systems, a pre-reforming process is applied. For which hot gases from the SOFC, may be used to provide the thermal energy needed for the pre-reforming process

II.2. Gas turbine

The gas turbine expands the hot gaseous mixture leaving the combustion chamber to deliver useful power. This engine is used to drive simultaneously the electrical generator and the air compressor.

The turbine outlet temperature can be determined by:

$$\frac{T_{out}}{T_{in}} = PR^{\frac{k-1}{k}} \quad (21)$$

Taking into consideration the turbine isentropic efficiency η_{is}, the produced power is calculated by

$$\dot{W}_t = \eta_{is} \dot{m}_t C_{pg} (T_{in} - T_{out}) \quad (22)$$

Where $\dot{m}_t$ is the total mass flow rate given by :

$$\dot{m}_t = \dot{m}_a + \dot{m}_v + \dot{m}_f \quad (23)$$

II.3. Combustion chamber

As indicated in figure (1), the combustion chamber is fed by the compressed air, the fuel and the SOFC exhaust gas including the unreacted hydrogen hydrocarbure and other effluents like excess air. The reactions occurring in combustion chamber are:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (R7)

$C_2H_6 + \frac{7}{2} O_2 \rightarrow 2CO_2 + 3H_2O$ (R8)

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ (R9)

$H_2 + O_2 \rightarrow 2H_2O$ (R10)

$CO + \frac{1}{2} O_2 \rightarrow CO_2$ (R11)

The fuel supplied the proposed cycle is the natural Tunisian gas. Its composition is reported in table (5)

II.4. Compressors

These components receive air at ambient temperature and pressure to be compressed to the desired pressure resulting in an increase in its temperature. Model of the compressor is based on the perfect gas equations and polytropic transformations. The exhaust isentropic temperature is calculated by:

$$\frac{T_{out}}{T_{in}} = \left[\frac{P_{out}}{P_{in}}\right]^{\frac{k-1}{k}} = PR^{\frac{k-1}{k}} \qquad (24)$$

Mechanical power consumed by the compressor:

$$w_c = (\dot{m}_a \Delta H_c)/\eta_c \qquad (25)$$

Where ΔH_c is the isentropic enthalpy variation through the compressor.

$$\Delta H_c = H_{out} - H_{in} \qquad (26)$$

II.5. Heat exchangers

In the proposed system, multiple gas to gas heat exchangers are used for heat recovery processes. It is assumed that there is no heat transfer between these recuperators and the surrounding environment. The effectiveness- NTU method is used to determine the actual temperature changes for both cold and hot fluids, based on the heat exchanger type, effective heat transfer coefficient and surface area. For a cross flow and unmixed fluid type heat exchanger, the effectiveness is expressed as [23]:

$$\epsilon = 1 - exp\left\{\frac{NTU^{0,22}}{c}\left[\exp\left(-cNTU^{0,78}\right) - 1\right]\right\} \qquad (27)$$

$$C_r = \frac{C_{min}}{C_{max}} \qquad (28)$$

$$NTU = \frac{UA}{C_{min}} \qquad (29)$$

$$Q_{max} = C_{min}\left(T_{in}^{hot} - T_{in}^{cold}\right) \qquad (30)$$

$$Q = \Delta H_{cold} = -\Delta H_{hot} = \varepsilon Q_{max} \qquad (31)$$

Overall cycle efficiency

The overall cycle efficiency including the gas turbine cycle and the SOFC system is expressed by:

$$\eta = \frac{\text{Net system Power Output}}{\text{Total Energy input}} \qquad (32)$$

The Net system Power Output NPO is expressed by:

$$NPO = P_{SOFC} + W_{TG} - W_{aux} \qquad (33)$$

The Total Energy Input TEI is given by:

$$TEI = LHV * \left(\dot{m}_{fSOFC} + \dot{m}_{fGT}\right) \qquad (34)$$

III. Analytic Study

The local environmental conditions of the south of Tunisia are considered to choose operating parameters when the performances of the SOFC gas turbine hybrid cycle are determined. The effects of main operating parameter such as the ambient temperature, the current density, the SOFC pressure and the degree of pre-reforming are analyzed. The required calculations are performed using EES software. The Operating variables ranges are indicated on table (6).

Table (6): Operating variables ranges

Parameters	*values*
Compressor isentropic efficiency(%)	*90*
Recuperator effectiveness (%)	*90*
GT inlet temperature (◦C)	*1200*
Expansion ratio	*10*
Turbine isentropic efficiency (%)	*94*
Cell length (cm)	*150*
Cell outside diameter (cm)	*2,2*
Current density(A/m^2)	*3000*
Cell voltage (V)	*0,6*
Cell operating temperature (K)	*850-1200*
Fuel utilization (%)	*60*
dc–ac Converter efficiency (%)	*95*
Limiting current density (mA/cm2)	*300*

IV. Results and Interpretations

IV.1.Effect of the ambient temperature:

The ambient temperature is an important parameter affecting the performance of power generators. Gas Turbine and fuel cells performances are affected by ambient conditions. As the ambient air temperature increases, the compressed air mass flow rate decreases and to keep it constant compressors consume more electrical energy which reduces the net power.Fig1 shows that the efficiency of hybrid system decreases with increasing ambient temperature. It decrease from 67% to 65% as ambient temperature increase from 283,15 K to 323,15 K. This tendency is explained by the effect of ambient temperature on both SOFC and GT efficiencies. The modeling was carried out considering the pressure, the fraction of pre-reforming, the utilization factor were set respectively at 10^3 kPa, 0,8 and 0,6.

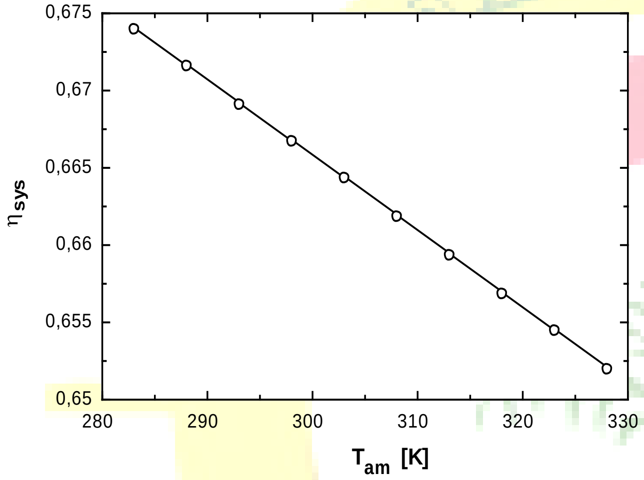

Fig1:Effect of ambient temperature on SOFC-GT hybrid system efficiency

IV.2.Effect of pre-reforming fraction

In order to improve the system performances, pre- reforming and internal reforming are combined. The internal reforming is beneficial since it ensures the consumption of the unreacted methane and carbon monoxide. While the external reforming is used to crack the long hydrocarbon chains and feed the cell with H_2in order to bring the operating point and increase the stack efficiency. To analyze the effect of pre-reforming fraction on the system efficiencies, the modeling was carried out considering the following operating parameters:

- Cell pressure10^3kPa,
- Ambient temperature 283,15 K
- Utilization factor 0.6.

The variation of the cell temperature according to the pre-reformed fraction X_r is presented in figure (2). The cell temperature rises from 629.9°C to 751.7°C for an increase of X_r from 0.5 to 0.9. This is due to the endothermic reforming reaction. Indeed, this reaction requires energy input which reduces the sack temperature. The temperature rising reduces the different polarizations. Therefore, the cell voltage increases as shown in figure (3).

The variations of the system efficiencies are presented in figure (4). For the X_r variation range, the SOFC efficiency increases significantly to reach about 62.5 %. While an improvement of about 13 % is obtained for the whole system efficiency.

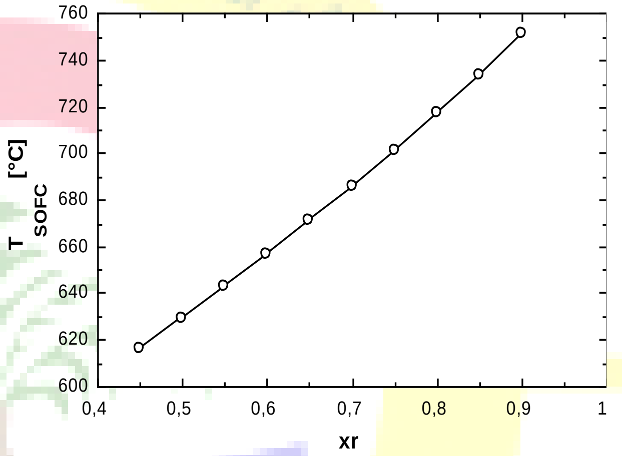

Figure 2: Effect of pre-reformed fraction on SOFC temperature

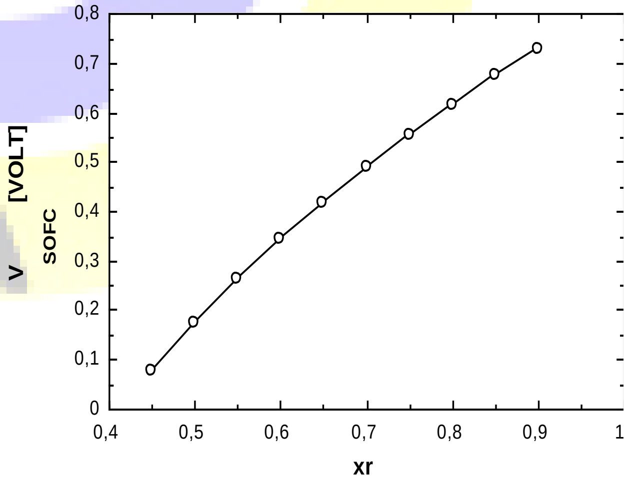

Figure 3: Effect of pre-reformed fraction on SOFC voltage

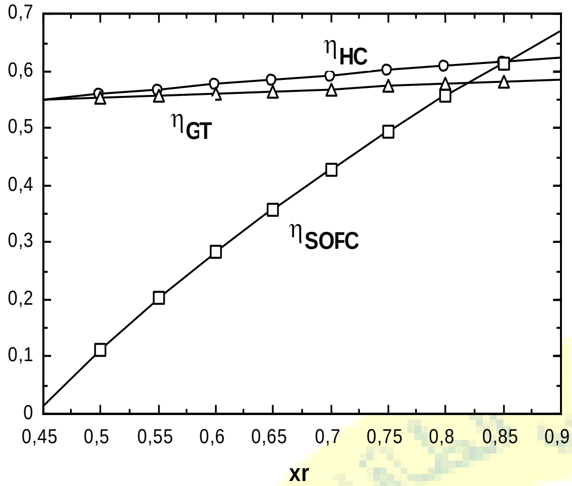

Figure 4: Effect of pre-reformed fraction on system efficiencies

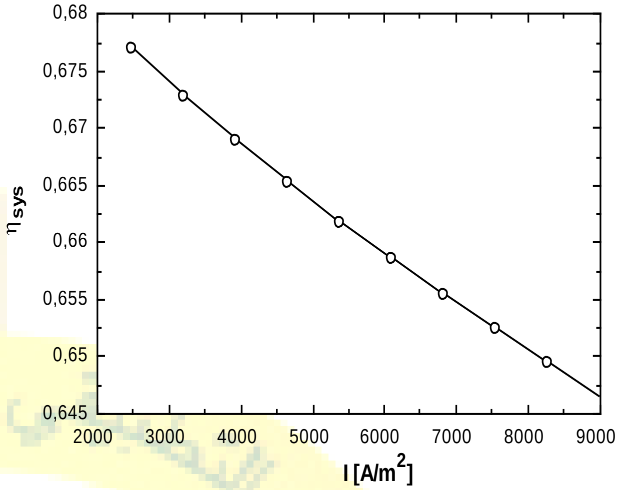

Fig5:Effect of current density on SOFC-GT hybrid system efficiency

IV.3. Effect of current density:

The operating current density for the SOFC operates from 2000 to 9000A/m^2.

Current density is an important parameter influencing cycle performance. Fig 5 and Fig 6 show the influence of current density on energy efficiencies for a fuel utilization factor of 0,6 and operating pressure 10^3 kPa .In fig5, the energy efficiency decreases with increasing current density. This trend can be explained by the decrease in cell voltage (Fig7) which is proportional to SOFC power as a result of the increase of ohmic activation and concentration losses. Fig 6 reflects the effect of the current density on the SOFC efficiency. They are negatively correlated. The SOFC efficiency decreases sharply by increasing the current density. It decreases from 67% to 35%when current density increases from 2500 A/m^2 to 6000 A/m^2.

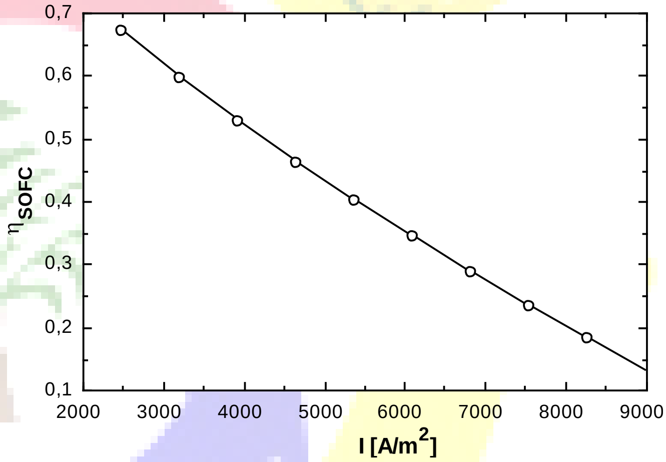

Fig6:Effect of current density on SOFC efficiency

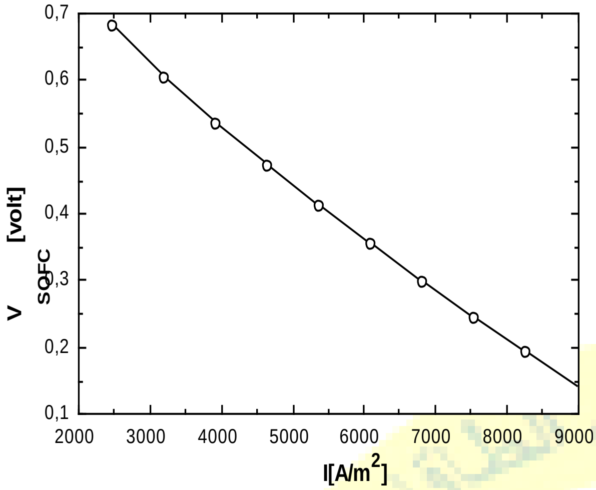

Fig7: Effect of current density on SOFC voltage

Conclusions

A hybrid combined SOFC-GT plant was presented and analyzed. The plant was fed by natural gas and therefore the fuel was preheated and pre-reformed partially before sending to the anode side of the SOFC. The hybrid recuperating was used to recycle back the gases issued from of SOFC to the topping cycle. The efficiency of the suggested plant was calculated to be higher than 50% which is significantly higher than the traditional plants. The thermodynamic and the electrochemical processes of the system are modeled and validated. Besides, a parametric investigation is performed to examine the effects of design and operating variables on the performance of the system.

The increase of the ambient temperature reduces the system efficiencies. The pre-reforming fraction, has a positive effect on the indicated parameters. While, the current density has a negative effect on the SOFC temperature and voltage. That leads to a decrease in the system performances.

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