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Kogeneracija z gorilnimi celicami v stanovanjskih poslopjih

Residential Co-Generation Using Fuel Cells

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Kombinirana proizvodnja električne energije in toplote (KPETH - CHP) ali kogeneracija je idealna uporaba gorilnih celic. V tem prispevku so predstavljena načela delovanja in različni tipi gorilnih celic. Podrobno je predstavljeno delovanje kogeneracije z gorilnimi celicami. Predstavljeni so nekateri komercialno uporabni sistemi in prednosti gorilnih celic. Podrobno je analiziran obrat s trdnimi oksidnimi gorilnimi celicami in plinsko turbino (TOGC in PT - SOFC in GT). Nekateri preliminarni rezultati kažejo, da lahko dosežemo električni izkoristek okoli 65%, medtem ko je izkoristek po prvem glavnem zakonu nad 80%.

(Ključne besede: kogeneracija, celice gorilne, zgradbe stanovanjske, izkoristek električni)

Combined heat and power (CHP) or co-generation is an ideal application for the fuel cell. In this paper the working principle and the different types of fuel cells are briefly presented. The typical layout of a fuel cell co-generation system is described. Some of the commercially available systems are considered and the advantages of fuel cells are discussed. In particular an integrated plant with solid-oxide fuel cells and a gas turbine (SOFC+GT) is analysed. Some preliminary results obtained using a simulation program show that an electric efficiency of approximatively 65% can be obtained, while the First Law efficiency is over 80%.

(Keywords: cogeneration, fuel cells, residential buildings, electrical efficiency)

0 UVOD

Velika zanesljivost, majhen vpliv na okolje in prilagodljiva velikost so nekatere značilnosti, ki dajo gorilnim celicam lastnost, da so idealna tehnologija za kombinirano proizvodnjo električne energije in toplote (KPET) [1]. Glavni cilj tega prispevka je podati splošne informacije o delovanju različnih gorilnih celic in se osredotočiti na izdelavo celic, ki bi bile primerne za kogeneracijo.

Nadaljnje izboljšanje izkoristka gorilnih celic je mogoče doseči, ko delujejo pri višjih temperaturah (~1000 °C) in pod tlakom, tako da spreminjajo izhodne pline v elektriko v plinski turbini. Ta izboljšava je mogoča samo danes zaradi sedanjih izboljšav v oblikovanju mikroplinskih turbin, ki omogočajo precejšnji izkoristek v manjših enotah (50 do 100 kW). Z namenom, da bi analizirali delovanje takšnega sistema gorilnih celic in plinske turbine, je bil razvit simulirni program. Zadnji del prispevka poroča o nekaterih predhodnih rezultatih z uporabo programa, ki prikazuje, da lahko dosežemo zelo visok izkoristek.

0 INTRODUCTION

High reliability, low environmental impact and size flexibility are some of the characteristics that make fuel cells one of the ideal technologies for combined heat and power (CHP) generation [1]. The aim of this paper is to provide some general information about the working principle of different types of fuel cells and to focus on the aspects that make them suitable for co-generative applications.

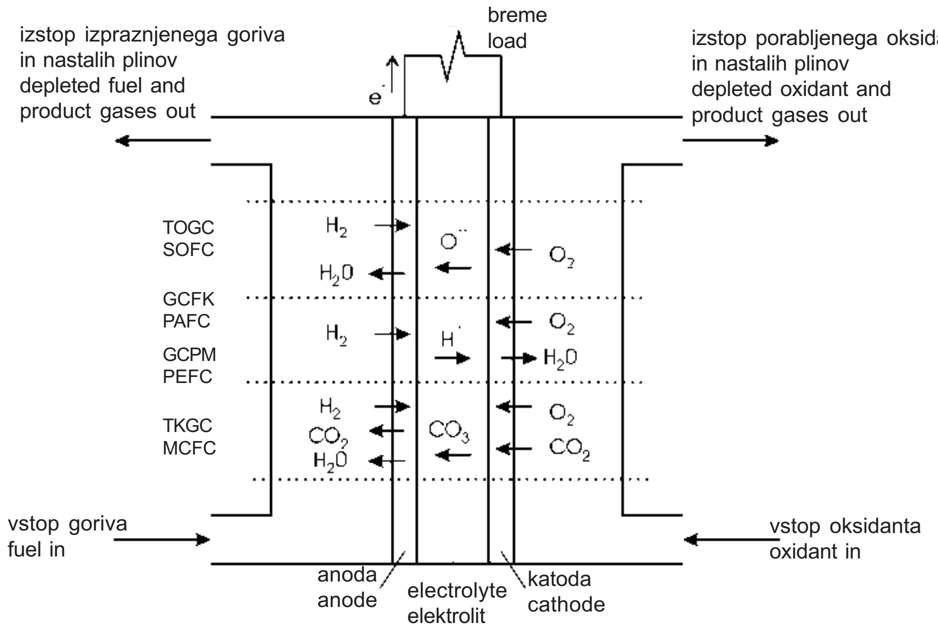
A further improvement in the efficiency of the fuel-cell co-generative system can be achieved when operating at high temperature (~1000 °C) and in high pressures, converting the exhaust stream to electricity via a gas turbine. This improvement has only recently been achieved because of advances in the design of micro gas turbines allowing an appreciable efficiency to be achieved even in small-size units (50 to 100 kW). In order to analyse the performance of these fuel-cell gas-turbine integrated systems a simulation program has been developed. The last part of the paper reports some of the preliminary results provided by the program, showing that a very high efficiency can be obtained.

1 GORILNE CELICE

Gorilne celice so elektrokemične naprave, ki spreminjajo kemično energijo neposredno v električno ([2] do [4] in [W1]). Osnovni del gorilne celice sestavlja elektrolit v stiku s porozno anodo in katodo na drugi strani. Shematična predstavitev gorilne celice je prikazana na sliki 1.

1 FUEL CELLS

Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy ([2] to [4] and [W1]). The basic physical structure of a fuel cell consists of an electrolytic layer in contact with a porous anode and cathode on either side. A schematic representation of a fuel cell is shown in Figure 1.



Sl. 1. *Shematični prikaz posamezne gorilne celice*
Fig. 1. *Schematic of an individual fuel cell*

Osnovno načelo za vse gorilne celice je takšno, kakršno uporabljajo elektrokemične baterije, ki jih poznamo v številnih področjih vsakdanjega življenja. Največja razlika je v tem, da je kemična energija shranjena v sami bateriji. Ko se kemična energija spremeni v električno, moramo baterijo zavreči (navadna baterija) ali ponovno napolniti (obnovljiva baterija). V gorilni celici se kemična energija stalno dovaja k anodi (negativna elektroda), oksidant pa h katodi (pozitivna elektroda). Plinasto gorivo je shranjeno zunaj celice, kjer tečejo kemične reakcije. Dve glavni značilnosti gorilnih celic, ki sta pomembni z vidika današnjih interesov, sta razmeroma velik izkoristek in majhen vpliv na okolje. Ker gorilna celica ne dela kot termodinamični krožni proces, zanjo ne velja pojem mejnega toplotnega izkoristka, izkoristek pa je v mejah od 40 do 55% v primeru majhne kurilnosti goriva (SKV - LHV) in vode, kot izstopnega produkta (če uporabljamo vodik). Razvrstitev gorilnih celic po tipu elektrolita in po nekaterih tehničnih lastnostih je prikazana v preglednici 1.

The basic principles of a fuel cell are those of electrochemical batteries, which are involved in many activities of our everyday life. The big difference is that, in the case of batteries the chemical energy is stored in substances located inside them. When this energy has been converted to electrical energy, the battery must be thrown away (primary batteries) or recharged (secondary batteries). In a fuel cell, the chemical energy is provided by a fuel that feeds continuosly to the anode (negative electrode) and an oxidant that feeds continuosly to the cathode (positive electrode). These gaseous fuels are stored outside the cell in which the chemical reaction takes place. Two major fuel-cell characteristics that have been important in driving the recent interest are the combination of a relatively high efficiency and a very low environmental impact. Since a fuel cell does not operate as a thermodynamic power cycle, the notion of a limiting thermal efficiency imposed by the Second Law is not applicable. The efficiency of typical fuel-cell plants are in the range of 40 to 55%, based on the lower heating value (LHV) of the fuel, and the exhaust stream of water (if hydrogen is used). A classification of fuel cells by the type of electrolyte used and some technical specifications are reported in Table1.

Preglednica 1. *Lastnosti gorilnih celic*
Table 1. *Attributes of fuel cells*

	GCPM-PEMFC	AGC-AFC	GCFK-PAFC	TKGC-MCFC	TOGC-SOFC	MGC-DMFC
elektrolit electrolyte	polimerna membrana polymer membrane	KOH	fosforna kislina phosforic acid	staljen karbonat molten carbonate	keramika ceramic	polimerna membrana polymer membrane
temp. (°C)	70-80	80-100	200-220	600-650	800-1000	70-120
gostota current dens.	velika high	velika high	srednja moderate	srednja moderate	velika high	majhna low
izvajalec reformer	zunanji external	zunanji external	zunanji external	zunanji / notranji external / internal	zunanji / notranji external / internal	notranji internal
CO_2	da / yes	ne / no	da / yes	da / yes	da / yes	da / yes
CO	ne / no	ne / no	ne / no	da / yes	da / yes	da / yes
področje uporabe application area	vesoljske postaje space station	vesoljske uporabe space applications	električne uporabe power applications	pridobivanje elektrike power generation	pridobivanje elektrike power generation	transport transportation
izkoristek efficiency	50%	50%	50%	60%	60%	ni poznan N.A.

GCPM: gorilna celica s protonsko membrano
PEMFC: proton exchange membrane fuel cell
AGC: alkalna gorilna celica
AFC: alkaline fuel cell
GCFK: gorilna celica s fosforno kislino
PAFC: phosforic acid fuel cell
Za izkoristek so navedene samo okvirne vrednosti.
Efficiency values are only indicative values.
TKGC: taljena karbonatna gorivna celica
MCFC: molten carbonate fuel cell
TOGC: trdno oksidna gorilna celica
SOFC: solid oxide fuel cell
MGC: metanolna gorilna celica
DMFC: direct methanol fuel cell

2 SISTEMI GORILNIH CELIC

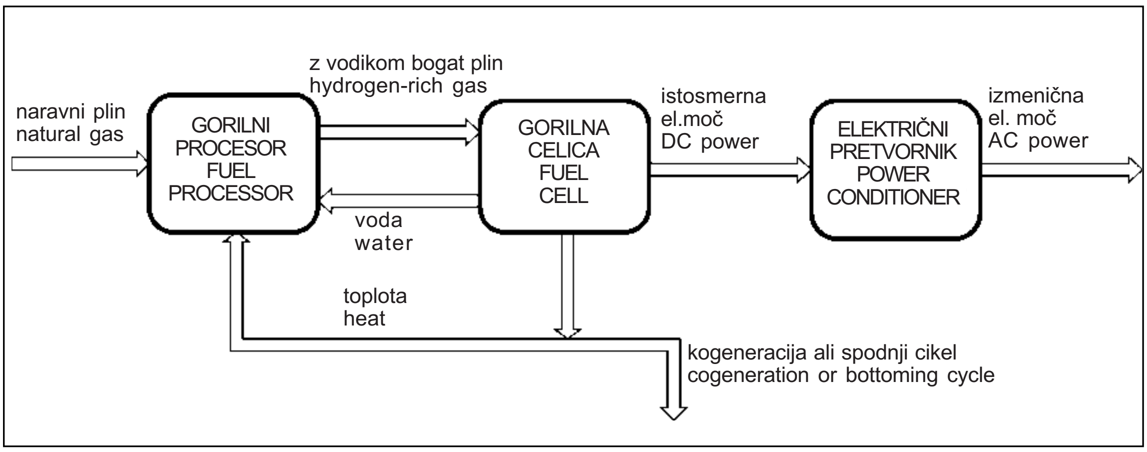
Gorilna celica povezuje vodik iz goriva in kisik iz zraka za pridobivanje električne energije (istosmernega toka), vode in toplote. Ta reakcija mora biti izvedena pri ustrezni temperaturi in tlaku. Okoli gorilne celice je treba izdelati sistem, ki celico oskrbuje z zrakom in svežim gorivom in pretvarja energijo v bolj uporabno obliko in odstranjuje izpraznjene reaktante in toploto, ki nastaja pri reakcijah v gorilni celici. Na sliki 2 je prikazan shematični pregled gorilne celice.

Posebno tedaj, ko uporabljamo nizkotemperaturne gorivne celice (t.j. AGC, GCPM, GCFK) in ko vodika ni na voljo, je treba preoblikovati (izločiti vodik) gorivo. Ta proces se izvaja v napravi, ki se

2 FUEL-CELLS SYSTEMS

The fuel cell combines hydrogen produced from the fuel and oxigen from the air to produce electrical power (DC), water and heat. This reaction must be carried out at a suitable temperature and pressure. A system must be built around the fuel cells to supply air and clean fuel, convert the power to a more usable form and remove the depleted reactants and heat that are produced by reactions in the fuel cell. In Figure 2 a schematic view of a fuel cells plant is shown.

Expecially when using low temperature fuel cell (i.e. AFC, PEM, PAFC) and hydrogen is not available it is necessary to reform (extract hydrogen) a hydrocarbon fuel. This process is carried out in an



Sl. 2. *Preprost blokovni diagram proizvodnje elektrike*
Fig. 2. *Power plant simplified block diagram*

imenuje *reformer*. Pridobi-vanje goriva je odvisno od goriva in tehnologije gorilnih celic. Slednji določa, katere sestavine so ustrezne in sprejemljive v gorivu. Na primer gorivo , ki se uporablja v GCPM, mora biti bogato z vodikom in mora imeti nizko koncentracijo CO (<20ppm). Medtem pa v TOGC-ju lahko uporabljamo metan in CO v celici. Če uporabljamo naravni plin, enega najpomembnejših goriv za kogeneracijo, moramo odstraniti žveplo in spremeniti plin v vodik v parnem reformerju. Koncentracijo CO moramo znižati z uporabo kemične preobrazbe in selektivnega katalitičnega oksidatorja.

Ko je gorivo pridobljeno, vstopi v elektrokemični del: v gorilno celico. Čeprav gorilna celica ni toplotni stroj, se gorivo vseeno proizvaja in mora biti odstranjeno. Glede na velikost sistema, temperature toplote in drugih zahtev, je treba toplotno energijo zavreči, uporabiti za pridobivanje tople vode ali spremeniti v elektriko v plinski turbini. Če se gorilna celica uporablja za pridobivanje izmenične električne moči, je potrebno, da sistem vsebuje razsmernik ter krmilnik toka, napetosti in nadzor frekvence.

appropriate deviced normally called *reformer*. The fuel processing depends on both the raw fuel and the fuel-cell technology. The latter determines what constituents are desirable and acceptable in the processed fuel. For example, fuel used in PEMFC needs to be hydrogen rich and have a very low CO concentration (<20 ppm), while SOFCs are capable of utilizing methane and CO within the cell. When using natural gas, one of the most desirable fuels for residential co-generation, sulfur has to be removed and the gas is converted to hydrogen in a steam-reforming reactor. CO concentration may be reduced using a shift conversion and a selective catalytic oxidizer.

When the fuel has been processed it enters the electrochemical section: the fuel cell. Although fuel cells are not heat engines, heat is still produced and must be removed. Depending upon the size of the system, the temperature of available heat and the requirements of the particular site, the thermal energy can either be rejected, used to produce hot water or converted to electricity via a gas turbine. If a fuel cell is used to supply AC, the system should include at least a DC to AC conversion unit, current, voltage and frequency control.

Preglednica 2. *Karakteristike gorilnih celic*
Table 2. *Pros and cons of fuel cells*

Karakteristike, ki jih ponuja gorilna celica ***Characteristics that fuel cells plants offer***
mirujoči deli v energetskem pretvorniku no moving parts in the energy converter
tiho delovanje quiet
velika možna razpoložljivost / zanesljivost / trajnost nizkotemperaturnih enot demonstrated high availability / reliability / endurance of lower temperature units
prilagodljivost za gorivo fuel flexibility
dobro obnašanje pri delovanju pri neračunski obremenitvi good performance at off-design load operation
modularna sestava za pokrivanje bremena modular installation to match load
(nanadzorovano) delovanje na daljavo remote / unattended operation
hitro prilagajanje na obremenitev rapid load following capacity
Splošne negativne lastnosti gorivne celice ***General negative features of fuel cells***
visoka cena na trgu market entry cost high
zanesljivost / trajanje visokotemperaturnih delov neizkazano reliability / endurance of higher temperature units not demonstrated
v nergetiki nepoznana tehnologija unfamiliar technology to the power industry
ni infrastrukture no infrastructure

3 KOGENERACIJSKI SISTEMI

Številna podjetja, General Electric, American Power Corp., Northwest Power Systems, Avista Labs, Ballard ([W2] do [W4]) se ukvarjajo z raziskavami in razvojem kompletnih kogeneracijskih sistemov v obsegu od nekaj kW do 250 kW in več.

3 CO-GENERATIVE SYSTEMS

Several companies, General Electric, American Power Corp., Northwest Power Systems, Avista Labs, Ballard ([W2] to [W4]) are involved in the research and development of complete co-generative systems, ranging from a few kW to 250 kW and over.

Najbolj uspešen doslej je bil PC 25 izdelan v podjetju ONSI (184 postrojenj prodanih v 14 državah). PC 25 [5] je paketna, samooskrbovalna fosforno kislinska gorilna celica z električno močjo 200 kW. Pri polni moči sistem pridobi 223 kW_t uporabne toplote pri temperaturah med 40 °C in 80 °C. Izkoristek pridobivanja elektrike je 40% glede na kurilnost (naravni plin). Izkoristek ostaja skoraj na istem nivoju med četrtinsko in polno obremenitvijo. Celotni izkoristek je 84% pri 100% obremenitvi. Raven zvočnega tlaka je pod 60 dBA pri 10m od naprave. Elektrarna vsebuje vse potrebne komponente: za preobrazbo naravnega plina v (izmenično) električno moč, pridobivanje uporabne toplote za stranke in oddajanje odvečne toplote v zrak. Cena je približno 3000 $/kW. Obstajajo številni demonstracijski projekti, ki bazirajo na GCPM, toda njihova pojava na trgu je stvar bodočnosti. Preglednica 3 prikazuje nekatere tehnične podrobnosti elektrarne, ki bo v kratkem na trgu.

The most successful to date has been the PC 25 produced by ONSI Corporation (184 plants sold in 14 countries).The PC 25 [5] is a packaged, self-contained, phosforic acid fuel-cell power plant with a continuous electrical rating of 200 kW. At full load the system provides 223 kW_t of useful heat at temperatures between 40°C and 80°C. The electrical generation efficiency is 40% on a lower heat value (natural gas LHV) basis. The efficiency remains almost at the same level at loads between one quarter and full load. The total efficiency is 84% at 100% load. The sound pressure level is below 60 dBA at 10 meters from the plant. The power plant includes all components required to convert natural gas into utility AC power, provide useful heat to the customer and reject excess heat to air. The cost is approximatively $3000/kW. There are many other demonstrative co-generative systems based on PEMFC technology, but these have yet to enter the market. Table 3 shows some technical specifications of a power system which will soon be available.

Preglednica 3. *Karakteristike skoraj komercialne elektrarne, ki temelji na PEMFC*
Table 3. *Specification of a near commercial power system based on PEMFC*

izhod output	7 kW zvezno 15 kW vrhunec 7 kW continuous 15 kW peak
napetost voltage	120/240 @60Hz 100/230V @50Hz
izkoristek cikla simple cycle efficiency	40% @2 kW izhod / output 29% @7 kW izhod / output
izkoristek kogeneracije cogen efficiency	> 75%
uporabljena odpadna toplota recoverable waste heat	> 2 kWh @2 kW izhod / output > 11 kWh @7 kW izhod / output
gorivo fuel	naravni plin utekočinjen propan natural gas liquid propane
intervali servisiranja maintenance intervals	9000 h
projektna doba trajanja design life	15 let 15 years

4 TRDNO OKSIDNA GORILNA CELICA V KOMBINACIJI S PLINSKO TURBINO

Plinske turbine v kombinaciji s trdno oksidno gorilno celico (TOGC - PT) so bile obravnavane v številnih študijah ([6] do [9]), toda številne so obravnavale MW postrojenja. Dandanes so na voljo številne nove možnosti, ker je interes za proizvodnjo elektrike v mikro turbinah (30 do 200 kW). Številna podjetja, ki se ukvarjajo z mikro turbinskimi generatorji, sedaj oglašajo svoje izdelke za končne uporabnike, družbe in proizvajalce energije ([10] in [1]). To pospešuje uporabo TOGC s PT celo v stanovanjskih objektih, kjer 200 kWe plinska turbina daje izhodno moč 30kWe.

4 SOLID OXIDE FUEL CELLS IN COMBINATION WITH A GAS TURBINE

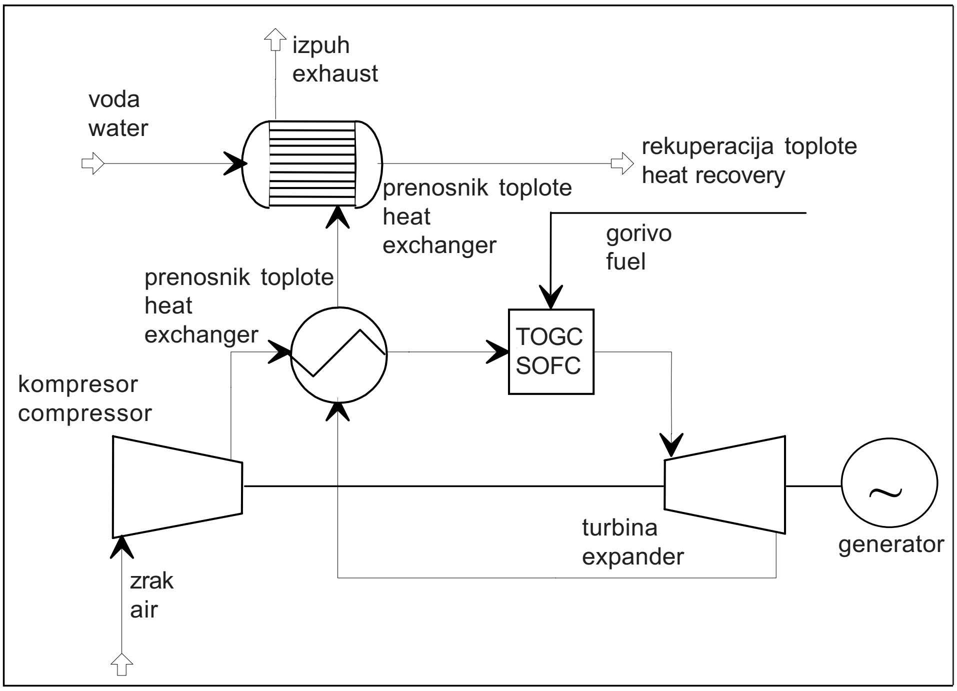
Studies of a gas-turbine cycle with a solid-oxide fuel cell (SOFC-GT) have been carried out by several researchers ([6] to [9]), but most of them have been considering MW sized power plants. Recently, new opportunities have arisen as there has been a sustained interest in power applications for microturbines (30 to 200 kW), and several microturbine-generator manufacturers are now announcing commercial availability of their products, targetting end-users, utilities and energy service providers ([10] and [1]). This context facilitates the SOFC-GT integration even for residential co-generation, where, for example, the gas-turbine output of a 200 kWe system is calculated to be approximatively 30 kWe.

V TOGC visoke temperature (~1000ºC) zagotavljajo, da vse sestavine goriva, v kombinaciji s potrebno količino vodne pare, oksidirajo v trenutku in dosežejo termodinamično ravnotežje, če dovedemo zadostno količino zraka. Zaradi visokih temperatur so drage reakcije nepotrebne kar omogoča neposredno porabo goriva v sami celici. Ker je trdni elektrolit normalno zelo stabilen, ni premikanja elektrolita. Raziskujejo dva različna modela: cevni model in ravninski model. V našem delu smo uporabili cevni model.

Shematična predstavitev krožnega procesa je prikazana na sliki 3. Prej obdelano gorivo (metan) in oksidant (zrak) vstopata v gorilno celico po kompresiji. Oksidacija poteka večinoma v gorilni celici. Celotna reakcija pa se konča v zgorevalni komori. Zgoreli plini pod tlakom odtekajo skozi turbino. Izstopna para iz turbine zagotavlja toploto ne samo za pripravo goriva, ampak tudi za pridobivanje tople vode.

In SOFCs the high temperatures (~1000 °C) ensure that all fuel compositions, when combined with the necessary amount of water vapor, will oxidize rapidly and reach thermodynamic equilibrium if sufficient air is provided. The high temperature makes expensive reactions unnecessary and permits direct processing of fuel in the fuel cell itself (i.e. internal reforming). Because the solide-oxide electrolyte is normally very stable, no electrolyte migration problems exist. Basically two different designs are under development: the tubular design and the planar design. In our work we have been considering the tubular design.

A schematic view of the considered cycle is presented in Figure 3. The preprocessed fuel (methane) and the oxidant (air) enter the fuel cell after being compressed. The fuel oxidation reaction occurs predominantly within the fuel cell. The reaction is completed in a combustion chamber. The pressurized-fuel combustion products are exhausted through a turbine.



Sl. 3. *Obtočni diagram krožnega procesa s TOGC*
Fig. 3. *SOFC-GT cycle flowsheet diagram*

Za raziskavo procesa smo uporabili simulirni računalniški program, ki je vseboval tudi simuliranje trdno oksidne gorilne celice, napisane v jeziku Fortran ([11] in [12]). Simulirni model je bil razvit za raziskovanje:
- delovne temperature in tlaka,
- sestav plinov reaktantov,
- izkoristka uporabe goriva.

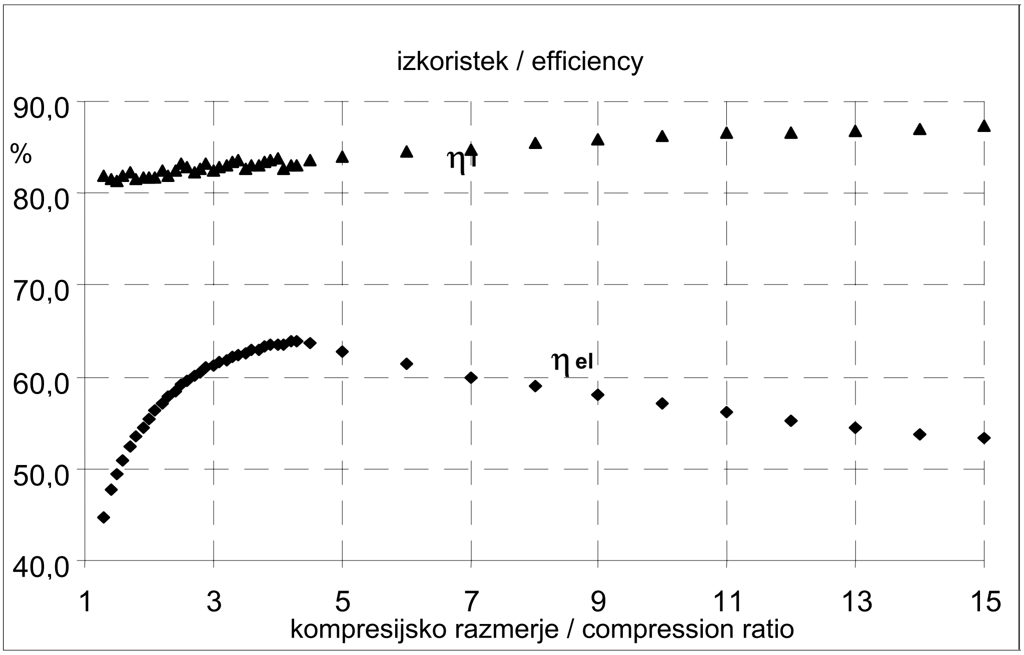
Načrtovani izkoristki za glavne komponente so: kompresor in turbina (izentropno) 79,5% in 84,5%; generator in razsmernik: 92%.

The cycle was studied using commercial process-simulation software integrated with a solid oxide fuel cell steady-state operation simulator that has been implemented using Fortran ([11] and [12]). The simulation model has been developed with the objectives of evaluating the performance of the system when varing:
- operating temperature and pressure,
- reactant gases composition,
- fuel utilization coefficient.

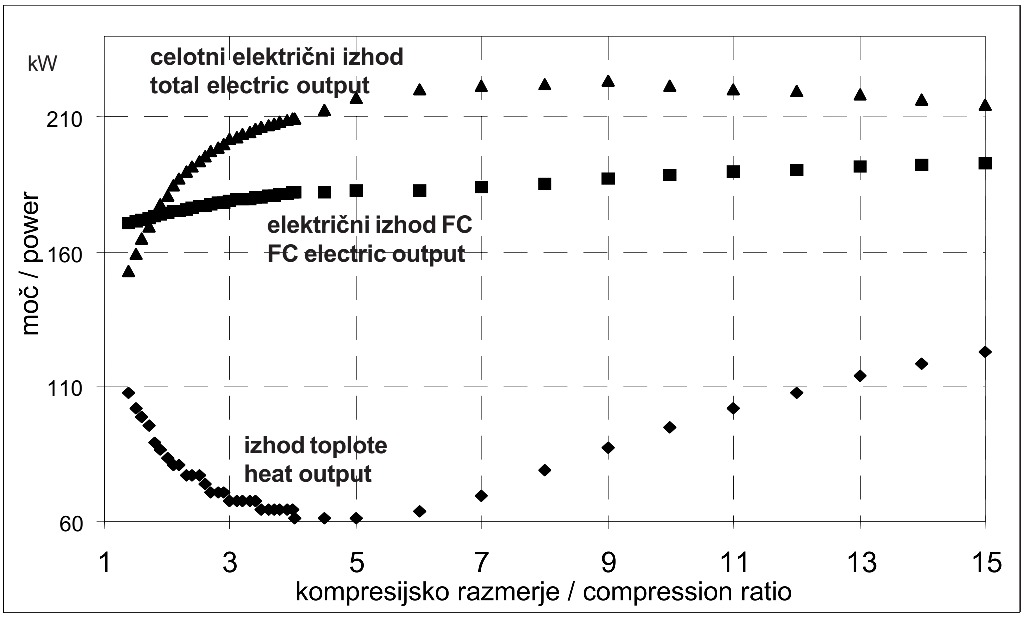
The assumed efficiency for the major components are: compressor and turbine (isoentropic) 79.5% and 84.5% respectively; generator and DC/AC conversion: 92%.

Predhodni rezultati so predstavljeni na sliki 4 in sliki 5. Slika 4 prikazuje električni izkoristek in izkoristek po prvem glavnem zakonu v odvisnosti od kompresijskega razmerja. Največji električni izkoristek dobimo pri kompresijskem razmerju 4,3, in sicer je izkoristek 63,8%, medtem ko je izkoristek po prvem glavnem zakonu 83,1%. Ta električni izkoristek je zelo visok, če ga primerjamo z običajnimi sistemi proizvodnje elektrike, tudi večjimi. Na sliki 5 je prikazana izhodna moč v odvisnosti od kompresijskega razmerja. Kjer je električni izkoristek višji, je izhod toplote na minimumu. Nato se zopet

Preliminary results are reported in Figure 4 and Figure 5. Figure 4 shows the electric and First Law efficiency as a function of the compression ratio. The maximum electric efficiency is obtained when operating at a compression ratio of 4.3 and it is 63.8%, while the First Law efficiency is 83.1%. This electric efficiency is very high when compared with any conventional power-generation systems, even those of larger size. In Figure 5 the system power output is plotted versus compression ratio. Where the electric efficiency is higher the heat output is at a minimum, and then increases again because the power system



Sl. 4. *TOGC - PT: Električni izkoristek, izkoristek po prvem glavnem zakonu v odvisnosti od kompresijskega razmerja*
Fig. 4. *SOFC - GT: Electric efficiency, First Law efficiency as a function of the compression ratio*



Sl. 5. *SOFC - GT: Električni izhod v odvisnosti od kompresijskega razmerja*
Fig. 5. *SOFC - GT: Power outputs as a function of the compression ratio*

zvišuje, ker je sistem opremljen s pomožnim gorilnikom, ki skrbi za stalno temperaturo vhodnih plinov v gorilno celico. Električna izstopna moč turbine je največja pri eni petini celotne moči.

is provided with an auxiliary burner in order to keep constant the temperature of the reactant gases entering the fuel cell. The turbine electrical output is at maximum of one fifth of the total power.

5 SKLEP

V prispevku je predstavljeno delovanje gorilne celice predvsem z vidika, da so gorilne celice ugodne za kogeneracijo v stavbah. Predstavljeni so nekateri sistemi. Predlagan je bil sistem s trdno oksidno gorilno celico in plinsko turbino, ki je bil simuliran z matematičnim modelom. Glavni rezultati tega dela so:

- gorilna celica je idealna tehnologija za kogeneracijo v stavbah,
- danes je samo en sistem kogeneracije na voljo na trgu, toda številni proizvajalci zatrjujejo, da bodo njihovi sistemi kmalu na voljo,
- trdno oksidna gorilna celica se teoretično lahko poveže z mikroplinsko turbino, tako da proizvaja elektriko z visokim izkoristkom tudi pri manjših močeh,
- izračunani električni izkoristek sistema je 63,8%.

Sistemi TOGC in PT so zelo obetajoči tudi za stanovanjske enote, čeprav je treba ugotoviti možnost in trpežnost v primerjavi z običajnimi sistemi.

Široka uporaba bo dala gorivnim celicam cenovno primerljivost z drugimi sistemi. Za gorilne celice že desetletja trdijo, da se bodo pocenile, toda čas za to še ni prišel. Potreba po gorilnih celicah v avtomobilski industriji in nizkoemisijskih vozilih naj bi vplivala na razvoj in možnost, da gorilne celice postanejo cenovno ugodne.

5 CONCLUSION

In this paper the working principle of fuel cells has been briefly described, focusing on those aspects that make this technology attractive for residential co-generation. Some of the existing systems have been presented. Then a system based on solid-oxide fuel cells and a gas turbine has been proposed and analysed using a mathematical model. The main conclusions of this work are:

- fuel cells seem to be one of the ideal technology for residential co-generation;
- to date only one co-generative system has reached commercial maturity, but many manufacturers are now announcing the commercial availability of their products;
- Solid-oxidef fuel cells can be well integrated, theoretically, with a micro gas turbine to yield high-efficiency power-generation cycles, even in the sub-MW power range;
- the calculated electrical efficiency of the system is 63.8%.

SOFC-GT systems seem to be very attractive even for residential-size power units, although reliability and durability comparable with conventional power plants and lower cost, essential to market entry, have still to be proved.

However, their use will become widespread when they become cost-competitive. Fuel-cell advocates have been promising reductions in price for decades, but the time might actually be at hand. The need in the automotive industry for fuel cells in zero-emission vehicles may fuel an explosion in the technology development and manufacturing capability, finally bringing to reality the time of low-cost fuel cells.

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6 LITERATURA
6 REFERENCES

[1] Willis, H.L., W.G. Scott (2000) Distribuited power generation, *Marcel Dekker, Inc*, New York.
[2] Stauffer, D.B., J.H. Hirschenhofer, R.R. Engleman, M.G. Klett (1998) Fuel cell hanbook, *FETC*.
[3] Appleby, A.J, F.R. Foulkes (1989) Fuel cell handbook, Van Nostrand Reinhold, New York, NY.
[4] Kordesch, K., G. Simader (1996) Fuel cells and their Application, VCH.
[5] Ansaldo (1994) The PC25 Fuel cells co-generation power plant, CLC S.r.L., Genova, Italy.
[6] Harvey, S.P., H.J. Richter (1994) Gas turbine cycles with solid oxide fuel cells, Part I: Improved gas turbine power plant efficiency by use of recycled exhaust gases and fuel cell technology. *Journal of Energy Resources Technology, vol. 116*.
[7] Harvey, S.P., H.J. Richter (1994) Gas turbine cycles with solid oxide fuel cells, Part II: A detailed study of a gas turbine cycle with an integrated internal solid oxide fuel cells. *Journal of Energy Resources Technology, vol. 116.*

[8] Lubelli, F., A. F. Massardo (1998) Internal reforming solide oxide fuel cell-gas turbine combined cycles (IRSOFC-GT). Part A: cell model and cycle thermodynamic analysis. *International Gas Turbine and Aeroengine Congress & Exhibition*, Stockholm, Sweden.
[9] Van Schie, N. (1995) Solide oxide fuel cell in combination with gas turbine. *Netherland Energy research Foundation Report,* ECN-I-95-020.
[10] Campanari, S., S. Consonni, G. Lozza, E. Macchi (1998) Libro bianco sulla cogenerazione, Volume IV: "La micricogenerazione: le tecnologie del futuro, *Associazione Termotecnica Italiana del Gas, Milano,* December.
[11] Valente, R. (2000) Modellizzazione d' un impianto a celle a combustibile per la produzione combinata d' energia elettrica e calore. *Master Thesis, Università di Trieste*.
[13] Achenbach, E. (1994) Three dimensional and time-dependent simulation of a planar SOFC stack. *Journal of Power Sources, 49*, 333-348.

Medmrežje
In the Web

[W1] http://www.fuelcells.org
[W2] http://www.northwestpower.com
[W3] http://www.gefuelcell.com/homegen_prod_desc.html
[W4] http://www.ballard.com

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