Use of Fuel Cells on a Land Vehicle and its Modelling with CAD System

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Abstract:- The attainment of rational energy use can be obtained by using a co-generation system, which is a system able to produce thermal and electric power at the same time, or better through a trigenerative system able to produce the necessary cooling energy to air conditioning from "waste" thermal energy. If a system of electrical energy production gives consistent quality and quantity of thermal energy as a by-product, it is always convenient beyond that useful to recover it. In this way, both a higher efficiency of the whole system and an obvious reduction of the polluting emissions (otherwise produced if the thermal energy rate is generated in a separate manner) are obtained. Among the energy production systems that have the characteristic of "trigenerate" in addition to the production of primary energy in the shape of mechanical or electrical energy, fuel cells in tandem with heat pumps are undoubtedly among the more innovative energetic systems, in terms of energetic sustainability or environmental sustainability. These innovative fuel cell systems are the object of study of both research bodies and automotive constructors as an alternative to traditional internal combustion engines. In this paper, the analysis of these fuel cell systems, working in the propulsion and in the trigenerative order, in the low-power field is carried out, in terms of some significant parameters based on the use of the fuel, on its electric power conversion performance and above all on the environmental impact of the considered system. Then the determination of the said system is achieved in an application to a real case relative to land traction. Finally, through CAD modelling, the feasibility of rationally positioning the two energetic systems, the propulsive and the trigenerative ones, inside the vehicle, is highlighted.

Key-Words:- Environmental Sustainability, Energetic Sustainability, Fuel Cell, Trigeneration, Hybrid propulsion system, CAD system.

1 Introduction

Although human progress and technological development are the goal to reach, awareness of the enviromental situation and a suitable action plan, on the part of mankind, is by now necessary in order not to further damage the atmosphere. City centers are the main cause of this scenario, just because of the incessant production of polluting substances coming from an uncontrolled use of the mass of cars and from thermal energy production systems presents in residential centers and in the various inhabited structures.

Surely, also industrial zones, in this context, play an important role and do not contribute to the pursuit of an ever increasing Environmental and Energetic Sustainability with respect to the current energetic resources. There are two processes to be addressed, the degenerative process of the total climatic situation due to the polluting substances, and the progressive one of the new energy production systems that are advancing in the global technological panorama. The real problem lies in the fact that, while the first process is extremely fast, the second is very slow. This slowness is due to an economy that does not invest too much in alternative research and that finds it hard to separate itself from the oil politics that today continue to condition the world much more than in the past. The problem of the environmental impact of systems of energy transformation, in both the traction and the stationary field is currently a topic of great interest in the world-wide panorama, because it has reached worrisome levels. In this context, fuel cells [1, 2, 3] have a fundamental role as eco-friendly systems with a high energetic efficiency and elevated flexibility of use because they allow both high efficiencies and significant reductions of the polluting emissions to be realized, conjugating perfectly in extremely flexible systems with the requirement of being able to arrange the variousenergetic productions. Supplying heat at low cost as waste of electric power production, of a certain thermal level, fuel cells can be suitable employed in cogenerative or trigenerative order.

In this paper a vehicle for camping at low environmental impact is analyzed. Research in the field of low emission vehicles, is oriented towards hybrid propulsion systems, where close to a traditional internal combustion propellent an electric motor together with a generator, a bench of storage cells and static power converters are present.
In this paper, the conventional propellent is replaced by fuel cells that constitute the propeller of the vehicle and also they act as a generator of electrical, thermal and cooling power in the case when they are combined with heat pumps. Two fuel cell systems are used: one for propulsion and one for the feeding of the services inside the cab. The first system feeds the propeller and produces a thermal energy rate that is entirely recovered (because it is of a PEMFC system that works to approximately 100 °C) in the reformer section , while the second system is working in a trigenerative order to satisfy the energetic required from the auxiliaries. In such a way it is possible to have a simpler energetic management and moreover to avoid problems consequent to the excessive overdesign of the trigenerative system. In the context of environmental and energetic rationalization, this prerogative makes the considered camper van very attractive.
It becomes therefore completely independent in terms of thermo-electrical requirements, also in stop areas where the vehicle cannot be fed from the outside.
Then, through CAD modelling, the feasibility of rationally positioning the two energetic systems, the propulsive and the trigenerative ones, inside the vehicle, is highlighted. The energetic-environmental analysis is carried out through an environmental index used for a comparison between the systems studied in this paper and the traditional ones, in addition to two indices for the evaluation of the possible fuel saving and efficiency of conversion of its chemical energy in the other types of energy demanded.

2 Environmental evaluation of energy systems

To estimate the polluting substances in terms of CO and NO_x avoided from the energetic systems object of study in this paper, an index of the environmental impact (I_{amb}) [4] was defined. The aim is to transform the produced polluting substances in terms of carbon monoxide (CO) and nitrogen oxides (NO_x) equivalents and to estimate the environmental impact of the considered energetic systems with the following equation (1):

$$I_{amb} = \sum_i p_i \cdot Q_i \qquad (1)$$

where:

Q represents the emitted quantity of the polluting substances, reported in table 2 and expressed in [kg_Q/kWh];

p is the weight, expressed in $\frac{kg(CO+NO_x)_{eq}}{kg_Q}$, depending on the quantities of the polluting substances and calculated by the:

$$p = \frac{CO}{X} * i_1 + \frac{NO_x}{X} * i_2 \qquad (2)$$

where:

CO and NO_x represent the limit values of this polluting, [kg/year];
X is the limit value of the considered polluting substance, [kg/year];
i_1, i_2 are the percentages in volume of CO and NO_x emitted from the considered energetic systems, (fuel-cell system composed of a stack and reformer section, or diesel engine).

The unit of measure of I_{amb} is $\frac{kg(CO+NO_x)_{eq}}{kWh}$.

It is important to stress that the polluting CO and NOx are predominant in the emissive propulsive computation.

2.1 Energetic indices of the trigenerative system

With the aim of being able to estimate the environmental impact of the vehicle, some indices [5] are taken in consideration, they highlight the fuel saving with respect to the traditional systems and its use. The energetic system is analyzed splitting its thermal power into a quota for the production of sanitary warm water and for heating, P_C, and in a quota necessary to the absorption system for the production of the cooling energy demanded from the air conditioning, P_f. The first parameter taken in consideration is the fraction of the saved fuel of the trigenerative system (FCR), this parameter allows us to highlight the saving of primary energy, in terms of fuel consumption, with respect to the separate production of the several typologies of energies; this factor can be expressed from the equation (3) in which η_e^* represents a conventional electrical efficiency, in this case, equal to 0,38 (as stated by the Italian Energy Authority) and η_t^* represents a conventional thermal efficiency, in this case, equal to 0,80 (as stated by the Italian Energy Authority):

$$FCR^{TRIG} = \frac{\left(\frac{P_e}{\eta_e^*} + \frac{P_C}{\eta_t^*} + \frac{P_f}{\eta_t^*}\right)^{CONV} - \left(\frac{P_e}{\eta_e} + \frac{P_C}{\eta_t} + \frac{P_f}{\eta_t}\frac{1}{COP}\right)^{TRIG}}{\left(\frac{P_e}{\eta_e^*} + \frac{P_C}{\eta_t^*} + \frac{P_f}{\eta_t^*}\right)^{CONV}} \quad (3)$$

where the apexes CONV and TRIG are for conventional and trigenerative, respectively and where:

P_e electrical power [kW];
P_C thermal power for heating and warm water production [kW];
P_f thermal power for air-conditioning [kW];
η_e electrical efficiency of the energetic system;
η_t thermal efficiency of the energetic system;
COP coefficient of performance of the heat-pump.

Moreover, the fuel utilization factor (FUC) is considered. It provides the measure of how much energy is effectively produced by the system for the fuel unit used. This is in order to have an exhaustive picture on the efficiency of the transformation and utilization cycle of the primary energy, understanding the contained chemical energy in the departure fuel. Equation (4) reports such an index:

$$FUC^{TRIG} = \eta_e + \eta_t + \frac{P_f}{COP}\frac{1}{Q_{fuel}LHV} \quad (4)$$

where:
Q_{fuel}, trigenerative system fuel flow, [kg/s];
LHV, lower specific heat of the feed fuel [kJ/kg].

3 Camper van

As an application to a real case a camper van commonly employed for long journeys and staying in tourist areas (whose technical card is reported in Table 1) is considered.

Model	Mondial 62L
Engine	Diesel
Powerful engine	2.8 l – n.4 cylinders
Power	108 kW

Table 1 Technical card of the camper van.

Two fuel cell systems are used: one for propulsion and one for the feeding of the services inside the cab.
The analyzed vehicle is independent in terms of electrical, thermal and refrigerators requirements from the installation on the vehicle of a trigenerative system. In particular this system is a fuel cell system, thanks to which, also when the camper van stops in the appropriate areas for camping, it does not need to connect to the mains network. All that allows to reduce in considerable way the emissions produced from the vehicle, in the case in which the user is fed from energy produced through traditional energetic systems. With regard to the propulsion, two cases can be distinguished, i.e. the case in which the propellant is the diesel engine of the vehicle and the case in which a fuel-cell system with polymer electrolyte is used, this type being the more consolidated technology for the applications in the field of the traction [6, 7].

3.1 Hybrid system

From the point of view of propulsion the vehicle modified in this way becomes a real hybrid vehicle, and then it becomes a first rank system with low polluting emission. The plant adopted, is a hybrid-series type [8], summarised in Figure 1, in which propulsion is given to an electric motor, while the fuel cell system directly provides the electric power to feed the electrical system.
In particular, the configuration adopted, is denominated "range extender"; the fuel cell system assures the autonomy of the vehicle supplying the energy that the batteries distribute, while the batteries have the function of assuring the power demanded in driving manoeuvers, so as to have null balance in every storage cell load-discharge cycle.
Specifically, the stack recharges the traction batteries assuring a determined charge level, the batteries follow the demand for power of the vehicle; the stack also supplies energy to its own auxiliary. This configuration, as mentioned above, allows a higher level of autonomy and a better economy of the fuel with consequent lessening of the emissions.

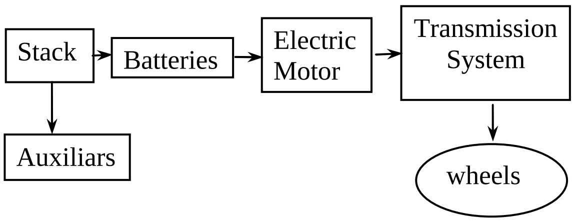

Fig. 1 Hybrid vehicle scheme.

Moreover, it avoids overdesigning the APU (Alternative Power Unit), which is the alternative power unit, represented in this case by the stack, assuring therefore a size of the fuel cell system suited to the vehicle energy demand [9]. The electric power produced by the propulsion system is of a continuous type, and is characterized by a voltage value just of the chosen fuel cell operating characteristics. The electric motor adopted, is a motor that works on alternate current and is characterized by a fixed feeding voltage, while the electrical accumulator system is able to work also if it is fed by continuum current at its own characteristic voltage. The electrical connection to the traction battery package is realized through a converter step-up (see Figure 5) that transfers the power generated by the stack to the batteries, raising the voltage from the measured value at the ends of the stack, to that of the batteries package. The electronics of the induction motor and inverter and the dc-dc converter used for the vehicle auxiliary feeding are connected to the node battery. In Figure 2, the variation of the batteries charge state (SOC), during a normal city operation, is reported, it can be seen how a value of 40% of the charge state is reached, the fuel cell system enters in operation to recharge the batteries. The traction system, moreover, provides the regenerative braking and the consequent available energy recovery in the braking and/or deceleration phases, which is sent into the traction batteries package, this recovered energy can be used as a supplement to the APU, further reducing fuel consumption. As far as the control system is concerned, it manages the flow of power between batteries and motor, and between the wheels and rigenerative braking.
For this type of propulsion, the control system is constituted of two fundamental elements:
- the controller;
- the power component. The controller manages and guides the instructions, and therefore it takes part in the cell operating system, depending on the battery load state.

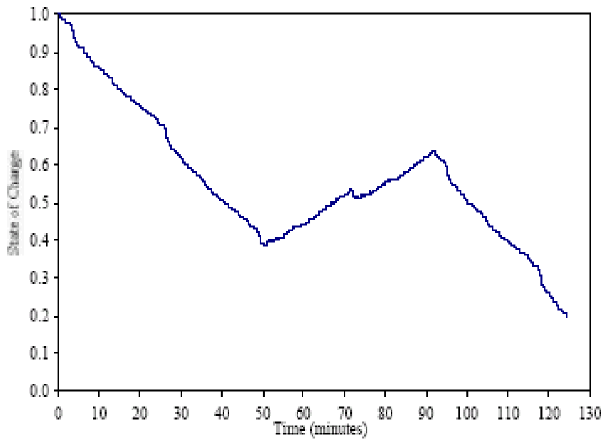

Fig. 2 Variation of SOC during an urban cycle [8].

The power component doses the power flow as a function of the power consumed by the electric motor. Regarding the camper feeding services, in terms of electrical, thermal and cooling requirements, two types of fuel cells working at low temperature are considered in this paper.

3.2 Camper propellent

From the point of view of the traction, the action of the camper van is considered in the course of a cycle ECE15+EUDC ("European Cycle Emission" used when the city use of the vehicle is supposed, and "Extra-Urban Driving Cycle" used when an extra-city use of the vehicle is supposed). In Figure 3, the power demanded from the propellent is reported, while the power distributed from the fuel cell system during the cycle is reported in Figure 4.

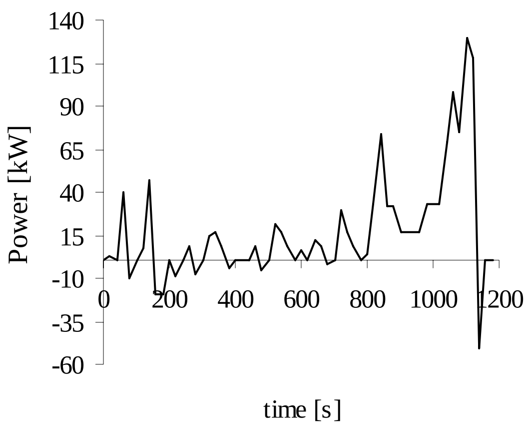

Fig. 3 Variation of the power needs at the wheels during a cycle.

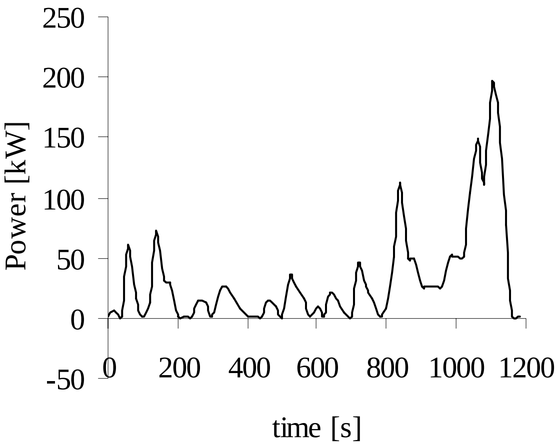

Fig. 4 Fuel cell system supplied power for cycle.

The plant model adopted considers an electric power lung [10, 11], as illustrated in Figure 5, consisting of a system of electrical accumulators whose stored energy is exploited in the starting stage, in order to satisfy the demand for energy during the temporal interval between the moment in which the vehicle is started to the moment in which the primary fuel is transformed into hydrogen in the reformer and the latter into electric power in the stack.

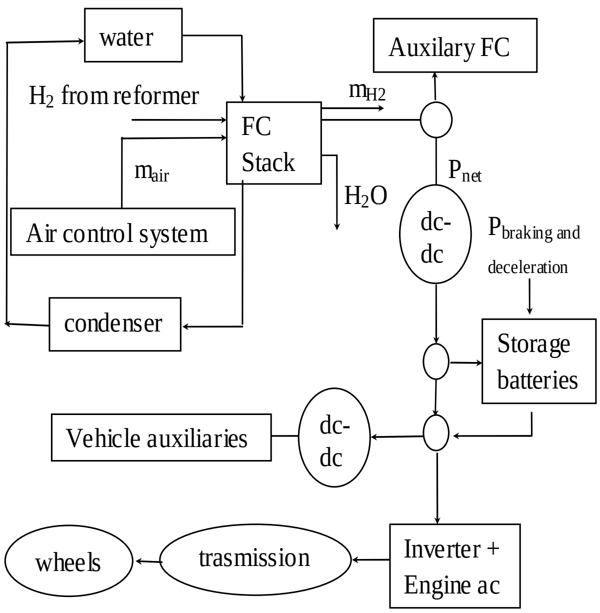

Fig. 5 Schematic representation of a Fuel Cell propulsion system.

The system of accumulators is used when there are peaks of demand for electric energy, because, as known [12], the reformer is not able to follow the demand for the propellant, and also to recover the energy generated in the deceleration and braking phase.
The flow of hydrogen generated from the reformer is constant [13], so the surplus energy demanded from the electric motor fed by the fuel-cell system is supplied from the accumulators.
The thermal energy produced during the propulsion, is used inside the same system in the section of the fuel reformer.
The water exiting from the stack is recirculated and sent into the clean-up section, where the carbon monoxide rinsing happens, this water is collected with the water contained in the reforming section.

3.3 Camper Services

A fuel-cell system of the PEMFC type, electrolyte polymer fuel cell or of the PAFC type, acid phosphoric fuel cell, to feed the passenger compartment appliances. In particular, because the consumption of the services of the camper van (consisting of the appliances, the warm or cold air production and the sanitary warm water production) are not greater than the consumptions of an ordinary home, for the analysis reported in this paper, these latter consumptions were assumed.
As previously illustrated, a second fuel-cell system is considered for feeding the services in the vehicle, in particular a comparison between a PEMFC system and a PAFC system was carried out. The thermal energy produced as primary process waste from electric power production, is split into a quota used for producing sanitary warm water and necessary for the winter heating of the vehicle and the quota for the summer conditioning.
In Table 2, the number of appliances and electrical accessories with the corresponding absorbed electrical power are reported.
The schematic representation of the feeding network of the services of the camper van is reported in Figure 6. The network provides all the components necessary to the energy for reaching the consumers with the demanded voltage and frequency.
Moreover, a system of storage cells allows storage of surplus electric power, in order for it to be used when required.

Unit	number	Power W
Neon lights	11	6
	2	12
	1	22
Fan	1	45
	1	14
Fridge 135 l	1	85
15” TV	1	39
Radio	1	35

Table 2 Appliances and electrical accessories of the camper van.

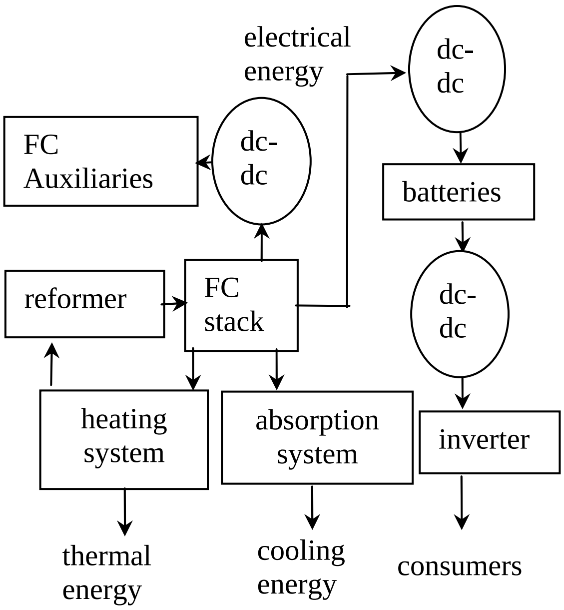

Fig. 6 Fuel cell system.

3.4 Reforming system

In any case, the feeding of the fuel cells for both systems is carried out with natural gas for which a reforming section is considered in the vehicle.

In order to produce the hydrogen necessary to the stack operation the natural gas auto-thermal reformer (ATR) is used [14, 15], this is an economically favorable technology compared to a steam reformer. The fuel, natural gas, is pumped from the tank and injected into the reforming reactor, in the integrated auto-thermal reformer assembly; this is made up of the real reformer auto-thermal reactor, the high and low temperature water-gas shift section, the sulfur removal where the alloyed sulfur is removed and the water boiler that provides the heat necessary to vaporize the fuel and the water. It also is less subject to wear and better addresses the various load variations demanding hydrogen production. The better adaptation to load variations is due to the fact that the heat necessary to the reforming reaction, is supplied by a partial combustion reaction that happens in parallel with the reformer reactions, and in the same reaction atmosphere following:

partial fuel oxidation

$CH_4 + ½ O_2 = CO + 2H_2$ (esothermic reaction);

fuel reformer

$CH_4 + H_2O = CO + 3 H_2$ (endothermic reaction).

Carbon monoxide and hydrogen are obtained from both the methane reactions, together with water vapor and the inerts contained in the air, they constitute the reformed flow sent to the reactor converting the carbon monoxide into carbon dioxide and other hydrogen. After the reactor, the clean-up section of the carbon monoxide is present, where the rate of carbon monoxide contained in the reformed flow is reduced, by washing the flow with water. The thermal exchange in terms of efficiency and exchange time, is better than what happens in the steam reformer. In the steam reformer [16], in fact, the necessary heat to the reformer is produced by a suitable burner, with a heat exchanger in order to manage the thermal energy to transfer to the fuel conversion reaction, the thermal exchange therefore happens with lower efficiency and demands a greater temporal interval.

3.5 Modelling the camper van

In this section a fuel cell system for the camper van was modelled through the software pro-engineer, for optimizing the spaces inside the vehicle and to verify the effective feasibility of the allocation of the aforesaid system inside the vehicle, as shown in Figure 7.

Modelling allowed optimization of the spaces of the vehicle occupied from the new system, assuring moreover, the possibility of maintaining the accesses and the necessary spaces for a possible maintenance and the necessary ventilation of the premises in order to avoid the excessive overheating of the electrical components however present.

From the point of view of the management of the spaces, the trigenerative system in all placed under the plan of the cab in the double pavement of which the camper is normally equipped for the transport of baggage, and that can be replaced in this function by suitable racks located on the roof or on the sides of the vehicle.

Fig. 7 Camper van modelled with Pro-E

In Figure 8 a photo of the double pavement of which the camper is equipped is reported. A "wireframe" model of the camper is visible in Figure 9. The external transparent covering gives the perception of the disposal space.

Fig. 8 Water tank and piping in the double pavement.

Moreover, the trap doors for the double pavement are visible in Figure 10 used for the system control and maintenance operations. A view of the fuel cells system is visible in its totality in Figure 11, which puts all the vehicle in the "wireframe" modality with the single exception of the trigenerative system.
In Figure 12, the various components of the propulsive system and annexed captions are shown. The serial combination of the stack with the batteries package and with the inverter, in its turn linked to the electric motor, typical of the range extender configuration, is clear.

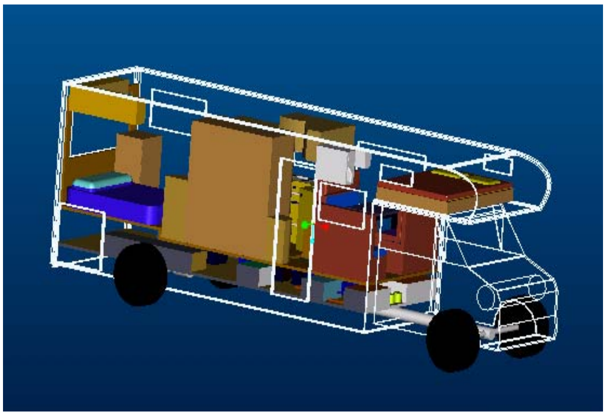

Fig. 9 A camper van representation.

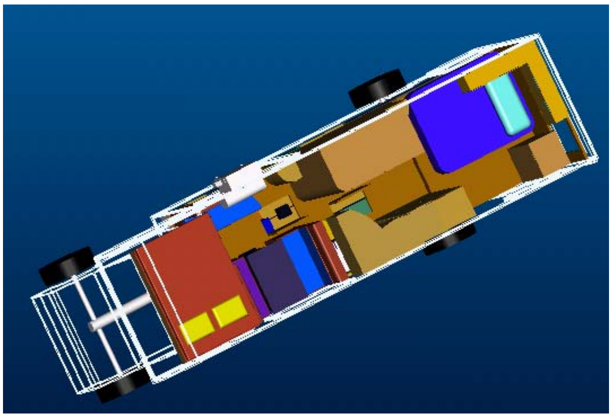

Fig. 10 Trap doors for the double pavement representation.

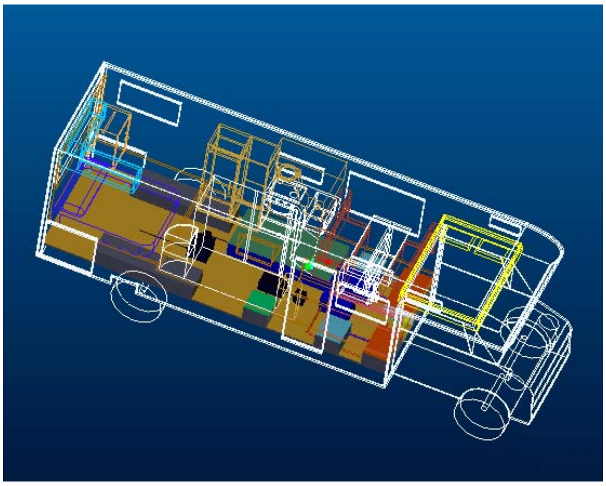

Fig. 11 Representation of the traction and electric energy production plant.

Similarly, in Figure 13 the components of the trigenerative system feeding the users are illustrated. Also in this case it is possible to note how the accumulator system is a good interface between the electrical energy generated by the stack and user demand, in the form of a serial combination. The electrical alternate current for users is directly provided, after conversion, from accumulators at 220 V. Thereafter, it is provided to the camper van electric distribution system then to be used as a common abitation.

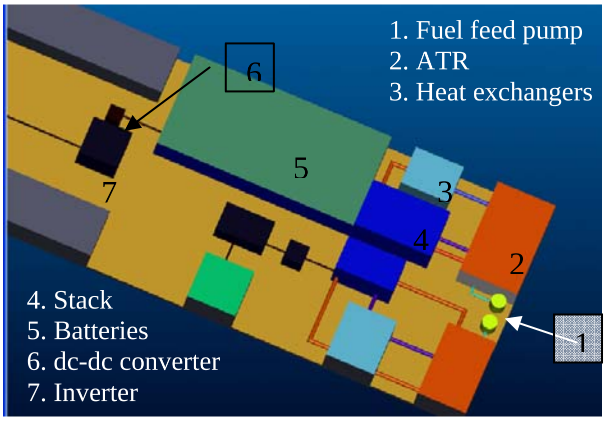

Fig. 12 Components of the propulsive system.

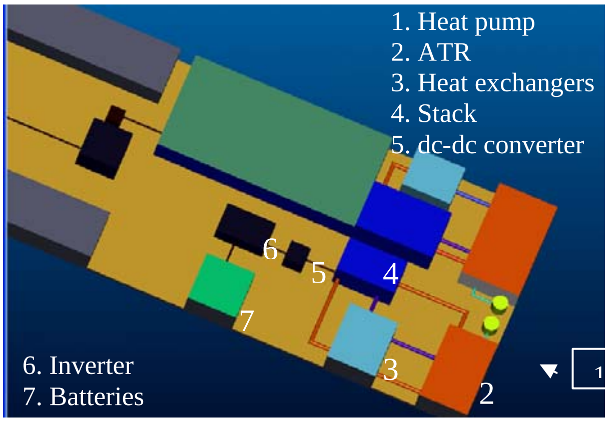

Fig. 13 Components of the system for the service feed.

3.6 Demand and supplied energy

The thermal and cooling requirements, with regard to the air conditioning, are satisfied through an absorption system [17]. It consists of a water/air heat pump whose fluid carrier is the fuel-cell cooling system circuit water, which allows the thermal recovery of the waste heat deriving from the emissions produced by the reformer and by the warm water of the electrochemical process. A 100 liter boiler is proposed for sanitary warm water production. Inside the boiler a coil is covered with water that recovers waste heat, so as to guarantee a temperature in the boiler of approximately 45 °C (stand point temperature). Moreover, the system provides for electric integration in the storage boiler, which starts functioning when the heat recovered is insufficient to maintain the stand point temperature, effectively rarely used, established for the boiler and governed by the regulations relative to low-temperature heating systems, such as that installed in the vehicle.

In Figure 14, the electrical, thermal and cooling requirements for a representative day are reported, in the case when the camper van operates in summer, winter or intermediate season.

From Figure 14 it can be noted how the electrical requirements are constant during the seasons, the electrical absorption is not, in fact, dependent on the environmental conditioning and heating.

The fuel-cell systems were designed for providing the internal electrical and thermal requirements of the camper van; therefore the indexex introduced in the previous sections were determined. With regard to the propulsion, the environmental impact index was estimated for the propulsion system presented and then it was compared with the index characterizing the conventional propulsive system.

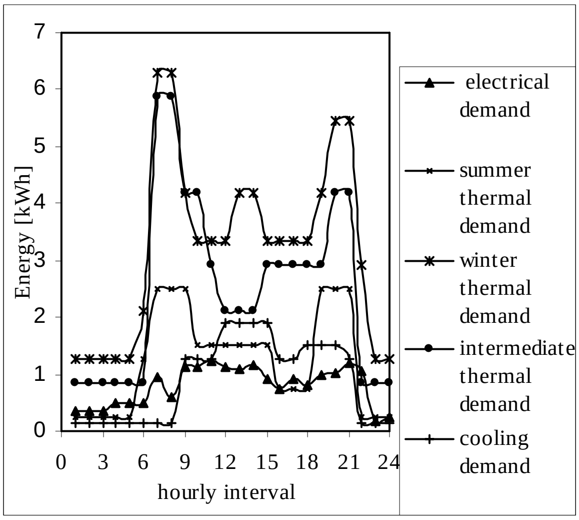

Fig. 14 Electrical, thermal and cooling demands for day.

For both the two fuel-cell systems the produced energy (electrical, thermal and cooling) was estimated, as can be observed in Figures 15 and 16, adopting the pursuit of the electrical load. Electrical production was increased, in part with the aim of satisfying the possible insufficiency of thermal energy, which can be verified, in particular, during the winter when the thermal energy requirements are more consistent both for heating and sanitary warm water production, but especially for accumulating electric power during the cell operating period, considering the possibility of

turning it off in that period of the day the energetic demands are minimal.
To face this increment, the electric energy produced in surplus is accumulated in an appropriate system constituted of recognized batteries with which the vehicle itself is equipped for emergencies. The system is able to release the accumulated energy during the time bands in which the system is turned off.
From Figures 15 and 16 it can be noted that both the fuel cells give good results on the three representative days, summer, winter and intermediate season, considered in the analysis, because they follow the variation of the demanded load very well.

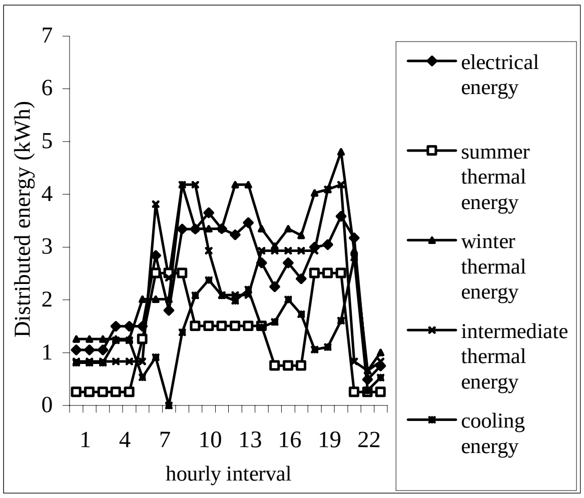

Fig. 15 Energy supplied by a PEMFC system.

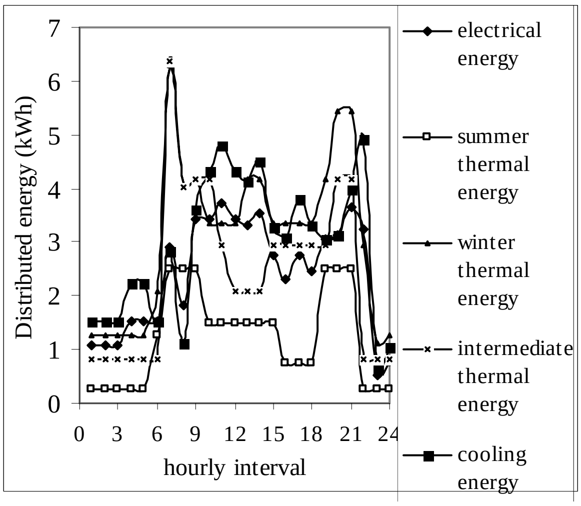

Fig. 16 Energy supplied by a PAFC system.

3.7 Indeces evaluation

Considering the parameters analyzed for the two fuel-cell systems, it can be observed from Figure 17 that with regard to the saved fraction of fuel, the lower value of the PAFC system is due to the greater flow of fuel required from this system, for the same distributed electrical power regarding the PEMFC. Consequently, as far as the fuel utilization factor is concerned, the higher value of the PAFC is due to the greater thermal efficiency characterizing these systems. However, both the systems are profitable in terms of saved fuel and conversion efficiency with respect to the traditional systems, a saving of 40% for the PEMFC and 28% for the PAFC with an excellence conversion efficiency, 94% and 98%, respectively, confirm the thesis that these systems can be employed with great benefit as energy generators.
In terms of the environmental impact index, as can observed from Figure 18, the comparison of the polluting substances emitted from the considered energetic systems and propellent with the limiting values established by law reported in Table 3, shows a drastic reduction of about 50% in the atmospheric polluting by the cell with respect to conventional engines.
Moreover, it is interesting to point out the reduction of the polluting emissions that the system has realized, this enormously strengthens the proposed thesis, which is to have therefore obtained a vehicle to reduce environmental impact.

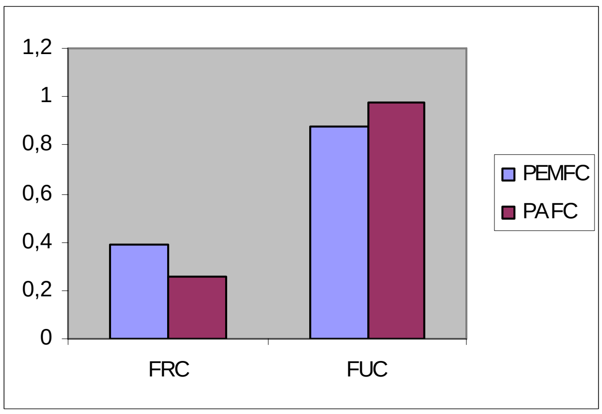

Fig. 17 A comparison among the parameters of the two systems PEMFC e PAFC.

pollution	CO_2	CO	SO_X	NO_X	COV
Limit Value [kg/year]	100 $x10^6$	500 $x10^3$	150 $x10^3$	100 $x10^3$	100x 10^3
Reformer [kg/kWh_f]	186	0,16	-	0,85	0,48
Diesel Engine [kg/kWh_f]	180	0.872	-	0.930	0.436
PEMFC [kg/kWh_f]	-	0,011	-	0,016	0,002
PAFC [kg/kWh_f]	-	0,008	-	0,007	0,002

Tab. 3 Gas pollution emissions and legal limits.

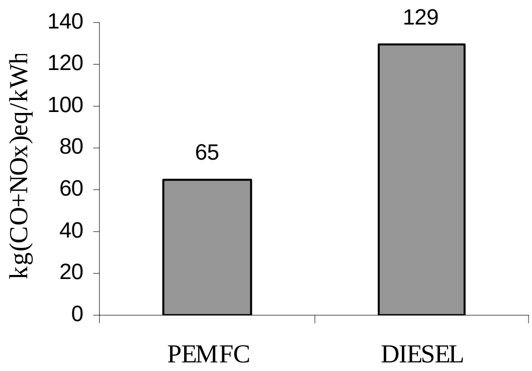

Fig. 18 Environmental impact index.

In Figure 19, the lower quantity of CO_2 produced by the energetic systems considered in this paper can be noted, compared to traditional systems.

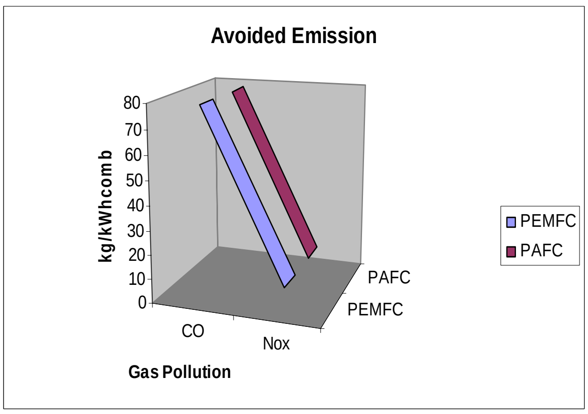

Fig. 19 CO_2 and COV emission avoided.

It is evident that in the reforming section the transformation of the natural gas into rich hydrogen current is followed by the production of a meaningful amount of CO_2. The low polluting emission in terms of CO and NO_x in relation to the emissions avoided of the aforesaid polluting substances is evidenced in Figure 20.

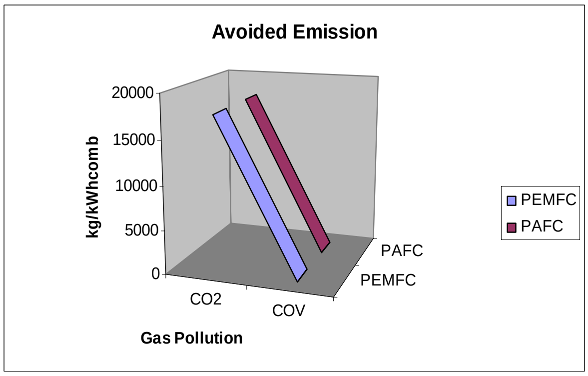

Fig. 20 CO and NO_x emission avoided.

4 Final considerations

Recently hydrogen has been the object of numerous research projects oriented toward the evaluation of the feasibility of its use, therefore, it can be seen as an energy carrier replacing the fossil fuel with more renewable energetic sources. Currently, hydrogen is produced, mainly, from petrol and its derivates and, therefore, it cannot be considered as a renewable energy.

Surely hydrogen and fuel cells are a good combination in the pursuit of Energetic and the Environmental Sustainability.

In this paper the feasibility of application of two fuel cell systems to both the propulsion and services of a camper van, has been investigated.

It must be concluded that the systems considered, because of the small consumption needed (the camper van does not consume more than a small flat in energetic terms), cannot be used to their maximum potential.

Herein, starting from the determination of an environmental impact index, for a more correct evaluation of the impact that the vehicle has on the atmosphere in terms of CO, NO_x, two indices representative of the fuel use were then determined. The environmental impact index allowed the determination in an effective way of the emissions avoided in terms of CO, NO_x with respect to traditional systems. Moreover, the two relative indices, FRC and FUC, the former related to the fuel saving realized by the reformer-fuel cells system and the latter that evaluates the fuel conversion yield in electric power, point out in a comparison of fuel cell systems with traditional systems, their prerogatives in terms of greater fuel saving and a higher energetic conversion efficiency .

The camper van modeled with the "pro-engineer" software has been optimized in its spaces, placing the two fuel cells systems in the double pavement of the cab, so as not to substract space from the cab and not to create discomfort to the user of the camper.

Therefore, despite exorbitant costs, owing to an unsuitable energetic policy with regard to fuel cells, in truth these systems represent a tangible and realizable solution, above all in the automotive field and in that of small consumptions.

It is possible to think of a future employment of the fuel cells in trigenerative order for feeding the energetic requirements in the residential field, in particular it would be interesting to consider the behaviour in terms of energetic efficiency and discouragement of the polluting emissions of a fuel cells system at high temperature compared with the traditional thermal centres commonly employed in residential complexes for the production of thermal energy and fed with methane gas, and also compared with the conventional centres for the production of electric power.

Particularly interesting would be to employ a SOFC (Solid Oxide Fuel Cell) that, as known, works at temperatures near to 1000 °C, to an entire condominium, or a residential complex, which supplies electric, thermal and cooling power to all the apartments, even together with heating/conditioning systems at low temperature, such as the most modern pavement systems .

References:

[1] L.J.M.J. Blomen, M.N. Mugerwa, *Fuel Cell Systems*, Plenum Press, N Y, 1993.

[2] J. Larminie, A. Dicks, *Fuel Cells Systems Explained*, J.Wiley & Sons Ltd, England, 2000.

[3] *Fuel Cell Handbook*, by EG & G.Services Pearson, Inc. Science Application International Corporation, U.S.Department of Energy, Ottobre 2000.

[4] P. Arcuri, G. Florio, P. Fragiacomo, Energy and Environmental Analysis of Cogenerative Fuel Cells, in CD ROM *Proceeding of International Symposium Energy and Environment 2004*, Sorrento (NA), 2004.

[5] L. Fabiano, G. Florio, P. Fragiacomo, Propulsion and Trigeneration by Fuel Cell: an Eco-friendly Camper van, Proceeding of the *5th WSEAS International Conference on environment, ecosystems and development* (EED07), Puerto de la Cruz Tenerife Spain, December 14-16, pp.394 - 399, 2007.

[6] S. Ashley, Fuel Cell: Start to Look Real, AEI, pp.64-74, 2001.

[7] J. Friednam, A. Eggert, P. Badrinarayanan, J. Cunningham, Balancing Stack, air supply, and Waret/Thermal Management Demans for an Indirect Methanol PEM Fuel Cell System, *Society of Automotive Engineers*, SAE-International 2001-01-0535, pp.37-43, 2001.

[8] K. H. Hauer, R. M. Moore, S.Ramaswamy, The Hybridized Fuel Cell Vehicle Model of the University of California, Davis, *Society of Automotive Engineers*, SAE-International, 2001.

[9] M. Stratonova, S. Lasher, E. Carlson Assessment of Fuel Cell Auxiliary Power Systems for On-Road Transportation, Applications, Hydrogen, Fuel Cells, and Infrastructure Technologies, FY Progress Report, 2003.

[10] Y. Baghzouz, J. Fiene, J. Van Dam, L. Shi, E. Wilkinson, R. Boehm, Progress on Improvements to a Hydrogen/Electric Hybrid Bus, Proceedings of the *2000 Hydrogen Program Review* NREL/CP-570-28890, 2000.

[11] *Hydrogen and Fuel Cell Engines and Related Technology*, Course Manual, College of the Desert and Sunline Transit Agency, 2001.

[12] A. Eggert, D. Friednam, S. Ramaswamy, K. Hauer, J. Cunningham, R. Moore, Simulated Performance of an Indirect Methanol Fuel Cell System, *Society of Automotive Engineers,* 2001-01-0544, pp. 99-107, 2001.

[13] P. Fragiacomo, G. Lucà, Energy Analysis of Vehicles using different PEMFC Systems, *International Symposium Energy and Environment 2002*, Capri, pp. 471-482, 2002.

[14] L. Thompson, Fuel Processor for PEM Fuel Cells, FY Annual Progress Report, U.S.Department of Energy 2003.

[15] R. Kumar, P. Kulkarni, C.t Moorefield, S..Barge, and V. Zamansky, Fuel Cell Distributed Power Package Unit: Fuel Processing Based on Autothermal Cyclic Reforming, Hydrogen, Fuel Cells, and Infrastructure Technologies, FY Progress Report, 2003.

[16] P.L. Spath and M.K. Mann, Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming, Report n° NREL /TP-570-27637, Golden, CO, USA, National Renewable Energy Laboratory, 2001.

[17] A. Perago, D. La Forgia, A. Ficarella, *Progettazioni Tecniche e Materiali, Impianti di riscaldamento e condizionamento negli*

edifici residenziali, Maggioli Editore, Maggio 2005