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POSSIBLE USES FOR THE HYBRID ELECTRIC VEHICLE IN MOBILE DISTRIBUTED GENERATION

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SUMMARY

This paper analyses the opportunities and dilemmas derived from the current technological state of electric vehicles - EVs. One type of EV, the hybrid electric vehicle – HEV, when parked, can operate as a mobile distributed power generator that can also provide ancillary power services such as decentralized back-up power and supply electrical energy and heated water. Hence the concept of a *cogenerating vehicle* is used throughout this paper. Such concept widens the range of power supply options and, consequently, of strategic planning in the power industry.

KEY WORDS:
Distributed Generation – Hybrid Electric Vehicles – Energy Efficiency - Environment - Planning

1.0 INTRODUCTION

This paper presents and discusses the opportunities and dilemmas derived from the current technological state of EVs. New types recently introduced in the market, such as the HEV, may be used as a means of transportation and, when parked, as electric generators integrated to the power grid. The HEV has an internal combustion engine - ICE that, coupled to a generator, recharges the batteries, Whenever necessary, they supply the electric energy used to drive the wheels. The set works in an optimized manner with both reduced fuel consumption and extremely low emission levels. When parked, HEVs may be connected to the power grid, and therefore become a distributed generation mobile unit that can additionally be used to supply heated water. The concept of a *cogenerating vehicle*, used throughout this paper, is derived therefrom. Such concept widens the range of electrical power supply options and aims to minimize the impacts of temporary emergencies in low-voltage networks. It also complements conventional network electricity supplies, thereby decreasing the need for investments and reducing transmission and distribution losses, an average of 15% in Brazil .

Interestingly enough, after a period in which electric vehicle-related activities in Brazil where limited mostly to initiatives in the academic sphere, the theme has reappeared within the broader scope examined in this study. More recently, in fact, considerable technical studies on the theme have been published. A new scenario has emerged in which the Brazilian industry is beginning to commercialize non-road EVs and HEV buses. Traditional vehicle manufacturers also plan to introduce EVs that include devices to connect to the power grid [1 - 5].

This paper begins with a brief description of the existing EVs, followed by a discussion on the peculiarities of the HEVs as well as some of the possible trends associated with its development. Item 5 presents the calculations made on the potential use of the HEV in the current scenario and intricate Brazilian energy matrix. The final part of this study outlines the conclusions and recommendations for further research on this theme.

2.0 ELECTRIC VEHICLES

EV are defined as vehicles powered by at least one electric motor. Although there are many models of EV at different stages of development, they can be grouped in two:

- Group I: Battery Electric Vehicles
  - I.1 Non-road EV
  - I.2 General Road Use

- Group II: Hybrid Electric Vehicles - HEVs
  - II.1. Using internal combustion engine
  - II.2. Using fuel cells

The electric motor, or motors, in Group I vehicles are powered exclusively from batteries. In this case, electricity is stored in chemical form to be used later by the electric motor. Group I vehicles therefore need to recharge their batteries from the power grid. Typical vehicles in subgroup I.1 are non-road electric vehicles that use small-power direct current motors[6]. The larger, general-use vehicles in subgroup I.2 generally

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use more efficient induction motors. Some vehicles rely on more than one electric motor within a single car. Others may feature regenerative breaks, i.e. when stepping on the break, the electric motor is transformed into a generator and recovers part of the inertial energy that would otherwise be dispersed also when the vehicle runs downhill. Figure 1 summarizes these electric vehicle concepts where EMG means Electric Motor-Generator.

power grid ⇒ batteries ⇔ EMG ⇔ wheels

fuel ⇒ converter ⇔ EMG ⇔ wheels

Figure 1 – Groups I and II Schemes

The main characteristic of Group II is that it uses at least one fuel as a primary source of energy. As they are nonetheless electric vehicles, hybrids run on at least one electric motor. The term *hybrid* is thus explained from the fact that although these vehicles are electrically propelled, they run on fuel rather than electricity. Control systems play a fundamental role in HEVs, supervising a great number of regulatory functions of the generator, motors, regenerative brakes, battery power supplies etc. In fact, HEVs feasibility had to wait for the miniaturization and low costs of modern computers as well as advances in power electronic devices.

Various configurations are possible for subgroup II.1. The series hybrid, Figure 2, uses an internal combustion engine, ICE, to run the electric generator, which in turn permits the existing battery bank to remain permanently charged. In addition, the need for battery recharging is eliminated. Vehicles of this subgroup may run on any regularly distributed fuel, such as gasoline and diesel oil.

fuel batteries
⇓ ⇓⇑
ICE ⇒ generator ⇔ ctrl system ⇔ EMG ⇔ wheels

Figure 2 – Series Hybrid Electric Vehicle Scheme

Another type of HEV is the Parallel Hybrid Vehicle (Fig. 3), where the ICE can drive both the wheels and the electric motor through a special mechanical coupler that also permits both motors to run simultaneously [7]. This architecture takes advantage of the best features of each motor that are turned on or off to maximize the HEV's performance. Because of the vast number of possibilities for coupling the devices, there are various models of parallel HEVs.

fuel ⇒ ICE ⇒ shift gear
⇓ ⇓⇑
battery ⇔ ctrl system ⇔ EMG ⇔ wheels

Figure 3 – Parallel Hybrid Vehicle Scheme

In addition to the HEVs that use internal combustion engines, subgroup II.2 vehicles use fuel cells to generate electricity on board. In this case, electricity is produced directly from the oxidation of hydrogen [8]. These vehicles may be fueled directly with hydrogen, whether through a network, a complicated solution since this gas is highly flammable [8], or in the form of metal hydride [9]. The gas can also be produced in a reformer, Figure 4, a device that removes hydrogen atoms from molecules of fuels such as methane, methanol, ethanol, etc.

fuel
⇓
reformer ⇒ fuel cell ⇒ ctrl syst ⇔ EM ⇔ wheels

Figure 4 – Fuel Cell Vehicle Scheme

Vehicles in subgroup II.2 offer significant advantages since they contain no moveable parts and feature extremely low tail-pipe emissions. For this reason, many auto manufacturers and various governments – including Brazil's – are investing in this technology, with many experimental passenger cars and buses already in the testing phase. Generalized use of these vehicles, however, may take some time since fuel cell prices are still high and an adequate fuel solution needs to be defined.

Clearly, the current technological environment foresees subgroup II.1 developing earlier. In fact, these vehicles are already commercialized at a regular basis and indicate characteristics of general use [1]. Thus, the term HEV in what follows will refer to subgroup II.1 vehicles. Most of the conclusions, however, may be extended to subgroup II.2 vehicles, which should enter later in the market.

3.0. HEV ADVANTAGES

3.1 High Energy Efficiency

HEVs have a 20 to 30% higher energy efficiency than equivalent conventional cars [7] due to at least four factors that make these vehicles intrinsically superior: 1) the ICE runs at a constant speed only in regions of high performance; 2) the regenerative break mentioned in item 2 plays a significant role, especially in urban courses; 3) HEVs do not consume energy while sitting in traffic; and 4) the EMG-battery-control system set is extremely efficient.

3.2 Low emissions

HEVs produce significantly lower emissions than conventional vehicles, in great part because their ICEs operate in a constant speed and have less power than those of equivalent conventional vehicles. For example, a traditional city bus running on diesel oil requires about 200 HP, whereas a similar hybrid electric bus uses only about 80 HP. Table 1 compares emission levels of different pollutants between a gasoline-powered HEV and a recently-manufactured traditional gasoline vehicle.

Table 1 – Emissions from Electric Vehicles vs. Internal Combustion Vehicles

Pollutant	Group II.1 Gasoline HEV (g/km))	Recently produced Internal Combustion Vehicle (g/km)
CO	0.290 (*)	0.700 (+)
HC	0.002 (*)	0.142 (+)
NO_x	0.030 (*)	0.200 (+)

Note:(*) IEEE Spectrum Nov. 1998; (+) Ministry of Science and Technology Publications; CO (carbon monoxide), HC (hydrocarbons), NO_x (nitrogen oxides)

3.5 Other factors

HEVs combine the benefits of electric vehicles – less noise pollution, smooth accelerating and easy steering – and the comfort of conventional vehicles – autonomy and easy refueling [7].

HEVs have already passed the consumer testing phase, with an estimated 150,000 circulating in the USA and Japan by the end 2002 [15]. The major auto manufacturers will be introducing HEV models in the market in 2003, and in the city of São Bernardo do Campo, São Paulo State, Brazilian-made and designed hybrid electric buses have been circulating since 1999 [1].

Although HEV prices are still typically higher than those of conventional vehicles, life cycle analyses show that they can be favorably off-set by the lower operational costs. With an increase in scales of production, prices tend to drop and a new paradigm may be established in the industry.

4. HEVs AND DISTRIBUTED GENERATION - DG

In addition to the advantages HEV brings as a vehicle, when parked it can also be used as a generator on wheels that, connected to the consumer, fulfills local energy needs and increase power quality. In this way, it is also interconnected with the power grid and therefore acts as a distributed generator (DG). HEVs can both supply electricity locally and provide ancillary services to the grid.

4.1 HEV as cogenerator

HEV´s ability to generate electricity may be useful in special situations, for example, during camping trips or in isolated areas. Its role as *cogenerator* offers a competitive potential against centralized generation. This particular use of the HEV is obviously subject to environmental restrictions related to emissions, which may vary according to type and location of the HEV .

4.2 HEVs and ancillary services

As seen by the power grid, the HEV serves mainly as a decentralized power backup that can react almost instantaneously to satisfy the network's requests. Its sophisticated control systems can be programmed to operate independently or in coordination with other HEVs. HEVs may be dispatched by a central operator [10] to meet the real-time power requirements of the grid. Therefore, HEVs may provide ancillary services. In other words, they may locally complement the central generation system [15] with operations such as: taking on part of the load in emergency situations; analyzing (locally and in real time) the characteristics of the energy supplied in order to improve its quality; correcting the power factor; supporting the power grid in cases of network recomposition; and generating power during peak hours.

4.3 HEVs and the Brazilian Power Sector

In an interconnected power grid, generator sizes and locations are irrelevant. Economies of scale, however, favored large-sized plants despite transmission and distribution losses averaging 15% in Brazil. Because of hydro generation, there is a predominance of long transmission lines as well as a greater need for additional investments to guarantee network reliability in such vast territory. Many rural areas still have no access to electricity even when located close to high-voltage circuits: this situation represents a distortion in energy supply.

Passenger vehicles are, on average, parked and idle for 22 or more hours per day. Because they are geographically spread out, yet usually close to consumers, HEV may be considered sources of complementary generation to the Brazilian power grid, with a great potential for investment reduction. Obviously, in addition to a coordinated operation, an environmental assessment should also be made due to the emissions produced by the ICE.

Indeed, although the HEV's electrical power - typically 30 kW - is small, it exceeds by far individual needs and 4 vehicles could would be enough to supply a group of about forty homes. The aggregate power of HEVs could be very important to increase Brazil's installed capacity. For instance, a penetration of 20% of HEVs on the one million plus vehicles yearly market would aggregate new DG power in the order of 2000 MW in just one year, considering that each HEV would add a moderate power level of 10 kW.

Thus, HEVs introduce a new chapter on the theme of distributed generation, no longer characterized as fixed. Parking lots may offer connection points in order to capture energy from cogenerating vehicles the energy that can be integrated to the so-called "micro-grids" or to local networks [13,14,16]. Utility companies should therefore pay special attention to the conditions laid out for connection and communication between vehicles and network in the years to come.

5.0 COGENERATING HEV ECONOMY IN BRAZIL

An intricate set of questions emerges from this discussion and requires, therefore, that specific evaluation methodologies be established [3,4,12,17]. Considering the discussion above, the growth of HEV use offer obvious interesting elements to electrical power companies from the economic and environmental standpoints.

5.1 Economy of Scope

It is impossible to clearly separate the costs and benefits associated with each HEV function – traction, generation, water heating and power grid support. The economic results will depend on whether these functions, combined, will generate attractive results. As an example of “economy of scope,” this is the case where the cost of performing multiple functions simultaneously proves to be more efficient than performing each function independently.

There are actually several ways of calculating the costs depending on the objective of the analysis. A realistic scenario, however, presumes that HEVs are purchased for transportation and their electric cogeneration is an additional benefit. In calculating electricity cost, therefore, investments are not taken into account and only the marginal cost of the fuel used to generate electricity is considered [17]. Furthermore, the avoided cost has been deduced from the fuel that would be needed to produce the heat generated by HEVs and used locally.

5.2 Fuel prices and electricity tariffs in Brazil

The economic performance of the HEV as generator depends on fuel prices and electricity tariffs. Table 2 compares fuel prices (taxes included) and energy contents in Rio de Janeiro for April 2002.

Table 2 – Energy Contents and Fuel Prices

Fuel	Un.	10^3 kcal/[u]	R$/[u]	R$/kcal
Diesel	l	9.54	0.6	0.63
Gasoline	l	8.33	1.5 – 1.8	1.8 – 2.2
Hyd. Ethanol	l	5.34	0.8 – 1.1	1.5 – 2.1
NGV	m^3	9.25	0.78	0.84

Fuel prices and taxes are a consequence of independent decisions from various government agencies with different logic and objectives and cross-subsidies. Subsidized for many years, diesel fuel still has a relatively low tax burden. Natural Gas for Vehicles -NGV, in turn, still sells quite modestly although sales are rapidly increasing because this fuel can substitute adapted gasoline-powered vehicles bringing fuel costs by half. NGV is significantly cheaper than distributed Natural Gas -NG, which costs 1.2 R$/m^3 (Brazilian currency, *reais*) at São Paulo’s gas utility company COMGAS – SP for medium-sized residential consumers.

Therefore, neither diesel nor NGV should be used as reliable references. Since gasoline and ethanol have approximately the same price per energy content, the latter has been chosen as reference in this analysis, as it actually proves to be the only fuel whose price closely reflects market conditions.

The price of electricity is based on a complex structure in which cross-subsidies currently favor high power levels. For lower power levels, both residential and commercial, consumer prices in Rio de Janeiro for April, 2002, taxes included, reached 344 R$/MWh. Higher load consumers are subject to a “green tariff” where peak hour rates are 863 R$/MWh*,* and off-peak hours 81.6 R$/MWh .

5.3 Cost of electricity produced by HEVs

Data from Table 1 allows the analysis to be completed, given that 1 kWh = 860 kcal and taking the following hypotheses into account:

a) HEV motor-generator efficiency à 30%

b) Energy content in 1 m^3 of hydrated ethanol:
5.34 g-cal à 6.26 MWh

c) Energy content in 1 m^3 of Natural Gas:
9.25 kcal à 10.76 kWh

d) Use of heat released from HEVs: 70 %

e) Natural Gas heat-production efficiency (residential boiler) à 85%

f) Final residential electricity price: à R$344/MWh;

g) Final NGV price à 0.78 R$/m^3

h) Final distributed NG price: à 1.2 R$/m^3

i) Final hydrated ethanol priceà R$1/l

To calculate the cost of electricity for HEV owners, a 1-MWh production was considered for HEVs while the other power sources were calculated from the given conversion and efficiency values. Figure 5 presents a simplified view, in block diagram, of HEV operation as a co-generating unit.

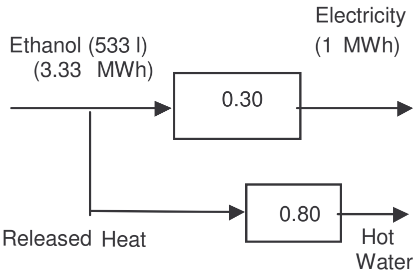

Figure 5 – Representative Block Diagram of the HEV as cogenerating unit (1 kWh = 860 kcal)

According to the conditions assumed by Figure 5, the total ethanol expense of a HEV owner would equal R$ 533.00. As the energy derived from released heat is 2.33 MWh, and considering that only 70% of this heat is used locally, a total of 1.67 MWh of power could actually be used. To obtain the same level of power using a boiler with 85% efficiency, 181 m^3 of NG would be needed. Therefore a HEV would save R$ 219 (1.2 R$/$m^3$ x 181 m^3) in expenses.

In sum, the equivalent cost of the electricity produced by a HEV corresponds to the difference between the total cost paid for ethanol and the avoided utility gas expense, which is equal to 314 R$ /MWh. Thus using HEV-generated electricity instead of the utility company is theoretically advantageous.

Given the aforementioned uncertainties and the number of presumed hypotheses, it is more accurate to consider that that both energies are produced within the same cost range as seen by the final consumer. Nevertheless, there remains no doubt that HEV-generated energy is competitive during peak loads even if not leveraged by the heat production.

5.4 The Economy of HEV Ancillary Services

The benefits of the HEV as an additional support for the power grid depend on the analytical perspective. Therefore, from the point of view of the HEV owners the fixed cost is basically related to their own energy consumption needed to maintain the vehicle available for corrective actions to improve power quality.

However, although the Brazilian legislation provides for ancillary services, these services are not yet regulated. Besides, the Brazilian tariff system does not unbundle the main cost component items such as the cost to guarantee a reliable service. As a consequence, utilities have little familiarity with distributed generation and are implicitly locating the power reserve in generators far from the consumers. On the contrary, HEVs could efficiently carry out this role, which would avoid the burden of a 2% fee on residential bills and 8% on industries for “emergency service capability,” a provision to rent emergency generators for a period of six years .

6.0 CONCLUSIONS

The emergence of electric vehicle technology has proven to be extremely important. The concept of a *cogenerating HEV* creates new challenges to network planning when considering the introduction of mobile distributed generation.

A partnership between *cogenerating HEV* distributors and consumers is well founded since the resources directed to the grid may be optimized if companies prepare themselves in advance for these new concepts.

The calculations shown in this paper have proven that electricity costs related to HEVs are more efficient in comparison to conventional vehicles. Nonetheless, since the results are influenced by distortions that affect prices and tariffs, they have a limited scope and cannot be completely generalized. Despite these limitations and simplifications, the electricity cost related to HEVs is potentially competitive in situations that could use thermal energy. HEVs can be particularly useful in environments such as hotels, hospitals, restaurants and residential complexes, where large quantities of heat are needed in areas which do not requires too high temperatures. It is also worth noting that the price and tariff alterations associated to the reference date used in the calculations do not affect the validity of these conclusions.

An increase in energy efficiency can result in significant cost reductions. For this reason, the introduction of HEV-based cogeneration through fuel cells, in which energy efficiency may reach over 40%, is quite promising due to an increase in its economic feasibility.

The calculations presented also show that the cost of electricity – with or without the thermal application – would be competitive, in any case, in terms of production during peak hours. This important conclusion must be interpreted with care since there is little possibility that the gains derived from a structure based on extremely high ratios between tariffs on and off peak hours will remain indefinitely.

The idea of HEVs becoming an important item for distributed generation deserves to be further explored since, as this study has shown, their increasing presence represents a real and irreversible alternative that is independent of great technological leaps [9].

Other practical technical aspects will be necessary depending on the type of connection used between HEVs and parking lot constructions. In fact, the planned connection must take the exchange of electricity and hot water into account. Furthermore, the communication protocols to be used for interconnecting HEVs with stationary electricity systems must be defined through analyses.

Any distortion in consumer prices – including tax burdens – for various forms of electricity become more apparent with the trend for greater dissemination of HEVs that has emerged due to the additional benefits these vehicles offer as mobile cogeneration units.

Additional research and new studies will be needed. Using pre-tested evaluation methodologies, a deeper analysis of the emissions produced by *cogenerating HEVs* should be undertaken if such technology is chosen as an option [3,4,12]. Besides, it must be examined the ethanol as a combustible for the future HEVs in Brazilian market. Its renewable characteristic and intrinsic economic advantages deserve a special attention.

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