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Analysis and Discussion on Energy Supply to Non-Road Electric Vehicles in Brazil

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Abstract – **This work describes the recharging supply of non-road electric vehicles acting in urban areas in Brazil. The fast penetration of these vehicles in the market imposes the introduction of new methodologies and procedures for planning studies in order to evaluate their possible effects on demand load and energy in a typical power system distribution area. A performance analysis of these vehicles is developed and additionally it is calculated the fuel savings and emissions avoided if internal combustion vehicles were utilized instead of non-road electric vehicles. The results show that the utilization of these vehicles presents potential opportunities for utilities and users with the advantage of diminishing the air pollution.**

Keywords – **distribution systems, electric vehicles, energy, air pollution**

I. INTRODUCTION

NON-ROAD ELECRIC VEHICLES or NREV are becoming an important market niche because they adapt to several applications. They are versatile and able to run in restricted areas as shopping centers, airports, hotels, parks, hospitals, garages, zoos, botanical gardens and so many other places. One of the reasons for this success comes from the possibility of working indoors and outdoors offering comfort to the users since they avoid air pollution and noise, both harmful to human health. Besides, their range surpass the ordinary requirements because the energy consumption is reduced thanks for the obligation to run at low speeds and to accelerate smooth.

NREV sales in Brazil are growing around 30% a year and it is possible to estimate that some metropolitan regions have more than a thousand in service.

A new type of load is a consequence of the recharging process that involves NREV. They have special characteristics of supplying and there is a need to examine in more detail the performance of these vehicles and their impacts to the power distribution systems.

Part two begins with brief comments on electric utilitarian vehicles and their general characteristics as type, system voltage and capacity. Also it is described how they are utilized at present moment in Brazil, showing important aspects as concerns to life cycle, economy and environment. The third part deals with the energy supply inside the vehicle that is from the batteries to the NREV wheels and some calculations are presented for accelerated and cruise conditions. A typical recharge algorithm [1] is utilized to evaluate the daily demand load as well the energy requirements at recharging mode.

Energetic and environmental impacts are described in the fourth part considering a NREV group in a urban area. A specific methodology [1] is also examined to evaluate the effects of the recharge on the daily load demand curve [2]. Environmental impacts are taking into account supposing the air emissions of an equivalent internal combustion vehicle group, ICV, instead of NREV [3],[6].

A power system distribution area of an urban center in Brazil [2] is investigated in the fifth part. It is considered two NREV penetration levels to establish the daily and annual impacts. It is included the emission damage costs imposed by an ICV equivalent group which is compared with the NREV group [3],[6]. Fuel and energy costs are also evaluated.

In the sixth part is presented a discussion on the results of the case study. Harmonics distortions are commented as an NREV impact under control since the recharging devices have appropriate compensation. NREV charger is not only a source of harmonics but these spurious effects may also be canceled by another NREV when they are recharged simultaneously [4]],[5]. Finally, the seventh part presents the conclusions. In spite of the potential benefits that are expected from the utilization of NREV in Brazil there is a enormous need of strategic policies in order to optimize the development of this promising technology.

II. A BRIEF DESCRIPTION OF NON-ROAD ELECTRIC VEHICLES IN BRAZIL

NREV can be defined as vehicles that act in restricted areas. In general the speed indoors is 10 to 20 km/h and outdoors it is around 30 to 40 Km/h. The average daily traveled distance is about 40 to 50 km intermingled with a reasonable number of starts and stops. In order to comply with these performance requirements even lead acid batteries are feasible and capable to offer a sufficient NREV range. This text concentrates the analyses basically on four wheel utilitarian vehicles, therefore it is not considered electric bicycles, scooters, lawnmowers, special electric airport ground equipment and electric wheelchairs.

Little attention has been given to some specific questions. NREV don't need to be registered in any government transit agency and it is not necessary a driver's license because they don't run on public roads. It is an advantage to their users but it introduces some difficulties to obtain statistical surveys in respect of the number of vehicles in circulation and of the geographical area they are in service.

NREV are bought as any electrical appliance. However, the energy consumption from the power distribution system don't occur simultaneous to this utilization but afterwards, that is, at recharge. The battery chargers are adapted to Brazilian low voltage installations. They work with a single phase voltage of 127 V or 220 V and a nameplate power between 2 to 4 kW, therefore, a power rating as a microwave oven, that is, similar to other household electrical devices. These considerations, in principle, can induce to think that there is not any appreciable effect to investigate. One of the purposes of this text, on the contrary, is to show that this subject deserves a special attention from the utilities. Since the penetration level of these vehicles are increasing they can represent additional energy sales without large investments.

Concerning to the NREV energy needs it is possible to foreseen significant increases as they penetrate in the market. A daily energy consumption of a NREV can reach 10 kWh/day. However the recharging periods, in general, occur at night giving an opportunity to power distribution companies improve the load factor, the power factor and raise the energy sales.

Another favorable aspect is the structure of the Brazilian energy matrix. Hydroelectricity is the primary energy source in 90% of the power plants. It is a remarkable exception when compared with other countries since the recharging supply is clean and renewable. It is also important to mention that this situation will not change significantly in a long term even, considering the introduction of a strong participation of natural gas in the power generation mix [6].

Some years ago NREV were not noticed by the people in Brazil. The majority of applications were limited to places out of sight of the public as fork-lifts in industries and depositories. This scenario has changed. Several manufacturers and dealers are establishing new NREV businesses. It occurs mainly, in the southeastern and south Brazilian regions. Due to NREV are local zero emission vehicles and save fuel these two arguments have been sufficient to increase the NREV penetration level in Brazil. In fact, unlike other countries, as for example, USA, which golf clubs are important clients for NREV, in Brazil the soccer fields are one of the precursors of the present market changes. Contused soccer players receive a fast help and removal from the game field by special NREV which are watched by millions of rooters and TV spectators. As soccer is the most preferred game in Brazil it works like a "NREV advertisement".

It follows a list of the common applications of NREV in Brazil:

a) Freight transportation in commercial buildings, industries, garages, depositories, airports, etc;

b) People transportation in parks, tourism activities, zoos, botanical gardens, camp clubs, soccer fields, hospitals, etc;

c) Client transportation in parking areas and shopping centers;

d) Vigilance and patrol of parks, beaches, parking areas, garages, residential areas.

e) Recreation

f) Transportation of garbage by municipalities;

g) Transportation of goods in pedestrian zones;

NREV models have been developed in Brazil and are available in order to comply with the mentioned applications and activities. Table I, shows, a survey of NREV technical characteristics.

TABLE I
Data of NREV Manufactured in Brazil

Manuf. (a)	Number of Std. Models (b)	Load (Kg) (c)	System Voltage (V) (d)	Battery Capacity (Ah) (e)
A	5	≤ 800 kg	6 x 6 and 6 x 8	220 and 165
B	8			
C	8			

(a)Manuf. means manufacturer; (b) Number of Std. Models means the quantity of models manufactured by A, B and C, respectivelly; (c)Load means the weight carried by the NREV; (d) 6x6 means the 6 batteries of 6 V each one; (e) Ah means Ampere.hour; All manufacturers announce that they can made special models in accordance with a client request.

3. ENERGY AND DEMAND REQUIREMENTS

From an energetic point of view a NREV can be seen as an equipment with two operation modes: recharging and running. Both reflect the NREV total energy consumption.

A flow of energy from the electric system to the batteries characterizes the recharging mode [6],[7]. The total recharging energy expended by a NREV group can be expressed by (1), in kWh:

$$E_c = \{\sum_{i=1}^{i=n} c_i V_i . A_i . DOD / \eta_{c_i}\} .1000 \qquad (1)$$

where:

$n -$ number of NREV

$c_i -$ number of batteries modules connected in series

$V_i -$ battery voltage of each battery in V

$A_i -$ battery capacity in Ah

$\eta_{c_i} -$ all over battery and charger efficiencies at recharge

$DOD -$ depth of discharge in %

The recharging mode depends on how the vehicle is utilized. When the NREV is in the running mode a flow of energy goes from the batteries to the vehicle motor [8],[9]. In fact the total instantaneous road power requirement at the wheels, can be calculated by (2) and the corresponding energy at each time interval by (3). A total amount of energy is expended from the batteries before each recharge. It defines the battery state of charge and consequently the corresponding energy to be replenished (4).

$$P_T(t) = P_I + P_{RR} + P_{AD} + P_D \qquad (2)$$

$$P_I = M_e . a(t) . v(t)$$

$$P_{RR} = K.W_V.g.v(t).\cos(\theta(t))$$

$$P_{AD} = (\rho.A_f.C_d.v(t)^3)/2$$

$$P_D = W_V.g.v(t).\mathrm{sen}(\theta(t))$$

where:

$P_I, P_{RR}, P_{AD}, P_D -$ powers to overcome inertia, rolling resistance, aerodynamic drag and grade in Watt

$M_e -$ mass equivalent in Kg, includes rotational inertia of 3% of the vehicle mass ($M_e = 1.03.W_V$)

$W_V -$ vehicle mass in Kg

$a(t) -$ vehicle's acceleration in m/s^2

$v(t) -$ vehicle's speed in m/s

$K -$ kinetic rolling resistance coefficient

$g -$ gravity acceleration in m/s^2

$\rho -$ is the air density in kg/m^3

$A_f -$ vehicle's frontal area in m^2

$C_d -$ vehicle's aerodynamic drag coefficient

$\theta -$ road angle with the horizon ($\theta \geq 0$)

$t -$ time in s

For simplicity it was not considered wind effects in (2). In order to evaluate K it is possible to utilize an empirical relation in (3) as a function of vehicle speed [9]. It does not take in account the wheel bearing loss power, assumed as negligible.

$$K = (0.033).(1 + v(t)^2/1500) \quad (3)$$

During a time interval $t_j = t_2 - t_1$, in s, the energy consumption from the batteries in kWh for each vehicle is:

$$w(t_j) = (1/(36.10^5.\eta_d)).\int_{t1}^{t2} P_T(t)dt \quad (4)$$

where:

$\eta_d -$ battery, motor and transmission efficiencies at discharge

NREV power requirements are related to the input command imposed by the driver. Accelerations occur to speed up the vehicle and they cause power peaks which are strongly influenced by the first term, P_I, power to overcome inertia, in (2).

Nevertheless NREV maximum speed is not high and the accelerate time do not need to be short. Therefore, in spite of a daily duty cycle with many starts and stops it is possible to get a good NREV performance. Simulations for an accelerate and cruise time periods is presented in TABLE II for a NREV of 1000 kg, C_d = 0.4 and A_f = 1,67 m^2.

TABLE II
Energy Consumption for Acceleration and Cruise Periods

Period	Time (s)	Speed (km/h)	Energy (W.s)
Acceleration	18	0 - 48	1.1239 x 10^5
Cruise	75	48	2.1408 x 10^5

Energy requirements are reduced when electric vehicles are equipped with regenerative braking [8]. It means that a quantity of energy is put back into the battery when the vehicle is decelerating. The kinetic energy is not totally recoverable. Two kinds of losses occur: the first is related to the regenerative braking system considered by its efficiency η_{reg}, the second occurs because the energy during braking goes to and from the battery before it can be used in a drive cycle [8]. This effect, indicated in (5), acts in such a way that diminishes the total amount of energy and must be algebraically added to (2):

$$P_{REG} = \eta_c.\eta_d.\eta_{reg}\{P_I + P_D\} \quad (5)$$

$$a(t) < 0 \text{ and } \mathrm{sen}(\theta(t)) < 0$$

Concerning about the demand requirements it is necessary to know the recharge algorithm. It is common to use a constant current constant voltage control scheme as in Fig. 1 representing a full recharge cycle [1],[10].

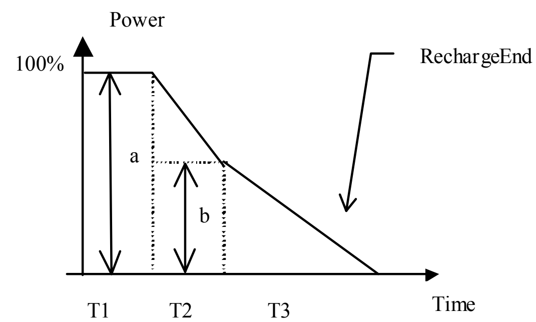


Fig. 1 Typical Charging Cycle for EV Batteries

The energy consumption is based on the geometric properties of Fig. 1. The third period T3 corresponds to an area of approximately 25% of the total area under power charging cycle. Both T1 and T2 are equal to 2 hours, and the remaining T3 period is equal to 4 hours resulting the relations in (6) for the demand parameters a and b in p.u. total energy required for recharging:

$$a = 0.625/3 \qquad b = 0.125 \quad (6)$$

It means that a recharge of 10 kWh corresponds an initial demand of 2.083 kW. Higher demand load parameters are needed for faster recharge cycles.

NREV battery capacities are established from the power and energy calculations with (2) to (4) in order to achieve a previous design criteria and expected drive cycle. Recent reports from the NREV manufacturers and technical publications [7] inform their battery system ratings. A survey of this data is presented on TABLE III taking in account Table I for typical utilitarian vehicles and personnel carriers. Daily energy and demand requirements are presented in the last two columns based on (1) and (6).

TABLE III
Daily Energy and Demand Requirements of a NREV

Battery System Ratings			Daily Requirements	
V	Ah	kWh	Energy kWh (a)	Maximum Demand
36/48	165 to 220	5.9 to 10.6	6.8 to 12.1	1.4 to 2.5

(a) DOD = 80% and η_c = 70% (conservative value); (b) See Fig. 1 maximum demand = 0.625/3 p.u.

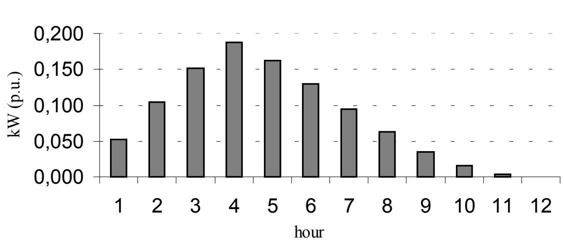
IV. ENERGETIC AND ENVIRONMENTAL IMPACTS

This section is dedicated to evaluate energetic and environmental impacts of NREV groups actuating in a urban area. As NREV have a geographical range of action and it is possible to consider them under the influence of a distribution system supply. Therefore, assuming that a NREV group belong to a distribution system area, its impact corresponds to the recharging demand load curve. The computations utilize a more realistic and non simultaneous starting process of recharging [1]. The demand in p.u. energy values along 12 hours as a function of the parameters a and b in (6) are presented on TABLE IV[1].

TABLE IV
Recharging Impact (p.u)

Hour	Demand Equations	Demand (p.u)
0	0	0,000
1	$a/4$	0,052
2	$a/2$	0,104
3	$(11/16)\, a + (1/16)\, b$	0,151
4	$(3/4)\, a + b/4$	0,188
5	$a/2 + (15/32)\, b$	0,163
6	$a/4 + (5/8)\, b$	0,130
7	$(1/16)\, a + (21/32)\, b$	0,095
8	$b/2$	0,063
9	$(9/32)\, b$	0,035
10	$b/8$	0,016
11	$b/32$	0,004
12	0	0,000

Figure 2 shows the demand load in p.u. energy values. The maximum demand is 0.188 p.u. and occurs 4 hours after the recharging process starts.



Fig, 2 NREV Recharging Impact

In general, environmental impacts of electric vehicles are evaluated supposing the utilization of internal combustion vehicles, ICV, instead of NREV. A benefit is expected to the air quality in terms of the pollution avoided. It is supposing an average daily traveled distance by utilitarian vehicles around 40 Km. Table V shows the resultant exhaust emissions of gasoline vehicles [3],[6].

TABLE V
Daily Emissions of Gasoline Utilitarian Vehicles

Pollutants (a)	g/km	kg/day
HC	0,300	0,012
CO	2,000	0,080
NO_x	0,600	0,024
SO_x	(b)	0,006
MP	0,128	0,005
CO_2	172,7	6,908
CH_4	0,093	0,004

(a) and (b) See Appendix A

V. CASE STUDY

The framework and concepts developed in previous sections are used to perform a case study. It was chosen a typical Brazilian urban area supplied by a feeder [2]. This area consists of 1345 residences, 50 commercial establishments and 6 industries with a monthly energy consumption of 412 MWh. Two NREV penetration levels, 5% and 10%, were considered based on the total consumer number. The intermediate value in the range of energy daily requirements on Table III was adopted. It corresponds to a conservative NREV specific consumption of 0,236 kWh/km. TABLE VI and Fig. 3 presents the recharging effects of the NREV groups on daily load area curve, starting this process at 8:00 PM and finishing 8:00 AM.

TABLE VI
Daily Load Impact of NREV Penetration

Description	Penetration Levels	
	5% (70 NREV)	10% (140 NREV)
NREV Energy Consumption (kWh)	661,5	1323,0
NREV Max. Demand(kW)	124,4	248,8
Max. Area Demand (kW)	1100 (7:00 PM)	1139,8 (22:00 PM)

Maximum demand without NREV equal to 1100 kW at 7:00 PM

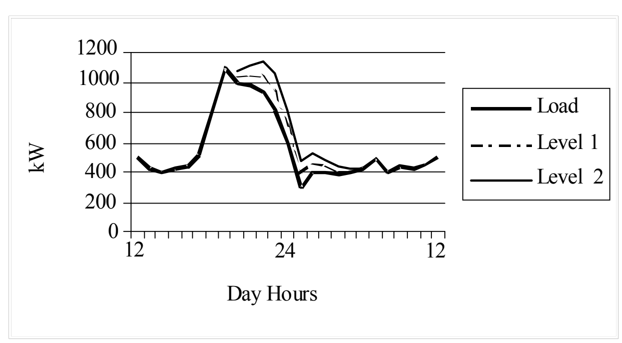


Fig. 3 Recharging Effects of NREV on Daily Load Curve

Air quality has a remarkable improvement with the introduction of NREV. It was not considered in this work the fuel and electricity chains related to ICV and NREV. As a matter of fact 90% of Brazilian power generation relies on hydro plants and even with the introduction of a strong percentage of natural gas units the new generation mix is still favorable to electric vehicles [6].

On the contrary the ICV fuel chain, that is, fuel transportation, refueling, oil refining, and exploration, is an additional disadvantage when compared with electrical vehicles [6].

TABLE VII shows the annual expenditures with energy supply to NREV as well with fuel to ICV. Both energy and fuel rates were submitted to a sensitivity analysis. Variations of ± 15% were admitted for energy and fuel rates in order to guarantees more robustness to the final results.

Table VII
Annual Energy and Fuel Expenditures with NREV and ICV

Penetration Level	NREV		ICV	
	Energy (MWh)	US$	Fuel (liters)	US$
5%	241.45	20903 to 28381	127750	73753 to 99782
10%	482,90	41806 to 56561	255500	147505 to 199566

(a) ICV efficiency of 0.125 l/km at low speeds; (b) energy rate for residential consumers equal 0.108520 US$/kWh ± 15%; (c) fuel rate equal to 0.672 US$/l ± 15%; ; (d) 1US$=2.5R$ (e) fuel and energy rates for August/2001;

Neoclassic economy utilizes the word *externality* to designate social impacts outside the commercial transactions [11], [12]. Air pollution from ICV is an externality example that has harmful consequences to human health, specially children and elderly people.

Social and environment costs is a consequence of ICV utilization because they are air pollution sources. Two concepts are utilized: the cost of damage and the cost of control. The first one try to express the *environment damage* for the society, while the second one, the necessary *environment protection* [11], [12]. This work deals with the first concept in order to evaluate the damage cost imposed by ICV utilization. TABLE VIII shows the externality calculations for, nitrogen oxides, NO_x, sulfur oxides SO_x and particulate matter, PM, in a yearly basis [3], [6].

TABLE VIII
ICV Annual Emissions and Damage Costs

Pollutants	Penetration Levels			
	5%		10%	
	kg/year	Damage Costs (US$)	kg/year	Damage Costs (US$)
NOx	613,2	1711 to 8780	1226,4	3422 to 17561
SOx	153,3	2020 to 8972	306,6	4041 to 17943
MP	127,8	2861 to 13181	255,5	5722 to 26362
Totals	-	6592 to 30933	-	13184 to 61866

Obs.: Damage costs in cents of US$/g [3], 0,279 to 1,4319 for NO_x, 1,318 to 5,8523 for SO_x and 2,2395 to 10,3179 for MP US$ referred to 1999

VI. RESULTS AND DISCUSSIONS

This paper presented an overview about the present situation of NREV in Brazil as well a scenario when a penetration level of 5 and 10% is assumed in a metropolitan area. In fact once the NREV sales are growing at least 30% a year it is expected a reasonable number of NREV acting in urban centers in few years. First it was showed how power and energy behaves when NREV batteries are in discharging and charging process. Additionally it was included performance comparisons between NREV and similar ICV with a special attention to air pollution issues. Second it was examined a distribution system area load supposing the introduction of a NREV group.

Practically the maximum area demand was not surpassed. A small amount equal to 3,6% has occurred for the highest NREV penetration level (10%) which is admitted to be reached at long term. For an intermediate penetration level equal to 5% the annual energy sales increased 58.6% without any impact on daily load demand. This last percentage doubles for 10% penetration level.

NREV energy annual costs are lower than ICV fuel annual costs. This condition is confirmed despite energy and fuel rates had been submitted to variations of ± 15%. In this situation NREV users can expect savings around 59.9% even taking into account the maximum energy cost in relation to the minimum fuel cost. It is interesting to mention that NREV prices can be lower than ICV prices and their maintenance costs are around 20% of similar ICV [13]. These two advantages, in general, are sufficient to compensate a constraint: the replacement of the NREV battery packs after approximately 5 years [6],[13].

ICV externalities represent a monetary damage value imposed to the environment by air pollution. Only the exhaust emissions were considered for just three pollutants resulting in a damage cost per year that ranges from US$ 94 to US$ 442. It shows a doubtless advantage when NREV is compared with ICV assuming active a sustainable environmental policy [6].

To complement this section a comment on harmonics distortion is necessary. Unlike ordinary impedance loads, the battery chargers are non-linear devices due to the presence of power electronics devices. Without appropriate compensation, such harmonic current and voltage distortions may have negative impacts on electric power quality [4],[5],[14],[15]. Besides total harmonic distortion diminishes as more electric vehicles are allowed to be charged at a particular point. Previous studies [4],[5] showed that it is not unrealistic a THD reduction since starting 5 electric vehicles sufficiently close each other because it is a stochastic process and cancellation of harmonics may occur. In fact the net current demand, power factor, harmonics of each electrical vehicle and battery state of charge are not previously known in spite the moment of recharging be the same.

VII. CONCLUSIONS

Potential opportunities are offered by NREV to users, manufacturers and electricity companies in Brazil. Significant additional revenues are expected without a necessity of immediate investments on the network capacity. Load factor improvements is a consequence since the recharge is, in general, at night. Energy expenditures for supplying NREV recharging is at least 50% cheaper than for refueling an ICV travel the same distance without worsening the air quality conditions. This effect can be represented by environmental damage in a life cycle basis taking in account the annual cost range evaluations. It can reach a present value amount of US$ 3359 per ICV considering an attractive rate of 10 % a year in the course of 15 years.

Some indispensable steps and initiatives are needed to become all these benefits effective and feasible. Municipalities and utilities must recognize the importance of including this subject in their strategic planning activities. Educational, health [16], [17] and promoting campaigns are desired in order to the Brazilian society visualize the electric vehicles, in general, as a profitable investment. Incentives to NREV owners and penalties to ICV utilization is one of the matters that deserves more attention from the public and private sector [18]. Universities and manufacturers must work together with the mentioned agents offering research results, products and technical support for best decisions.

Appendix A

The meanings of the pollutants that appear in Table IV are: HC (hydrocarbon); CO (carbon monoxide); NO_x (nitrogenous oxides); SO_x (sulfur oxides); MP (particulate matter); CO_2 (carbon dioxide); CH_4 (methane). SO_x emission factor is calculated as suggested by Murgel et al. in accordance with [19].

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