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São Miguel Island as a case study on a possible usage of Electric vehicle to store energy

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Abstract

Energy systems operation in isolated areas is frequently based on imported fossil fuels, which is a problem in different dimensions including environmental, economic and security of supply, with the latter being particularly relevant for any isolated system like Islands. Renewable energy is regarded as a solution to this problem, mainly in its transformation to electricity. This, however, excludes the impact of the transportation sector that represents a significant component of the imported fuels consumption. Other main limitations associated to renewable electricity consists on the need to increase the storage capacity that might attenuate the effect of intermittence of renewable energy sources and the disparity between supply and demand. In both problems - that are associated with renewable energy management - Plug-in Electric Vehicles (PEV) could be a part of the solution in that the use of vehicle to grid (V2G) technology can provide storage of electric energy during low demand times and use it to match the demand in peak hours and/or to avoid fossil fuel consumption.

Therefore, some of the main questions are: could the large scale PEV penetration lead to increases in the fraction of electricity produced from renewable? Is the usage of PEV batteries as a storage system truly the best solution?

This work analyses a case study in the Island of São Miguel in Azores, where energy systems modelling is used to assess to different roll out scenarios for large scale PEV penetration and discuss the possibility to increase the potential for the use of renewable electricity.

Keywords: BEV (battery electric vehicle), V2G (vehicle to grid), energy storage, energy source

1 Introduction

The instability of Crude Oil prices and the expected scarcity of oil reserves motivate numerous questions related to the future need for replacement of crude oil and derived products. Crude oil based products are part of our everyday life, from health equipments (through numerous artefacts that makes modern life possible), to power generation and transportation. Especially in isolated areas; strongly dependent on primary energy import; the fuel power plants are used as a fundamental part of the power generation chain. Therefore the production shortage or high prices of fuel can very easily and very directly affect our lives. Hence the increasing dependence of the transportation sector on fossil fuels needs special attention.

In addition, environmental problems, particularly those associated to global warming, as a consequence of carbon dioxide and air pollution in urban areas are already perceived by the society as very serious. These problems together with the Kyoto Protocol measures push manufacturers to introduce more effective and environment friendly internal combustion (IC) engines or hybrid engines. The transportation sector alone represents about 20% of the total CO_2 emissions from fuel. It is in this context that the automobile industry, together with the governments, would have to make significant active efforts to develop and enforce the usage of low emission vehicles [1].

The use of Plug-in Electrical Vehicles (PEV) is challenging, because they are directly powered by electric energy.

PEV can provide a wide range of services for the electric generation chain (ancillary services, regulation, back up power and peak shifting). These services could be offered either by the aggregator (an intermediate between the customer and the power generation company with interesting subsidies for vendors), by clusters of PEV owners (in the form of small individual companies) or even individual PEV owners to the local network operator. Hence the integration of PEV to the electricity production chain could be interesting for both sides (power comopany-customer). On the other hand, the implementation of PEVs has to be reasonably managed in order to eliminate possible negative impacts to the grid such as charging in peak hours and thus increasing peak generation capacity needs. The PEVs would be primarily used for transportation, but when not in use, they could be connected to the grid, providing storage and supply services to the grid approximately for 96% of the day [2], [3].

The PEV will be always close to the energy demand, and efficiency of stored energy in PEV´s batteries is presently potentially significantly higher than the energy stored in hydrogen and in fuel cells. Moreover in conjunction with the R&D of EVs it could be expected even higher storage efficiency in the near future.

One of the main tools of the project is the use of an optimization model (*TIMES*) that determines the least cost energy supply options for a given situation. To identify the more robust solutions, a number of scenarios are performed in order to minimize the effect of uncertainties.

2 PEV properties

The necessary electric and statistic properties of PEVs are needed in order to study and propose the roll out scenarios and the PEV impacts to the electricity grid.

The estimated electric properties are based on real existing and operating Electric Vehicle (EV), based on the Toyota RAV4 EV. The main characteristics of the vehicle are shown in Table 1 [4].

Data reports and statistics provided by the Government of Azores have been used and the impacts of the PEVs penetrations on the isolated grid were estimated. Related to this information we have used the worse case scenario for the average annual millage for light diesel fleet. This assumption should prevent the future rebound effect error, as well.

Vehicle characteristics were used for modelling the PEV use, such as presented in Table 2. The E_s value represents the useful stored energy in PEV´s batteries, according to a safety use and the battery´s depletion level. The values D_{dr} and D_{bu} are estimated from the average annual mileage for Azores´s light diesel vehicle fleet (S. Miguel, 15.706km), the D_{dr} represents the average millage of one way trip and D_{bu}, the average mileage buffer to return from that trip. The E_{ff} is the PEV´s driving consumption and the E_{ffi} is the PEV´s inverter efficiency. In order to ensure a safe trip, the value E_{saf} is taken into account. The safety range was chosen in order to represent the way to the nearest first aid point in case of emergency, from any starting point on the Island [5].

Table1: EV specifications (Toyota RAV4EV)

Description	Value
Battery Capacity	27 kWh
Battery weigh	551 kg
Number of Battery modules	24
Weight of Battery Module	21 kg
Nominal Module Voltage	12 V
Nominal System Voltage	288 V
Maximal Range	190 km
Minimal Range	130 km
Average Range	150 km

Table2: Important vehicle characteristics for modelling

Symbol	Description	Value
E_s	Useful Energy in Batteries	21,6 kWh
D_{dr}	Average millage simple way	21,5 km
D_{bu}	Millage buffer for return way	21,5 km
E_{ff}	Driving Consumption	0,139 kWh/km
E_{ffi}	Inverter Efficiency	75 %
E_{saf}	Safety Range (First Aid)	38,75 km

The potential available energy for providing energy storage services to the grid was estimated on statistic results based on real transportations rates, see Equation 1.

$$E_{storage} = \frac{E_s - (D_{dr} + D_{bu} + E_{saf}) \cdot E_{ff}}{E_{ffi}} \quad (1)$$

The statistic value of energy available for providing energy storage to the grid was estimated and used in different scenarios in order to simulate the impact of the PEV to the grid.

In order to estimate the potential impact to the S. Miguel grid, three different PEV penetration scenarios were taken into account, see accompanying Table 3. The penetration scenarios are based on light duty vehicle fleet (LDV). All others scenarios used the Base scenario (without PEV) as a reference value; low penetration scenario (LP), middle penetration scenario (MP), high penetration scenario (HP).

Table3: PEV penetration scenarios

Scenario/year	LP	MP	HP	LDV
2006	0%	0%	0%	46.704
2010	1%	2%	3%	49.000
2015	5%	8%	12%	53.000
2020	10%	15%	20%	55.000

The scenarios are based on statistic information about S. Miguel light vehicle fleet [5].

3 Electricity Demand

São Miguel Island is the main electricity consumer in the whole Azores's archipelago. There is no power connection to any major grid or even with other Islands.

All following scenarios and electricity demands were estimated in accordance to the real data from electricity consumption on S. Miguel Island. The total annual consumption at S. Miguel was 395 GWh (in year 2005), where 33% was produced from renewable, see Fig. 1 and Table 4.

Considering an increasing energy efficiency, demand side management policies and successfully implementations of end user policies, the demand growth has been estimated to increase 4% per year until the year 2015 and 2% until 2020, as represented in Table 4. The analysis and forecast of electricity demand is challenged to the significant increase of renewable fluctuation, especially in wind electricity production during the winter and autumn seasons. The winter season demand curve has the highest annual demand peak and could possibly be considered the most problematic in terms of charging and discharging electric vehicles. The estimated São Miguel´s daily electricity demand for 2010, 2015 and 2020 is shown in Table 4. The estimated growth is based on measured reference data from year 2006 [6].

The electricity generation plan includes possible renewable resource at the S. Miguel Island, like a plan to expand geothermal and wind farms up to the year 2013, which is reflected in following sections.

3.1 Renewable potential

São Miguel Island has relatively high penetration (43% in year 2008) of renewable resources for electricity production compared to other islands either in Azores or elsewhere in the world. However the largest part of the electricity production (57% in year 2008) is still based on Fuel power plant(s) using thick fuel oil that is costly, while there is still not significant use of the large and excellent wind energy capacity (average speeds 6.5-8.5 m/sec) that exists in the island.

Table4: Estimated Annual Electricity Production at S. Miguel till year 2020

Year	Annual Electricity production [GWh]	Renewable resource [% of annual]
2005	395	34
2010	485	44
2015	590	70
2020	651	67

According to the demand growth of 4% until the year 2015 and 2% until 2020 and the possible penetration and addition of different forms of renewable energy (geothermal, wind) in the energy mixture of the island´s electricity during these years then an estimation is made using the *TIMES* modelling tool. The detailed and estimated annual/daily electricity production and the percentage renewable resources share shows Fig. 1.

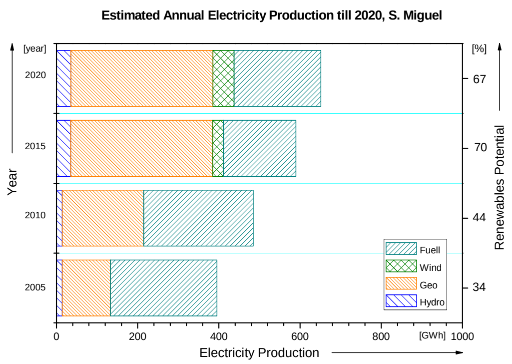

Figure1: Estimated Electricity Production and renewable share for S. Miguel until 2020 (base scenario, without PEV)

3.2 Renewable fluctuation

The fluctuation in renewable production causes some difficulties during their integration to the energy production chain. Only geothermal and hydro power plants are from this merit considered as a real base load power plant running round the clock. However, the high penetration of wind power shows some fluctuations during the day or even during the year. Despite the different wind availability during the year that makes the use of this resource rather difficult, it is still a resource and investment to be used for power generation planning.
The wind availability profiles during a year are shown in accompanying Fig. 2.

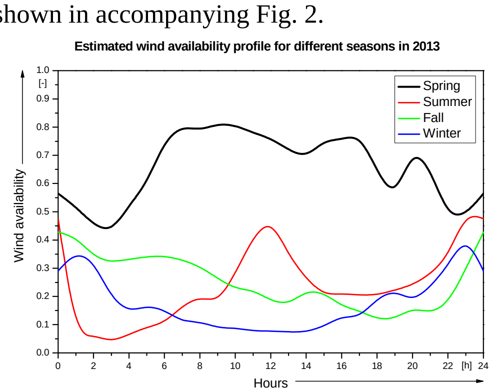

Figure2: Estimated wind availability profile for different seasons in year 2013

3.3 Threshold renewable penetration 2013

In order to make the charging and discharging of PEV as a meaningful task in economic sense and in order to activate the usage of PEV storage for peak shifting, the electricity generation from renewable needs to exceed some threshold limit. In term of this case study of isolated grid, the limit is dependent on off peak PEV charging. In case of this study we preferably consider the PEV charging in peak hours (when also the largets part of the consumer and vehicle remain home), however daytime charging has been estimated as a possibly better economical and technical solution using the *TIMES* modelling tool. The energy for charging PEV has been estimated in accordance to the annual average mileage of Azores' fleet.
The higher PEVs penetration result in an increase of the off peak electricity consumption. However, the large increase in renewable penetration in year 2013 cause the meaningfully usage of the storage capacity of PEV. The excess of renewable energy will be stored and later used in peak hours in order to reduce the peak load.
All scenarios shown are estimated for charging and discharging of PEV provided by a standard three phase connection. The line capacity limitation of 15kW will, for each PEV penetration, sufficiently provide the necessary storage capacity for providing peak shifting as modelled in following chapters [3].
The significant increase in renewable penetration in the year 2013 allows economically and ecologically feasible usage of the PEV potential storage. Fig. 3 shows the estimated electricity demand for each season of the year 2013. The usage of the battery storage is achieved by the combination of sufficient off peak electricity production from renewable resources together with the relevant seasonal demand pattern in these seasons. The simulations point out that the discharging of PEV is not primary oriented to the peak shifting, but rather to the fluctuation of the renewable resources. The main reason for this behaviour is due to the electricity production from the fuel power plant which produces the significant part of the electricity during the peak hours.

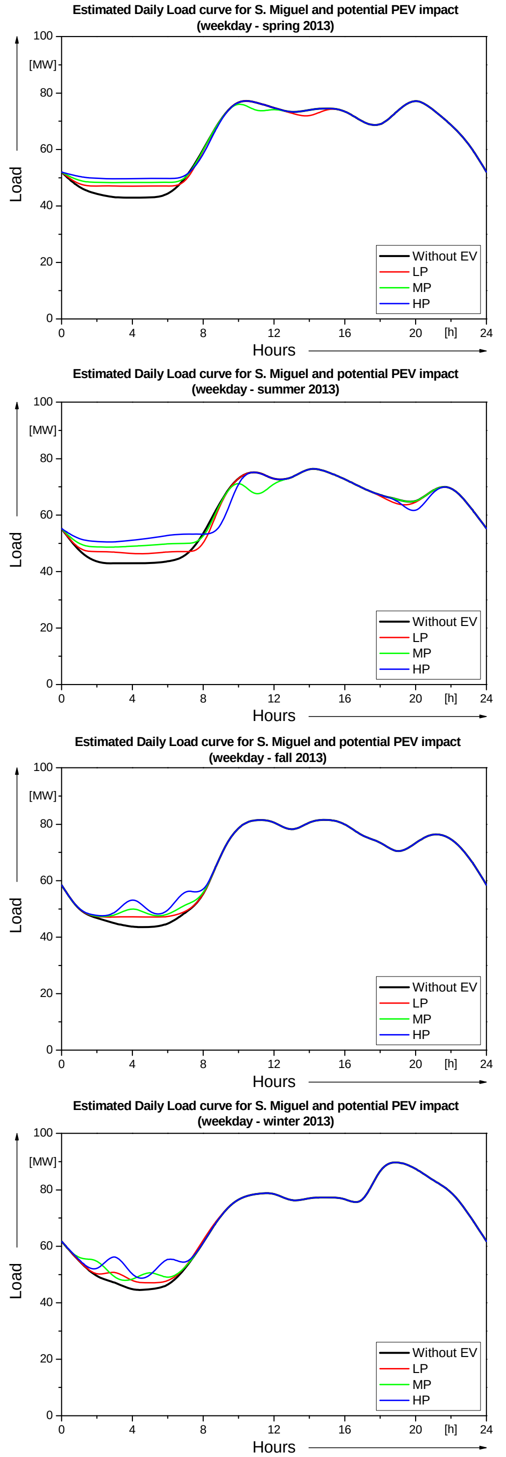

Figure3: Estimated daily electricity demand in accordance to the renewable fluctuations and PEV penetration scenarios on S. Miguel Island, year 2013

4 PEV as an energy Storage

The following sub-paragraphs discus the possible usage of PEV and V2G technology as a storage system, the impact to the electricity grid in isolated areas (like an island) and above all to the electricity generation form renewable resources in relative and absolute terms.

4.1 Energy storage

In accordance to the island consumption pattern and to the energy production from renewable resources, the usage of potential PEV energy storage was estimated as seen in Fig. 4.

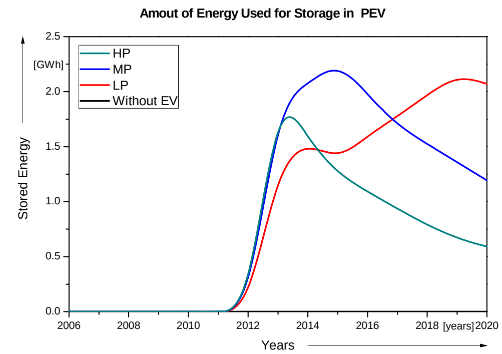

Figure4: The usage of PEV energy storage

The usage of energy storage sharply increases in the threshold year 2013, when the electricity production from renewable resources overruns the off peak electricity consumption. Hence the excess of electric energy could be reasonably stored in the PEV and the grid stability with full usage of renewable resource will be achieved, as well.

The scenarios with higher PEV penetration register a significant decrease of used energy storage till 2020. This decrease is caused also due the increase in off peak consumption (higher PEV penetration causes higher off peak consumption). Hence the excess of renewable energy production is lowering with higher PEV penetration, as we can see for HP scenario by the year 2020.

4.2 Renewable penetration

Fig. 5 shows the estimated development of renewable penetration. The four different scenarios differ beyond the threshold year 2013. The increase in PEV penetration causes higher electricity consumption. Hence, there is only a relative small increase in renewable penetration. The promotion of renewable energy penetration is restricted to the reasonable value from the grid stability point of view. The renewable energy penetration is also restricted due the different consumption patterns during the year and different wind power fluctuation during the year, see Fig.5. The renewable penetration achieves round 70% of the electricity production from year 2013 beyond. Even the different PEV penetration scenarios quite do not differ in terms of electricity production, the primary energy usage will decrease for higher PEV penetrations, because of the shift from the transportation sector to the electricity sector with high renewable penetration.

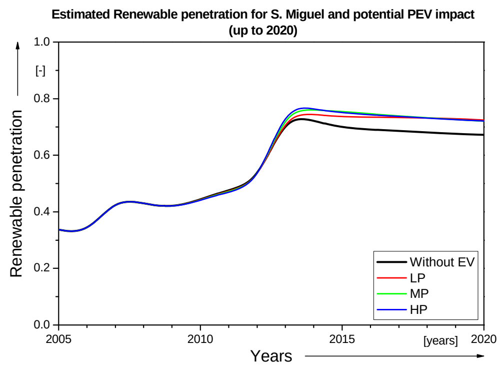

Figure5: Estimated penetration of renewable electricity generation till 2020

4.3 Wind energy production

In accordance to the previous subsections, the electricity production from the most fluctuating resource was estimated, see Fig. 6.

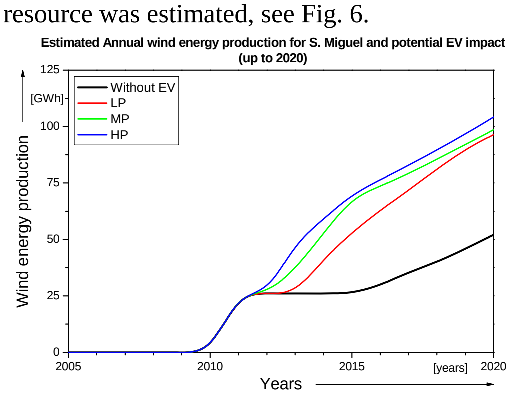

Figure6: Estimated wind energy production for S. Miguel till year 2020

Even through the relative renewable penetration do not differ for different PEV scenarios; see Fig. 5; the increase in electricity demand for higher PEV penetrations will be covered form renewable resources, especially from wind energy. The total wind energy production will increase for higher PEV penetration scenarios as shown in Fig. 6. The relative high renewable penetration will be achieved also for LP scenario, where the storage capacity increases in proportion to the renewable increase, seen Fig. 4 and Fig. 6. The increase in possible storage and back up power in PEV will promote the increase in renewable production from wind energy. PEV support to the grid and necessary back up capacity will promote higher absolute electricity generation from renewable sources in absolute values.

5 Conclusion

The penetration of PEV seems to be a promising technology for promotion of renewable resources. Using deep economical analysis in long term shows the need for reasonable usage of this potential energy storage in economical and technical sense.

The electricity production in isolated areas is typically based mainly on fuel power plants. Thus the increased PEV penetration generates an increase in off peak demand, which must be covered from renewable and non-renewable resources. Only the excess capacity of renewable resource could be feasibly recovered in the potential energy storage in PEV. In terms of isolated islands, the charging of PEV storage in off peak hours from non renewable resource and discharging during peak hours is not reasonable.

Due to the increase of PEV penetration, and despite the increase of the storage capacity, the storage possibility does not seem to be used in its full potential. The usage of the storage possibility is related to the energy produced from renewables, to the fluctuations in renewable production and to the base load. Therefore the scenario with the lowest PEV penetration (same amount of renewable available but with less base load) used relatively more storage capacity than the other scenarios.

Despite the relatively same renewable penetrations for different PEV scenarios, the significant improvement in total primary energy consumption from non renewable resources will be achieved. The shift from consumption of non renewable resources in transportation sector to PEV charged form electricity generated mostly from renewable resources will cause decrease in primary energy consumption and total CO_2 emissions, as well. The consequence of decrease in primary energy consumption will be important for independence of isolated areas, like islands, and also in monetary terms for importing fuels to these areas.

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