A Model for Electric Vehicle Integration in a Connected Microgrid considering Greenhouse Gas Emissions.

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Abstract– In this paper we present a solution for an interconnected micro grid's design including electrical vehicles. This micro grid is oriented to be placed in Guayaquil-Ecuador and integrates electric vehicle charge stations, a photovoltaic generator, a thermal unit, a battery energy storage system and an interconnection point to a distribution network. Moreover, the proposed microgrid includes an electric vehicle fleet oriented for the commercial sector. The model takes advantage of renewable resource generated locally (photovoltaic solar energy). This helps us to minimize the purchases from distribution network and to reduce costs for electric vehicles charging. Technical and economic considerations are taken into account in the present analysis. Additionally, the model minimizes the greenhouse gas emissions including as an input a tax rate for emissions. The simulations results allow us to determine the minimal cost of implementing the microgrid and the optimal strategies to reduce the implicit cost of integrating electric vehicles in the network.

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I. INTRODUCTION

Environmental concerns are changing the way how we generate and consume energy. In the last COP21 meeting in Paris, the world policy leaders agreed to reduce greenhouse gas (GHG) emissions as soon as possible, to limit global warming below 2ºC, and strive towards keeping global warming below 1.5ºC [1]. Transportation electrification is one of the most promising ways to achieve these COP21s goals and to limit the CO_2 emissions from the transportation sector [2]. An increasing number of electric vehicles (EVs) are expected to enter to the transportation market [3]. Automotive manufacturers are therefore developing both the plug in hybrid electric vehicles (PHEV) and the plug in electric vehicles (PEV) as commercial solutions[4]. In this paper PHEV and PEV will be named as EVs.

The integration of electric vehicles (EVs) in power systems represents a challenge for distribution networks. As it is demonstrated in [5], energy losses can increase up to 40% in off-peak hours under a raised EVs presence in a network. Additionally, some factors such as EVs level penetration on network, ambient temperature and start time of EVs charging, can affect the thermal aging of power distribution transformers reducing their lifetime [6]. In another hand, the power quality and voltage profile can be also compromised because of EVs presence in distribution networks [7]. All of these problems can be worse if the EVs charge process is uncontrolled in a network [8]. Therefore, in order to avoid the negative impacts of high EV penetration in power systems, more focus should be given on the development of EVs charging technologies and methodologies based on intelligent control strategies. As the market for EVs is increasing, it is necessary to investigate the impact of such electric vehicles on power systems [9]. On the other hand, when the EVs charge process is controlled with the objective of minimizing peaks in network load, we find that far less reinforcements are needed [10].

Besides the uncertainties that EVs can create in the actual power system, such electric vehicles can be seen as a tool to integrate renewable energy resources (RES) and demand response programs, enhancing the advantages of these vehicles [9]. For example, in [11] a combination between photovoltaic (PV) systems and electric vehicles (EVs) helped overcoming problems related to the feasibility of a more sustainable mobility in urban scenarios. Moreover, EVs and Battery energy storage systems (BESS) have showed to complement each other very well in power systems. Advantages of having both in power systems allow to manage possible imbalances in the network as result of RES integration [12].

Information and communication technologies (ICT) represent an important tool to integrate EVs in the power system. According to [13] is necessary to implement advanced communication and smart metering to ensure a right strategy for EVs charging. Currently, some standards have been published for example, the IEC 15118 is the communication standard for controlling the electric vehicle charging [14] in power systems. Communications play an important role in EVs operation because the battery chargers can be remotely controlled by the utility. The utility could have, by means of EVs, an extra tool for storing surplus grid energy and reuse it to support the grid during peak times [7]. The successful of EVs

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integration in power system can be achieved only in the presence of a communication system as well as a centralized control center coordinating the grid load, the RES production and the EVs charge process [15]. Therefore, it is very important to define new strategies to control the charge/discharge process of these vehicles to reduce uncertainties and impacts in the power system. Additionally, an optimal network planning will be required. For example, in [16] is demsotarted that an inappropriate siting and sizing of EV charging stations could have negative effects on the development of EVs and their massive use. Some solutions have been proposed to integrate efficiently EVs in distribution networks. In [17] a dc-grid interconnection is proposed to integrate EVs in power system and to enhance power handling capacity of AC distribution feeder. In another study, results confirm that simultaneous planning of charge station and distributed generation (DG) improves total costs, losses, voltage profile and reduces GHG emissions levels [18]. In another hand, ICT can help to estimate and prognosticate the state of charge of the EVs batteries and detect a fault in early stages [19].

Despite of electric vehicles (EVs) provide benefits for the society as a whole, there are several hurdles for their widespread adoption, mainly the high initial investment for EVs and the lack of charging infrastructure [20] [21]. It is necessary to define some market models which allow charging operators to recover investment for offering electric vehicles charging services. The prices in the businesses model must be lower than the implicit price for conventional combustibles. Some results suggest that for slow charging in home could be a feasible business under some conditions. For fast charging it requires more intensive infrastructure usage and higher levels of investment for networks reinforcement [22]. In another hand, owner can be resistant to use EVs because range anxiety [23] [24], it is the uncertainty generated by available energy in EVs batteries for a trip.

This paper describes a model to effectively charge electric vehicles inside a microgrid taking advantage of local generation. The microgrid proposed is connected to distribution network. Adapting some EVs smart charge strategies inside a microgrid can differ investment in distribution network. The energy surplus produced by RES can be used for EVs charge, allowing to reduce net energy costs bought from the grid. In the following sections are described the microgrids model, the results from simulations and some conclusions.

II. INTERCONNECTED MICROGRID MODEL

The microgrid proposed is interconnected with a distribution network as it is depicted in the figure 1:

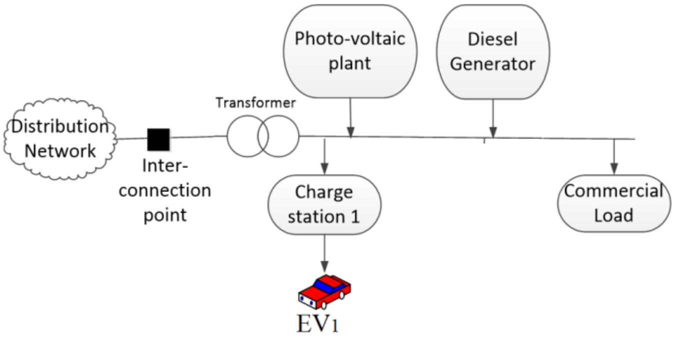

Fig. 1 Microgrid proposed.

The proposed microgrid has the following components:

- EVs fleet.
- Photo-voltaic plant.
- Diesel generator.
- Charge stations.
- Interconnection point with distribution network.
- Microgrids load.

Because the proposed microgrid is always connected to the distribution network, the diesel unit can be used only for emergency proposes.

A. *Electrical vehicle (EV).*

Because of the high variability and its uncertainty associated with energy generated by PV it is necessary to install a battery to smooth all this variation. The EVs battery can be used as storage unit in the microgrid.

1) EVs battery inputs: Inputs for battery model are technical details and costs. For technical details is possible to define batteries connections, initial state of charge, minimum state of charge, battery lifetime, round trip efficiency, and maximum charge/discharge current.

2) EVs battery outputs: The kinetic model for batteries is explained in [25] and is widely used to calculate the amount of energy that can be absorbed by or withdrawn from a battery bank during a period of time defined. The model is described by three important parameters including: the maximum battery capacity (Qmax), the capacity ratio (c) and a constant k related to the conductance between the available energy in the battery and its bound energy. The total amount of energy stored in a EV battery bank at any time is represented by equation 1:

$$Q_{TOT} = Q_1 + Q_2 \quad (1)$$

Where:

Q_1 = Available energy.
Q_2 = Bound energy.

The maximum EVs discharge power during a period Δt is given by the equation 2:

$$P_{batt,dmax,kbm} = \frac{-k.c.Q_{max} + k.Q_1.e^{-k.\Delta t} + Q.k.c.(1-e^{-k.\Delta t}))}{1-e^{-k.\Delta t}+c.(k.\Delta t-1+e^{-k.\Delta t})} \quad (2)$$

The maximum EVs charge power during a period Δt is given by the equation 3:

$$P_{batt,cmax,kbm} = \frac{k.Q_1.e^{-k.\Delta t} + Q.k.c.(1-e^{-k.\Delta t}))}{1-e^{-k.\Delta t}+c.(k.\Delta t-1+e^{-k.\Delta t})} \quad (3)$$

The available and bound EVs energy at the end of Δt are given by equations 4 and 5:

$$Q_{1,end} = Q_1.e^{-k.\Delta t} + \frac{(Q.k.c-P).(1-e^{-k.\Delta t}))}{k} + \frac{P.c.(k.\Delta t-1+e^{-k.\Delta t})}{k} \quad (4)$$

$$Q_{2,end} = Q_2.e^{-k.\Delta t} + Q.(1-c).(1-e^{-k.\Delta t}) + \frac{P.(1-c).(k.\Delta t-1+e^{-k.\Delta t})}{k} \quad (5)$$

Where:
Q_1= Available energy at the beginning of the period Δt.
Q_2= Bound energy at the beginning of the period Δt.
$Q_{1,end}$= Available energy [kWh] at the end of the Δt.
$Q_{2,end}$= Bound energy [kWh] at the end of the period Δt.
P= Power [kW] into (positive) or out of (negative) the battery bank.
k= Rate constant: how quickly the battery converts bound energy to available energy or vice-versa [h^{-1}]
Δt= Period [h].

In the table I are listed the main output parameters for EVs. EVs have a great charge flexibility because its distance range (approximately 175 Km. of autonomy [26]) and its availability in networks (95% of the time electrical vehicles are in idle mode (parked) [27].

Peak load in distribution network have a limit. In a conventional power system, the networks were planned and designed under some assumptions like demand growth. However, an EV can represent a load very similar a typical residential load, therefore, it is important to adopt a smart strategy for charging. The key elements of for EV charging are the following:

- Communication infrastructure.
- Power electronics.
- Charge interface.

Increasing the number of EVs in a distribution network feeder can be a problem in peak hours because it can overload key components and compromise the network. As EVs markets and charger stations grow, charging strategies will be shaped by additional rules and regulations. The absent efforts to help EVs drivers to learn and to practice the new rules for charging may create uncertainty and problems in the network [28].

TABLE I
EVS OUTPUT PARAMETERS.

Variable	Description
Bus voltage	The voltage of the array.
Nominal Capacity	The amount of energy that could be withdrawn starting from a fully charged state in kWh.
Usable Nominal Capacity	The capacity adjusted to the minimum state of charge of the battery, in kWh.
Lifetime Throughput	The total amount of energy that can be cycled through the EVs before a replacement.
Battery Wear Cost	The cost of cycling energy through the EVs, in $/kWh.
Average Energy Cost	The average cost of the energy that goes into the EVs [$/KWh].
Energy In	The total amount of energy charged to the EVs.
Energy Out	The total amount of energy discharged from the EVs.
Storage Depletion	The difference in the state of charge at the beginning and end of the year, in kWh/yr.
Autonomy	The capacity of the EVs divided by the average electrical load, in hours.
Losses	Annual energy losses due to inefficiency, in kWh/yr.
Annual Throughput	The total amount of energy that cycled through the bank during the year, in kWh/yr.
Expected Life	The number of years the bank will last before it requires replacement.

For simulation proposes is used the same kinetic model for EVs battery.

TABLE II
GRID RATES.

Rate	Price (USD$)	Sellback (USD$)	Period
Peak	0,2	0,08	13h00-21h00
Shoulder	0,15	0,08	08h00-13h00
Off peak	0,1	0,08	The rest of the day

B. *Grid model.*

1) Grid rates: The prices for grid scheduled rates are defined according to time of use (TOU). The rates defined are listed in table II. Since the system is oriented for commercial scenarios, the TOU is constant for every weekday. During the peak hours is not allowed to charge any battery.

2) Grid emissions: The values shown in table III correspond to the environmental characteristics of electric power generated. This data is taken as a reference form the Emissions & Generation Resource Integrated Database (eGRID) [29]. The United Stated Environmental Protection Agency (EPA) provides emissions coefficients for CO_2, SO_2, and NO_x for US locations and this represents a reference because in Ecuador there is not available data regarding this subject. Determining the total emissions of each pollutant associated with the grid corresponds to multiplication of the net grid purchases (kWh) times the emission factor (g/kWh).

TABLE III
ENVIRONMENTAL CHARACTERISTICS OF ELECTRICITY PRODUCED[29].

Pollutant	Value[g/KWh]
Carbon Dioxide (CO_2)	516,6
Sulfur Dioxide (SO_2)	0,85
Nitrogen Oxides (NO_x)	0,43

3) Grid Outputs: The output of the model for the grid contains variables like energy purchased in KWh, energy sold in KWh, peak demand in KW, and energy charge in USD (equation 6) [30].

$$Cost_{grid,energy} = \sum_{i}^{rate}\sum_{j}^{12} E_{grid\ purchases\ i,j} . C_{power,i} - \sum_{i}^{rate}\sum_{j}^{12} E_{grid\ sales\ i,j} . C_{sellback,i} \tag{6}$$

Where:

$E_{grid\ purchases\ i,j}$ = Energy purchased from the grid in the month j.

$C_{power,i}$= Price for rate i energy purchased.

$E_{grid\ sales\ i,j}$= Energy sold to the grid in month j.

$C_{sellback,i}$= Cost of energy sold for rate i.

C. *Commercial load.*

The commercial load data is synthesized by specifying typical daily load profiles and then adding some randomness. The daily load profile of the commercial load is specified by data in table IV.

TABLE IV
LOAD CHARACTERISTICS.

Data daily load profile	Value
Average [KWh/d]	5.465
Average [KW/d]	227,71
Peak [KW]	856,34
Load Factor (LF)	0,27
Random Variability (%)	10,00
Time step variability (%)	20,00

Load factor (LF) corresponds to the average load divided by the peak load (equation 7). The randomness is generated multiplying in each time step by a perturbation factor according to equation 8 [31]:

$$Load\ Factor = \frac{Average\ load}{Peak\ load} \tag{7}$$

$$\alpha = 1 + \delta_d + \delta_{ts} \tag{8}$$

Where:

δ_d= Daily perturbation value. Normal distribution (0, Random variability).

δ_{ts} = Time step perturbation value. Normal distribution (0,Timestep variability).

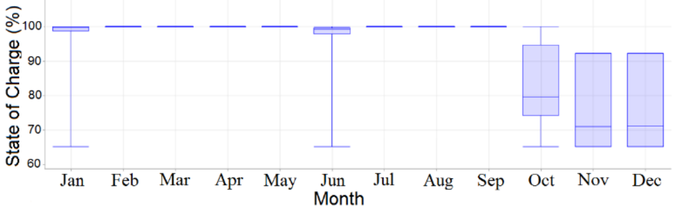

Fig. 2 State of charge EVs

D. *Photovoltaic Systems (PV).*

The size of PV in communities or buildings usually falls within several KW to 1 MW. Electricity produced by PV plant may vary significantly.

1) Inputs for PV model: The inputs for the model of PV are investment and operational costs, performance characteristics and the size of the PV panel in the sensitivity analysis. Also it is necessary to define the solar resource available in the project location. As project location was chosen Guayaquil, Ecuador. The global horizontal radiation (GHI) is the total amount of solar radiation striking the horizontal surface on the earth. For Guayaquil-Ecuador, monthly averages of GHI were gathered from the database of METEONORM program [32](figure 3).

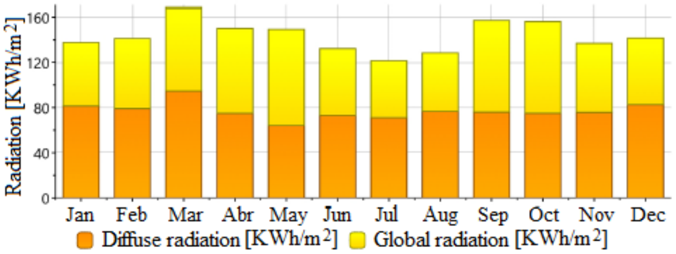

Fig. 3 Monthly averages of GHI for Guayaquil.

2) PV Power output: The power output of the PV panels in the microgrid is depicted by equation 9 [31]. The model presented below ignores temperature effects.

$$P_{PV} = Y_{PV} . f_{PV} . \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) \tag{9}$$

Where:

Y_{PV}= Capacity of PV array.

f_{PV}= Derating factor.

$\bar{G}_T$= Solar radiation incident n the PV panels.

$\bar{G}_{T,STC}$= Incident radiation at standard test conditions.

III. RESULTS.

The results were obtained using the models described in above sections. The models are part of HOMER (Hybrid Optimization of Multiple Energy Resources) which was developed by the National Renewable Energy Lab, a division of the U.S. Department of Energy [33]. The main parameters for simulation are listed in table V. For simulation proposes, a penalty for CO_2 emissions is included using as reference the value applied for USA [34].

TABLE V
PARAMETERS FOR SIMULATION.

Parameter	Value
Discount rate[%]	5%
Expected inflation rate [%]	2%
Project lifetime (years)	25
Currency	US Dollar
Dispatch strategy	Cycle charging
CO_2 emission penalty [$/t]	25 [34]

A. *Grid output.*

The results are listed in table VI:

TABLE VI
GRID RESULTS.

Variable	Annual Results
Energy Purchased [KWh]	1.782.897,00
Energy Sold [KWh]	275,00
Net Purchased [KWh]	1.782.622,00
Peak Demand [KW]	857,00
Energy Charge [USD]	311.565,00

The results for grid operation agree well with the proposed architecture for this microgrid. Since it is interconnected to the grid and because the penalty for pollution; the diesel unit is no used and all the energy comes from the grid. Considering the net annual load (table IV) the energy generated inside the microgrid represents a 12.7% reducing pollution and costs. Besides, the storage units inside the microgrid (EVs) allow selling energy back to the grid in a marginal value (0.13%)

B. *PV output.*

In the table VII are shown the results for PV panels:

TABLE VII
PV OUTPUT.

PV output	Value	Units
Capacity	200,00	KW
Mean output	28,94	KW
Mean energy output	694,61	KWh/d
Capacity factor	14,47	%
Total production	253.533,00	KWh/yr
Hours of operation	4.406,00	hrs/yr
Maximum output	182,00	KW
PV penetration	12,70	%

As shown in the table VII, the PV penetration is 12%. The storage units (EVs parked and connected to the chargers) included inside the microgrid can help to reach this value saving the energy surplus generated during the day by the PVs.

C. *GHG emissions.*

In the table VIII are shown the emissions results:

TABLE VII
EMISSION OUTPUT.

Pollutant	Value [Kg/KWh]
Carbon Dioxide (CO_2)	1.126.617,00
Sulfur Dioxide (SO_2)	4.884,40
Nitrogen Oxides (NO_x)	2.388,70

The net emissions were reduced for a factor of 12% because the energy generated by the PVs and stored by EVs inside the microgrids.

D. *EVs results.*

In the table IX are shown the results for EVs. The monthly state of charge of EVs is shown in figure 2.

TABLE IX
EVS RESULT.

Variable	Description
Bus voltage	24 V
Nominal capacity	270 KWh
Usable nominal capacity	94,5 KWh
Autonomy	0,42 hr
Lifetime Throughput	55.376,00 KWh
Average Energy Cost	0,19
Energy In	17.359,00 KWh/yr
Energy Out	13.973,00 KWh/yr
Storage Depletion	90/8 KW/yr
Losses	3.249,70 KWh/yr
Annual Throughput	15.623 KWh/yr
Expected Life	12 yr

The result show the EVs can offer a storage unit in the microgrid to smooth the energy produced by a PV system. During periods where there is an excess of energy produced by PVs is possible to take advantage and charge the electric vehicles connected to the micro grid. The autonomy of 0.42hr is enough to take any contingency measure in case of an outage, for example turning on the diesel unit. However,is important to know in order to keep this value the vehicles must be connected to the chargers and use the energy stored for this purpose. To do this, it is necessary to have an infrastructure that allows the flow of energy in both directions (charge / discharge) as well as is essential to have the permission from vehicle owners. It could generate a problem for EVs owner because they would like to have the EVs full charged for a trip. This problem is called range anxiety and represent an obstacle to integrate the vehicles in power system in two ways where EVs can provide some services to the utility. As it shown in figure 2, the state of charge of EVs is compromised when the solar resource is low or the load is high.

IV. CONCLUSIONS.

The EVs can serve to the power system during idle periods (when they are parked and connected to the chargers). Also in events like outage, the EVs can serve to keep the power system stable until a local thermal unit generate the power required. EVs clearly can be useful on these circumstances.

The policies can incentive the use of EVs, in the simulation, the microgrid operation cost is reducing taking in consideration taxes rate for CO_2 emissions. An integrated coordination between microgrids owners and regulators can help to increase using RES and EVs.

In order to avoid the negative impacts of high EV penetration in power systems, more focus should be given on the development of EVs charging technologies and methodologies based on intelligent control strategies.

The EV load can be managed through advanced and smart techniques such as the advanced metering infrastructure. It requires a high initial investment that is not considered in the simulation which can hurdle the implementation of EV chargers in a microgrid as well as the EVs penetration.

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