DEI Doctoral Research Seminars
POLITECNICO DI BARI

16° February 2022

Integration of electric vehicles in DC microgrids and distribution network

Ph.D. Student

Francesca Marasciuolo

Cycle XXXVI

Tutor

Prof. Maria Dicorato

Table of contents

Electric Vehicle Supply infrastructure (EVSI)

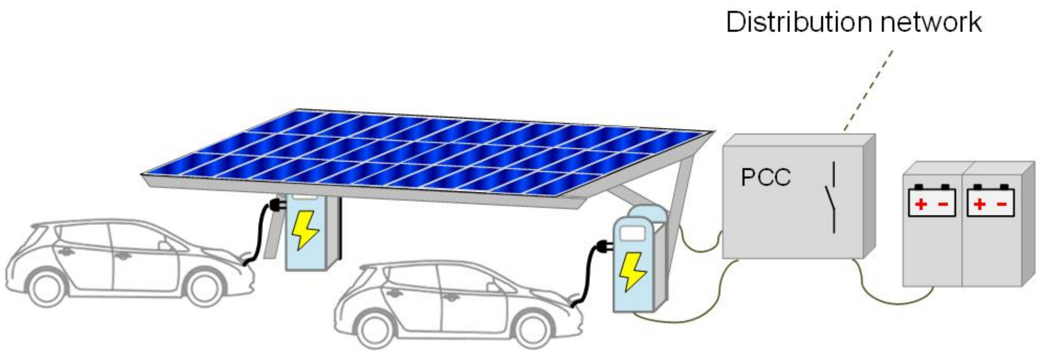
DC microgrid concept, Vehicle-to-grid (V2G) technology

Infrastructures for electric vehicle supply

- The presence of policy decision for the diffusion of charging infrastructures as well as the increased technology readiness are making electric vehicles (EVs) more and more attractive for the mobility needs of a wider portfolio of users, from public entities to service fleet and private citizens.
- However, the needs for EV charging process do not necessarily match with the secure operation of the electric system. In fact, internal EV controller usually aims to a charging process able to ensure EV availability for any next trip in a short time as well as to preserve battery life. This can result in massive power request for EV charge in limited time intervals and locations.
- In order to improve the environmental benefit of the exploitation of EVs, PV systems can suitably match their needs
- The introduction of V2G technology carries further possibility of power regulation, along with challenging technological issues.
- In this context, the possibility of realizing integrated infrastructures involving PV, EVs and energy storage is a timely topic in research and development.

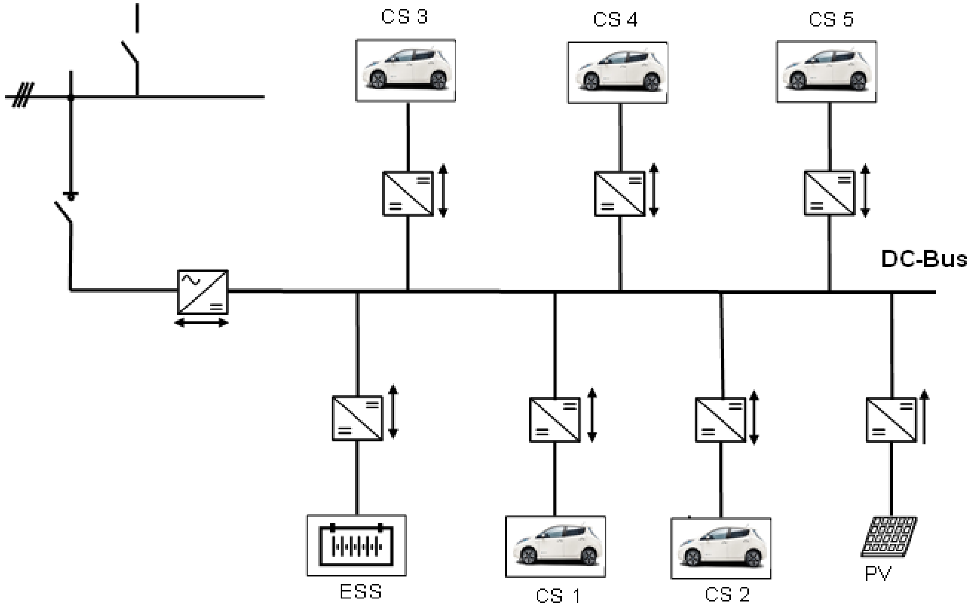
Infrastructures for electric vehicle supply

- An EVSI consists in a microgrid including PV generator, energy storage system (ESS) and V2G stations, with a single connection point to the distribution network, to efficiently feed a set of EVs to fulfill the mobility task for the selected user.
- It could be connected to the internal energy system of utilities or industries, as well as on the distribution network, as active component in the framework of smart grid.
- It can be designed with different structures, e.g., by adopting internal AC or DC distribution, or with several technologies of the three basic components.
- The modularity of EVSI can encourage their diffusion in public and private domains.



DC microgrid framework

- Advantages
  - Absence of synchronism with the external network and internal elements
  - Lower power distribution losses
  - Simpler and cheaper internal power electronics
- Disadvantages
  - Internal voltage control
  - More complex galvanic isolation
  - Corrosion problems on terminals



The PROGRESSUS Project

Goals and activities of Italian cluster

The PROGRESSUS Project

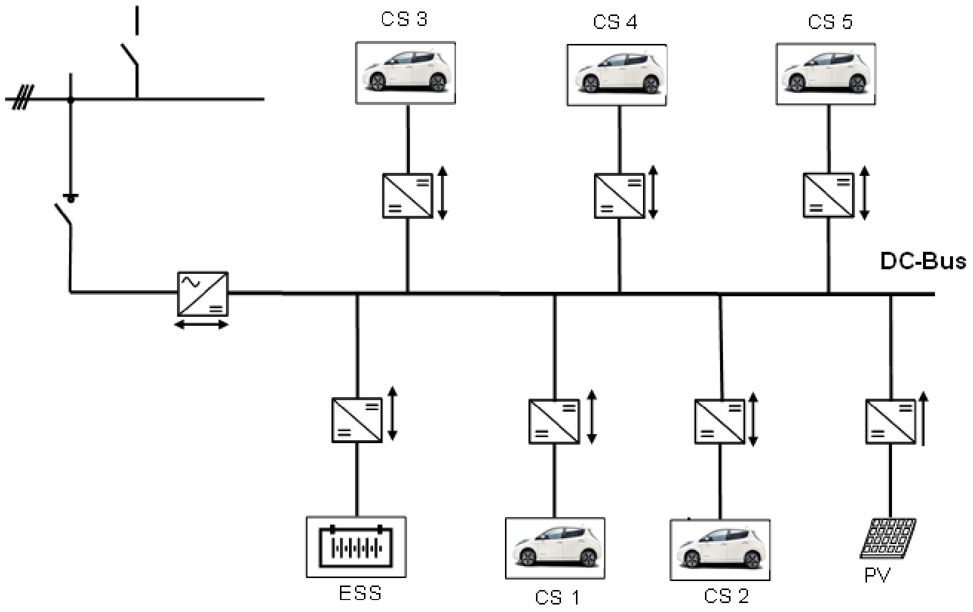
- The Electric Power System research group of Poliba is involved in the Project PROGRESSUS – " Highly efficient and trustworthy electronics, components and systems for the next generation energy supply infrastructure" presented under the call ECSEL-2019-2-RIA in Horizon 2020, started in April 2020.
- The EU-funded PROGRESSUS project aims to introduce a next-generation smart grid demonstrated by the application example of a smart charging infrastructure integrating seamlessly into current smart-grid architecture concepts.
- Partners from 5 Countries (DE, NL, ES, IT, SK).
- Activity of Italian Cluster in PROGRESSUS:
  - validating on-field the proposed energy management approaches and the novel ultra-fast chargers.
  - the tests will allow to collect real data of EV uses in a service fleet and to experience the actual effect of control strategies by means of proper measurements and data exchanges.

The PROGRESSUS Project

- The EVSI demonstrator will be realized at premises of Bari Port Authority, managed by ENELX and Politecnico di Bari, within initiatives for improving energy performances and towards integrated energy management of port area

Use Case: DC microgrid for EV supply

- The use case consists of a DC microgrid involving EV charging stations, PV and battery energy storage systems (BESS)
- Each component of the microgrid is connected to the DC bus by means of DC/DC converters (bidirectional for charging stations and BESS, unidirectional for PV system).
- At the point of common coupling (PCC) with the distribution grid, an AC/DC inverter ensures the connection.



Francesca Marasciuolo (francesca.marasciuolo@poliba.it)

Operational planning of an EVSI

Day-ahead programming

Optimal planning of an EVSI

- The inclusion of electric vehicle stations in microgrids can allow to exploit source controllability to obtain a safer network integration and hence sustain electric mobility diffusion.
- The integration of photovoltaic systems and electric storage in DC microgrid can easily enable vehicle-to-grid functionality.
- Performances of DC microgrid configuration with electric vehicle stations are evaluated, by solving alternative optimal operation procedures, aiming at minimum operation cost and minimum power exchange on daily horizon
- Optimization procedures with distinct economic and technical objectives are proposed and tailored to the architecture of a multi-plug EV charging station and a more complex DC microgrid architecture.

Optimal planning of an EVSI

Daily cost minimization

$$OF_1 = \Delta t \cdot \sum_t \left\{ \begin{aligned} & c_g(t) \cdot P_g^{in}(t) - r_g(t) \cdot P_g^{out}(t) + \\ & + w_B \cdot \left(P_B^c(t) + P_B^d(t) \right) + \\ & + \sum_j \begin{bmatrix} (c_{EV}(t) + w_j) \cdot P_j^c(t) + \\ +(w_j - r_{EV}(t)) \cdot P_j^d(t) \end{bmatrix} \end{aligned} \right\}$$

Daily energy exchange minimization

$$OF_2 = \Delta t \cdot \sum_t \left[P_g^{in}(t) + P_g^{out}(t) \right]$$

Daily cost minimization (without battery wearing costs)

$$OF_3 = \Delta t \cdot \sum_t \left\{ \begin{aligned} & c_g(t) \cdot P_g^{in}(t) - r_g(t) \cdot P_g^{out}(t) \\ & + \sum_j \begin{bmatrix} c_{EV}(t) \cdot P_j^c(t) + \\ -r_{EV}(t)) \cdot P_j^d(t) \end{bmatrix} \end{aligned} \right\}$$

Input

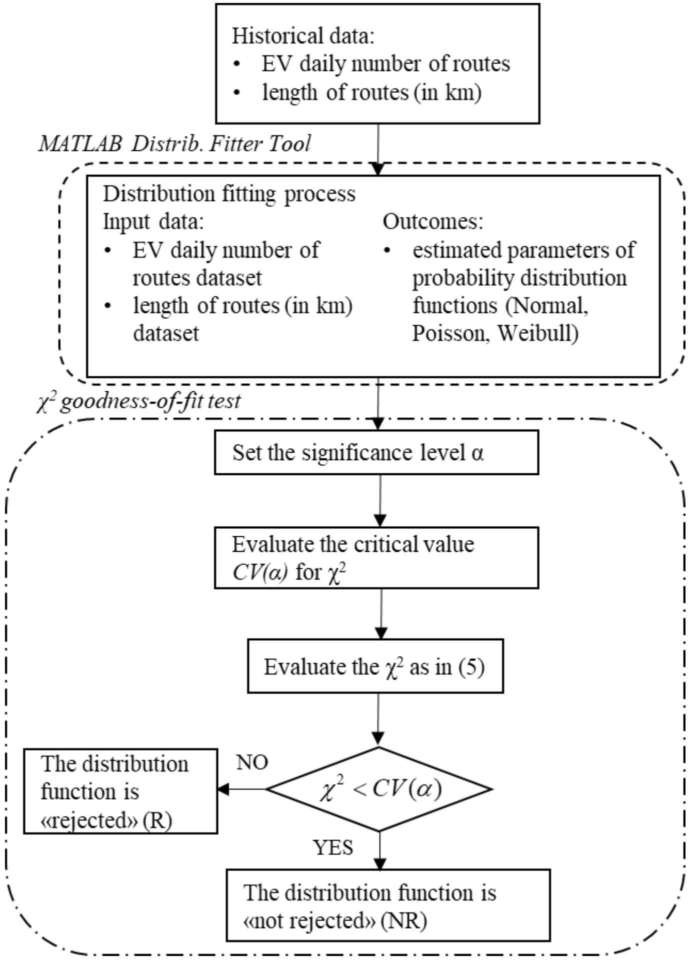
- Nominal sizes of components
- Features of PV plant
- Forecasted PV power
- Energy prices
- Forecasted EV usage

Output

- Scheduled power of charging stations
- Scheduled injected/withdrawn power from the external grid
- Scheduled charging/discharging power of BESS

Optimal planning of an EVSI

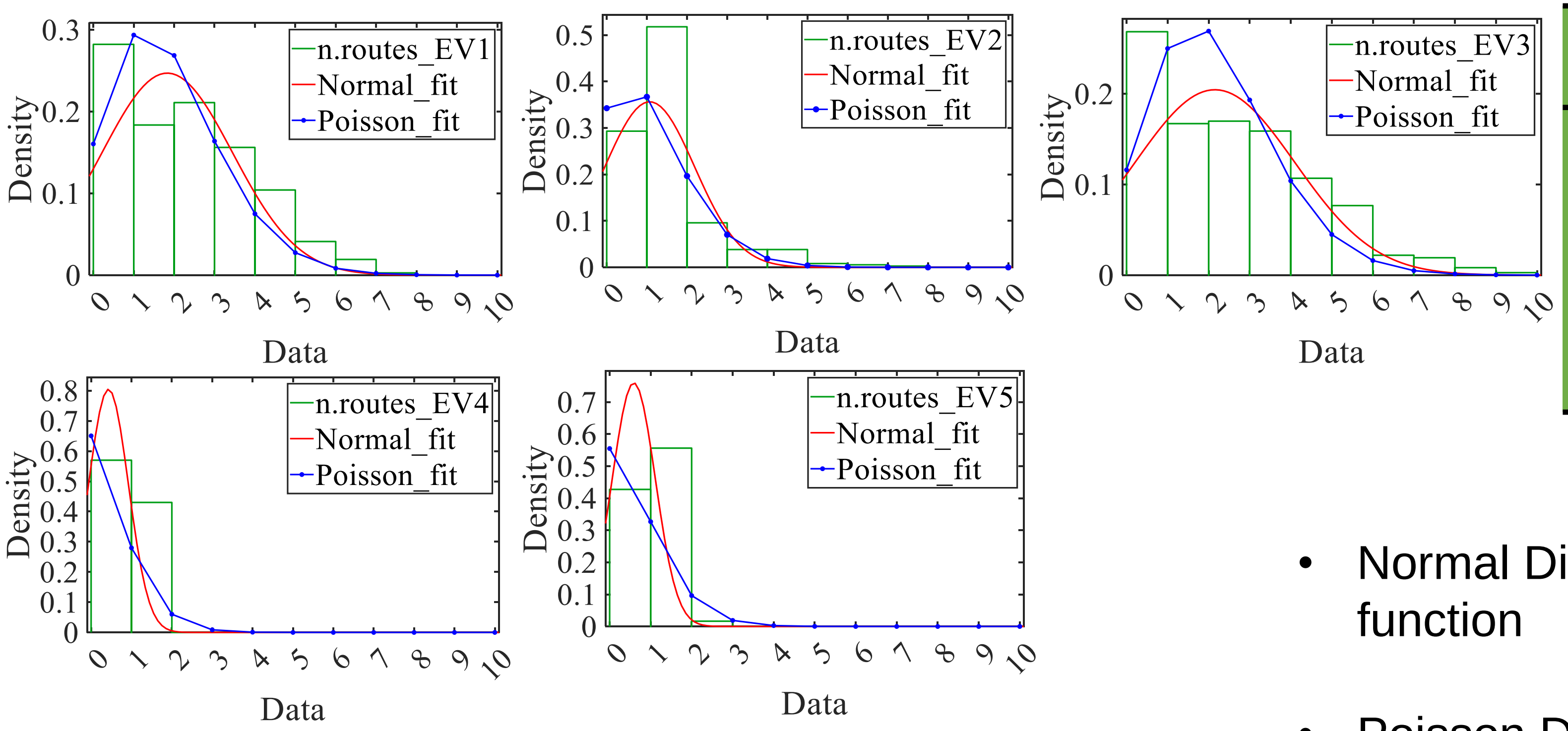
- **Statistical analysis for determination of EV usage**
- A stochastic approach for EV usage scenario generation has been exploited.
- EV mobility data are assumed corresponding to current exploitation of 5 fuel-based service cars, replaced by a suitable EV model. Data current uses are collected for a whole year of operation, and they are described by daily route length and number of travels
- Probability distribution functions are estimated and validated, in order to randomly generate samples of EV usage.
- The validation has been carried out using a goodness-of-fit test, in order to establish the distribution that would better fit data.



1. F. Marasciuolo, M. Dicorato, G. Tricarico, P. Montegiglio, G. Forte and M. Trovato, “The influence of EV usage scenarios on DC microgrid techno-economic operation ", Special Issue “2020 EEEIC / I&CPS Europe “, IEEE Transactions on Industry Application. (accepted)

Optimal planning of an EVSI

- **Statistical analysis of EV number of daily routes**



	Normal Distribution		Poisson Distribution	
	μ	σ	λ	cov
EV1	1.83	1.62	1.83	0.005
EV2	1.07	1.12	1.07	0.054
EV3	2.15	1.95	2.15	0.0059
EV4	0.43	0.25	0.43	0.0012
EV5	0.59	0.53	0.59	0.0016

- Normal Distribution function $$f_N(x) = \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-\frac{(x-\mu)}{2\sigma^2}}$$

- Poisson Distribution function $$f_P(x) = \frac{\lambda}{x!} \cdot e^{-\lambda}$$

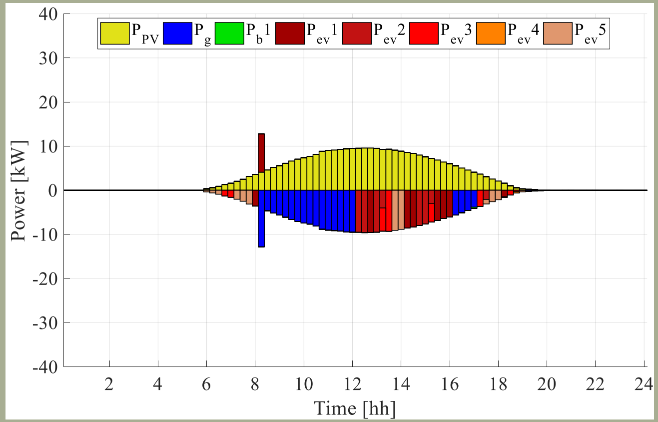
Optimal planning of an EVSI

- **Results of χ^2 goodness-of-fit test**
- The table collects result of the goodness of fit test.
- According to the statistical analysis outcome, the random generation of the routes of vehicles is carried out in the following parts by considering for each EV the not rejected distribution and extending the use of Poisson distribution where all the hypotheses are rejected.

	$\alpha = 5\%$	
Data \ Distrib.	Normal	Poisson
routes EV1	R	NR
routes EV2	R	R
routes EV3	R	R
routes EV4	R	NR
routes EV5	R	NR

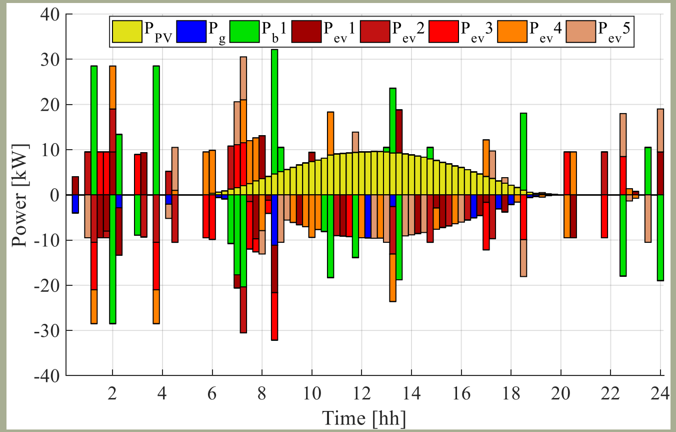
Results: scheduled power exchanges

Daily costs minimization



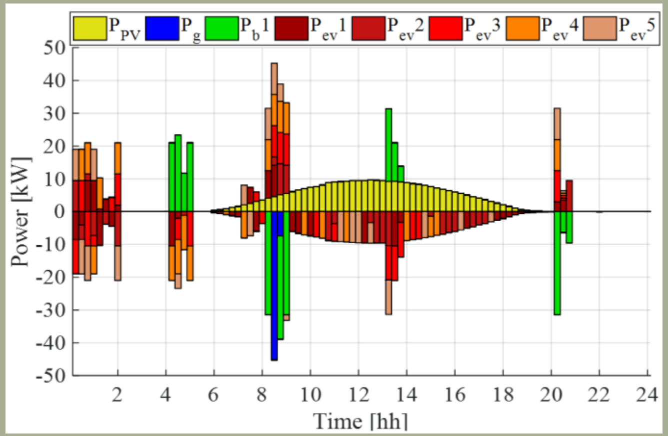
EVs are mostly dedicated to charge during the availability of PV production. The BESS is not exploited, due to the presence of wearing cost.

Daily energy exchange minimization



A more intense exploitation of EVs and BESS is observed. The absence of economic targets allows power exchanges over the whole day.

Daily cost minimization (without battery wearing costs)



EV discharges during the day are more frequent, due to the absence of wearing costs linked to EVs and BESS.

Local Energy Community (LEC)

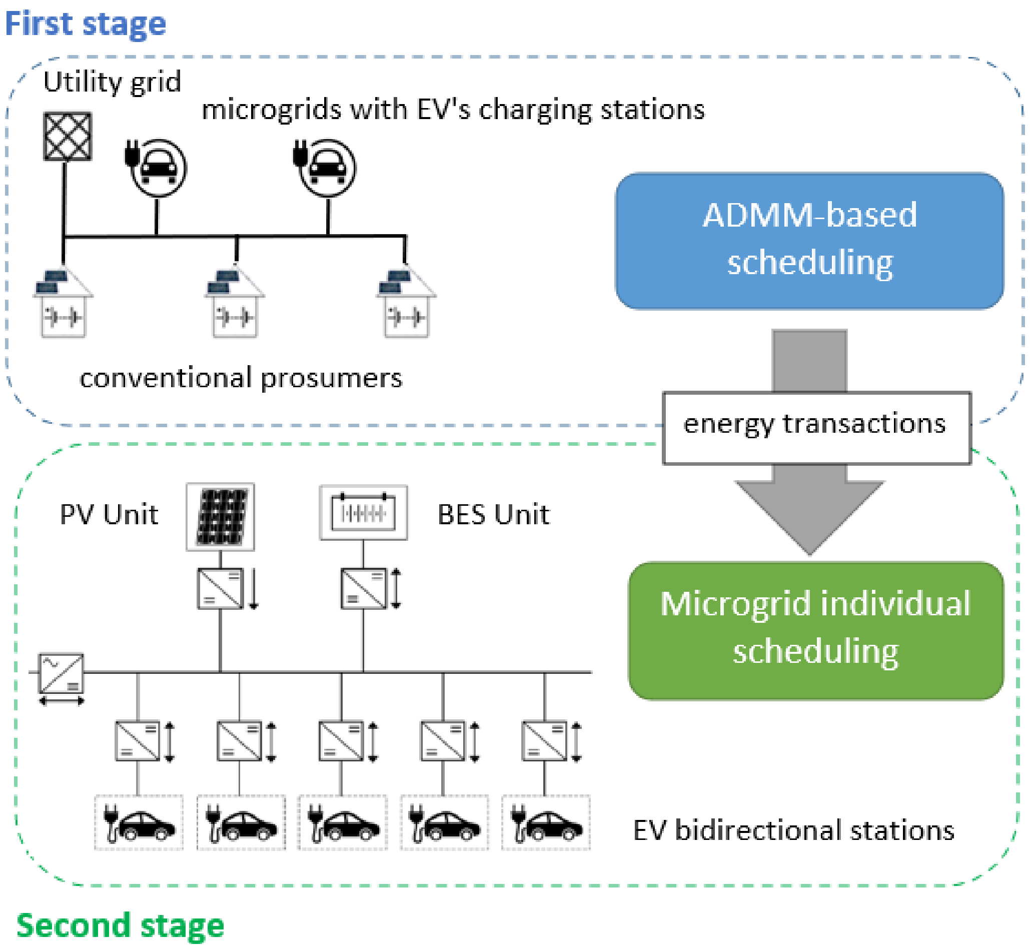
Integration of multiple EVSIs in a two-stage optimal energy management strategy

Local Energy Community

- The regulatory framework of many countries has allowed the development of the energy community concept. This energy system is composed of neighboring end-users that agree to collaborate to share their energy resources. In these entities, direct energy transactions among participants can be allowed.
- A common scenario studied in the literature corresponds to the scheduling of communities of prosumers, which might be equipped with generating units, e.g. photovoltaic (PV) units, battery energy storage (BES) units, and local loads.
- The implementation of an efficient energy management system (EMS) represents one of the main challenges for the successful implementation of energy communities. Distributed optimization approaches, such as the alternating direction method of multipliers (ADMM), are often preferred for their privacy protection and scalability features

Two-stage scheduling of a LEC

- A two-stage optimization procedure is proposed to coordinate the day-ahead scheduling of an energy community with the presence of DC microgrids equipped with clusters of bidirectional EV charging stations.
- The proposed day-ahead scheduling of an energy community of microgrids with the presence of EV charging stations is addressed by the two-stage scheduling approach illustrated in the figure.
- In the first stage, an ADMM-based optimization approach is employed to define the scheduling of the resources for all the hours of the next day.
- For each EV-based microgrid, the second-stage optimization defines the individual scheduling of each charging stations, keeping the feasibility of the global solution of the energy community. The second-stage optimization can fully exploit the V2G services provided by the connected EVs.



Francesca Marasciuolo (francesca.marasciuolo@poliba.it)

Two-stage scheduling of a LEC

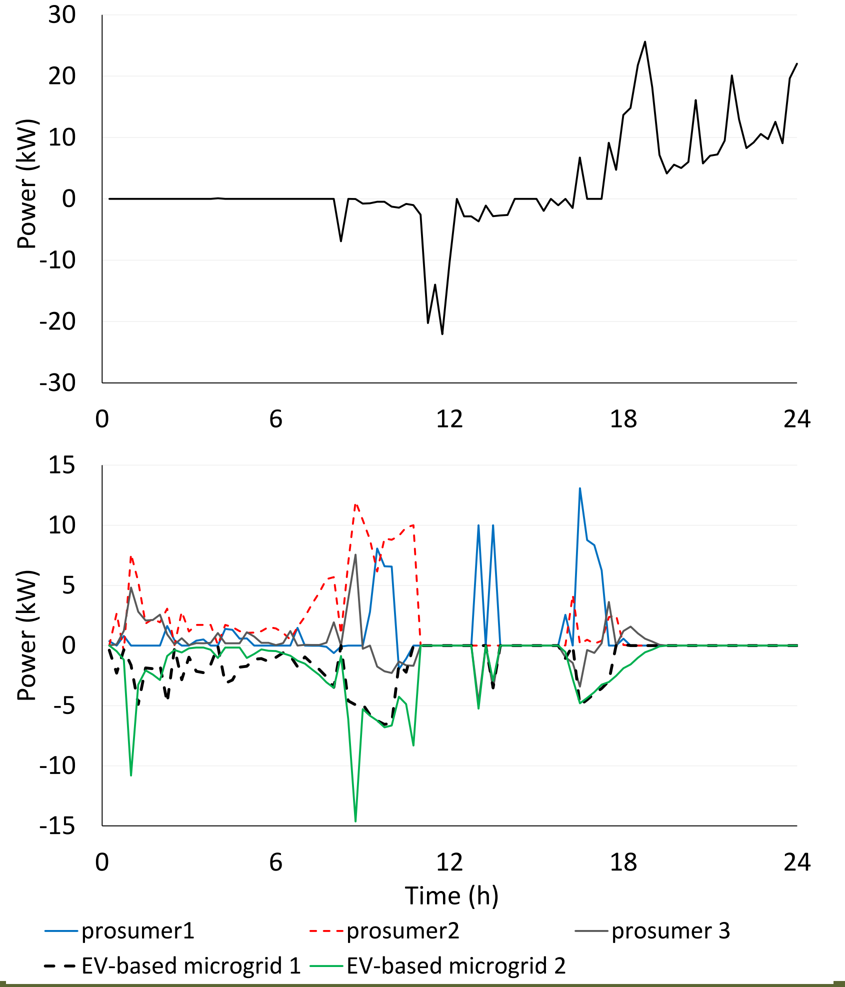
- The objective of the community EMS is the minimization of the total energy procurement cost during the next day. In the ADMM-based approach, the optimization is iteratively carried out by each participant. For each member i belonging to set Ω of the community participants, the local objective function is OFi
- The optimization problem for each microgrid with EVs aims to minimize an objective function that includes both the sum of quadratic deviations of bought and sold power in each time-step and the operating costs of the parking lot.

$$OF_i = \min \sum_{t \in T} \left[\begin{array}{l} \pi_{\text{buy}}^{t} P_{\text{buy\_Grid}\,i}^{t} \Delta t - \pi_{\text{sell}}^{t} P_{\text{sell\_Grid}\,i}^{t} \Delta t + \\ \sum_{\substack{j \in \Omega \\ j \neq i}} \lambda_j^t P_{\text{buy}\,i,j}^{t} \Delta t - \lambda_i^t \sum_{\substack{j \in \Omega \\ j \neq i}} P_{\text{sell}\,i,j}^{t} \Delta t + \ell_i^t \\ + C_S^t + w_{\text{BES}} \left(P_{\text{BES}\,\text{ch}\,i}^{t} + P_{\text{BES}\,\text{dis}\,i}^{t} \right) \Delta t \end{array} \right]$$

$$\min \sum_{t \in T} \left\{ \begin{array}{l} \left[\begin{array}{l} \left(\Delta t \cdot \left(P_{LEC}^{in}(t) - P_g^{in}(t) \right) \right)^2 + \\ + \left(\Delta t \cdot \left(P_{LEC}^{out}(t) - P_g^{out}(t) \right) \right)^2 \end{array} \right] \\ + \rho \cdot \Delta t \cdot \left[\begin{array}{l} w_{BES} \cdot \left(P_{BES}^{c}(t) + P_{BES}^{d}(t) \right) + \\ + \sum_{k}^{n_{ev}} \left(c_{EV,k} + w_{EV,k} \right) \cdot P_{EV,k}^{c}(t) + \\ + \left(w_{EV,k} - r_{EV,k} \right) \cdot P_{EV,k}^{d}(t) \end{array} \right] \end{array} \right\}$$

Results

- The obtained profile of the power flow exchanged between the community and the external energy provider (positive if imported by the community and negative if exported by the community) is reported. The community exports energy in the first part of day, then imports energy in the second one.
- The power flow exchanged by each participant inside the community (positive if absorbed and negative if injected) is shown. EV-based microgrids sell energy to the other prosumers of the community.



2. *F. Marasciuolo, C. Orozco, M. Dicorato, A. Borghetti, G. Forte, "Two-stage scheduling of clusters of charging stations for electric vehicles in a community of DC microgrids," EEEIC, 2021.*

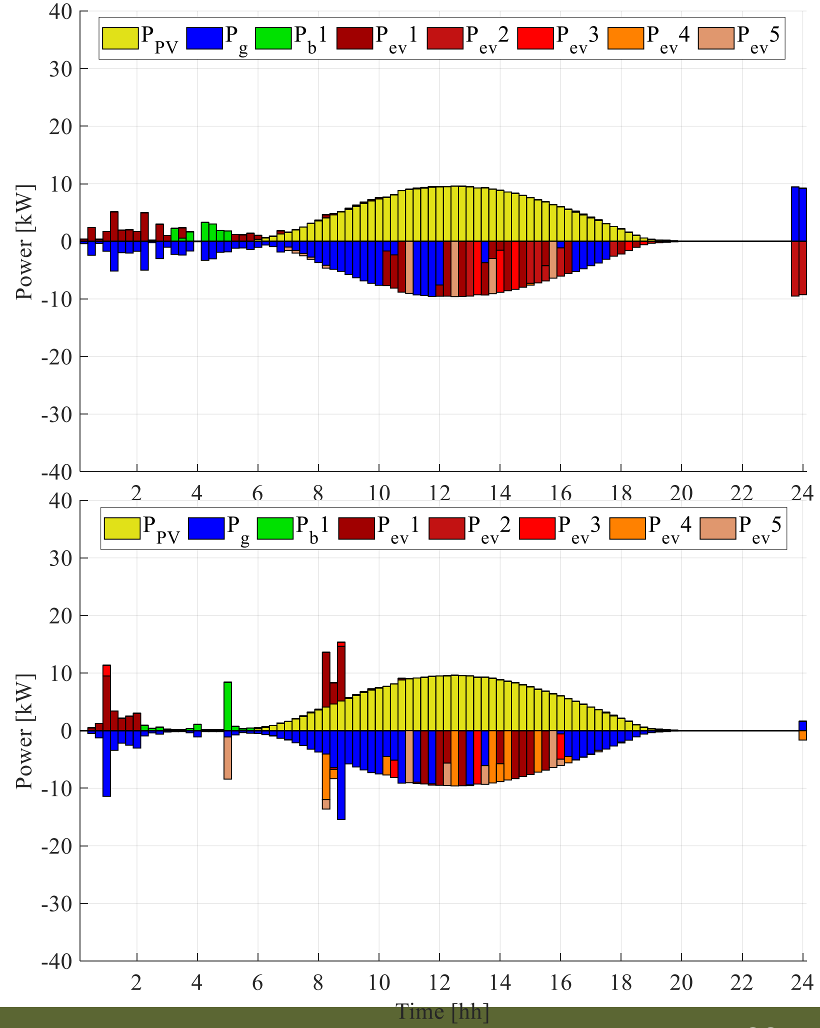
Results

- Power exchanges in parking lot 1 are shown. It can be noted that EV1 first operates in V2G mode to sell energy to the other prosumers of the community. Then, BES discharging occurs to provide energy to the community. PV plant production is mostly sold to the distribution grid during daylight time.
- In the second part of the day EV charging is provided always by PV plant. Only at the end of day energy from the distribution grid is bought to charge EV1.
- Similar considerations could be made for power exchanges in microgrid 2.

2. *F. Marasciuolo, C. Orozco, M. Dicorato, A. Borghetti, G. Forte, “Two-stage scheduling of clusters of charging stations for electric vehicles in a community of DC microgrids,” EEEIC, 2021.*

EV-based microgrid 1

EV-based microgrid 2



Conclusions

Discussion and future works

Conclusions

- Three operation procedures have been adopted for EV charging station management based on DC structure, involving technical and economic targets.
- Simulations have proved that EV and BESS wearing costs can hinder their exploitation under a plain economic target. EVs do not work in V2G mode even if other sources are not present.
- The fully equipped DC microgrid allows an improvement of economic and technical performances, although requiring higher investments.
- A two-stage scheduling approach has been proposed to deal with the day-ahead energy management of a LEC in the presence of EV charging station clusters.
- The first-stage scheduling provides an economic benefit for each participant, even for those with a relative low capacity to sell energy.
- The obtained results show that in the second stage EV-based microgrids better exploit the available energy resources with respect to the other prosumers of the LEC. Revenues for EV discharging encourages the use of V2G, with respect to the use of a dedicated BESS.
- The proposed two-stage scheduling proved to positively affect the energy exchanges both among community participants and resources within each microgrid.

Future works

- Dynamic modeling and behavior analysis of EVSI
- Short-term operation planning for technic and economic efficient performances (real-time optimal operation) aimed at providing grid services
- Fast charging integration in DC microgrid operation and management

Thank you for your attention

Francesca Marasciuolo (francesca.marasciuolo@poliba.it)
Interuniversity PhD course in Industry 4.0 - Università degli Studi di Bari – PhD School of the Politecnico di Bari