Pathways to Decarbonization of European Islands: Ensuring the Integration of High Renewable Energy and Power System Flexibility

BY SOPHIE CHLELA, SANDRINE SELOSSE AND NADIA MAÏZI

Sophie Chlela, **Sandrine Selosse** and **Nadia Maïzi** are with MINES ParisTech, PSL University, Centre for Applied Mathematics. Sophie Chlela can be reached at sophie.chlela@mines-paristech.fr

Abstract

The increase of renewable energy share in the power generation mix to achieve national and international targets of greenhouse gases emissions reduction comes with important consequences, especially for the electricity grid that has to increase its flexibility to assure the quality and reliability of supply. This requirement can be much more relevant when dealing with islands, as they have limited (or no) interconnections to the continent and thus have to rely more on more flexibile options to ensure the secure and cost-efficient operation of their energy system. In this context, a long-term prospective study, based on technico-economic optimization of TIMES model generator, is carried out to explore decarbonisation pathways that ensure grid flexibility of the two investigated European islands - Procida in Italy and Hinnøya in Norway. Emphasis is given to technical, economic and policy aspects of the evolution of the islands' power systems.

Introduction

Climate change mitigation measures include the reduction of greenhouse gas emissions [1] which translates in the decarbonization of the energy systems. The increase of the share of renewable energy sources in the production mix appears to be a valid solution. First and foremost, these technologies can ensure energy production at low (or null) carbon emissions. Second, in terms of electric power generation, they represent fast-paced growing resources and finally, in many cases, have already become cost-competitive with fossil-fuel-based generation[2]. The European Commission offers a favourable framework for the development of renewable energy through the policy support through the *Clean energy for all Europeans package* and considers increasing its share as fundamental for the achievement of the continent's energy and climate objectives [3][4]. However, the introduction of renewable technologies comes with important challenges, especially when dealing with electricity supply. In fact, the electric grid should assure at all instant a balance between the production and demand. Meanwhile, the electricity generated from some of the most commonly used renewable sources, namely solar photovoltaics (PV) and wind turbines, is dependent on external parameters such as weather conditions, and thus is strongly variable. Therefore, as the share of variable renewable energy (VRE) sources increases, the necessity to ensure a reliable power system for the satisfaction of the electricity demand becomes more crucial especially with the stochastic nature of VREs which explains the growing need of power system flexibility.

In this framework, islands present specific challenges when it comes to energy supply and security and economic development. Owing to their small size, islands constitute a marginal market for international suppliers of energy and energy services, and they are often not able to obtain beneficial prices from bulk purchases. In addition, their remoteness implies high transportation costs. Moreover, islands are among the first victims of climate change: consequences for small islands vary from property damage to rising sea levels and coastal erosion. The introduction of renewable energy could be much more relevant when dealing with islands. These territories are often characterised by an over-dependency on energy imports [5]. This is mainly due to the additional geographical constraints presented by these territories which imply a limited or inexistent mainland grid connection, a limited space availability for power production installations and/or a lack of access to road infrastructure. Hence, islands would naturally consider investing in sustainable energy solutions like developing domestic renewable energy within their territory. These actions would fit in a long-term strategy to ensure their autonomy and enhance their resilience, hence going beyond the achievement of the decarbonization goal, however inexorably accelerated by the exploitation of renewable energy on these territories. Moreover, energy autonomy of islands – defined as the ability of the energy system to function (or have the ability to function) fully without the need of external support like imports [6] - has been linked to the potential to reduce the cost of energy, and the ability to significantly reduce the carbon emissions associated with a community or region [6], [7].

The challenge

System flexibility, in electrical energy system context, can be described as the ability of a power system, including generators, to sufficiently respond to changes in production and/or demand without jeopardising the grid stability [8]. There is an interest to share the burden of the grid flexibility with the whole energy system and explore potential synergy effects across energy subsectors. The International Energy Agency (IEA) provides a techno-economic definition of flexibility: *"the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring* *instantaneous stability of the power system to supporting long-term security of supply"* [9]. Flexibility describes the degree to which a power system can adjust the electricity demand or generation in reaction to both anticipated and unanticipated variability. It also indicates the capacity of a power system network to reliably sustain supply during transient and large imbalances [10]the inclusion of variable renewable energy sources (vRES.

Possible solutions

There are several well-proven supply and demand side flexibility measures that can be used to introduce a better flexibility into the traditional energy system:(1) institutional changes (policies), (2) the adaptation of operational methods and of the production mix (Adaptation to demand), and (3) storage, demand management, the introduction of a more flexible generation system, as well as many other mechanisms suitable to each situation are some to mention.

Storage

They refer to technologies that store electrical energy and release it on demand when it is most needed through the conversion of electricity to other forms of energy and back again [14]. Given their valuable potential contribution to the grid management, these technologies are considered a prominent solution to integrate large amounts of VREs in power systems. The electricity storage can be installed at any level of the energy system: at the transmission or distribution grid, coupled with other generation facilities of used in behind-the-meter applications (i.e. used by final consumers). According to its location and operational mode, the regulatory framework and the market, it can provide several different services to the grid [14]. For example, if used at transmission or distribution level it can provide grid services (such as ancillary services or distribution network support), whereas if coupled with supply technologies it can provide bulk energy services (it can for example shift the electricity production of VRE to no production times, supporting the integration of these sources in the electricity grid). It can also be used by final consumers for energy management services (i.e. self-consumption, that improves the bill management, power quality and reliability, other than supporting the deployment of VREs at distribution level). Electric batteries can also be used for electric vehicles in the transportation sector.

Demand side management

Demand side management is one of the central methods used to improve the flexibility of the electrical system. It consists of using different techniques in order to influence the final electricity consumption according to the grid's characteristics. Load levelling, valley filling, and load shifting are some of the demand management mechanisms. It consists in the planning, implementing, and monitoring activities of electric utilities which are designed to encourage consumers to modify their level and pattern of electricity usage [11]. Therefore, with this solution, the consumers become active participants in the energy system (i.e. they become prosumers).

The implementation of these techniques, based on price signals, has two main benefits: for the consumers it can represent a saving in electricity bills, whereas for the grid it allows to shift the energy consumption from peak to non-peak hours. The target customers are typically residential and industrial ones. However, a proper market design should be assessed to make this solution a viable flexibility source for the system. At this aim, the introduction of a new figure called aggregator, whose role is to manage the energy potential coming from the demand side, is gaining pace in the electricity market.

Electric vehicles charging

We can consider three types of charging strategies for electric vehicles [12]. The uncontrolled charging consists of charging the vehicle at maximum power as soon as it connects to the grid. For passive control, only encouragements are given to owners to charge during low tariffs of electricity. For active control or smart charging, the charging is mostly made during low tariffs or off-peak periods in addition to a modulation of the charging power. Two possibilities for smart charging exist: unidirectional (V1G) or bidirectional (V2G) which consists of injecting power back to the grid. Below is a schematic summarizing the EV charging strategies. The V1G is a flexible solution that could be used by DSOs to better manage the electricity load due to electric vehicles that are connected to the grid. It consists in a modification in the recharge profile of a part of the EVs that is made through a modification of the input current that feeds the vehicle. In this way, it is possible to decrease a part of the demand of EVs that occurs at peak hours by shifting this load in off-peak hours.

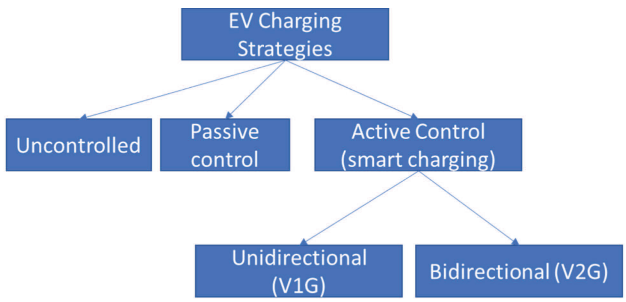

Figure 1 – Schematic summarizing the EV charging strategies adapted from [12]

Applications

Methodology

As part of this subject, a long-term prospective study is carried out to explore decarbonization pathways that ensure grid flexibility of two European islands, namely Procida in Italy and Hinnøya in Norway. Different possible evolutions of the energy system of the two territories are investigated through the implementation of long-term energy-planning models, based on the MARKAL-TIMES (Market Allocation) model, a methodological corpus developed within the ETSAP (Energy Technology Systems Analysis Program[1]). TIMES is an technico-economic model generator that can be applied to systems of any dimension, which provides a technology-rich basis for representing energy dynamics over a multi-period time horizon [13]. TIMES is a partial equilibrium model that uses a linear-programming approach in which the technical optimum is computed by minimizing the discounted global system cost. It is based on a bottom-up methodology, relies on investment, fixed and variable costs and are demand driven. Hence, the minimization of the total discounted costs of the modelled power system is made over a long time period (here 2050) under a number of environmental, technical and demand constraints [14].

Based on prospective studies using TIMES model, we investigate the applications of flexibility and the integration of renewable energy in the power systems. As such, for the case of the Italian island we study the investment in new technologies that include photovoltaics (PV) placed on rooftops of the buildings in the public, tertiary and residential sectors. They are coupled to Li-ion batteries and implemented in the model. We then implement a dynamic price of electricity during off-peak hours. As for the Norwegian island, we analyse the response of the low-emissive electric transportation to prices of electricity to control their charging.

Recommendations

This study is developed under a H2020 project, GIFT - Geographical Islands FlexibiliTy, as part of the European innovative projects developed to meet the sustainability goals for the energy sector. The achievement of the objectives proposed for this project will allow to decarbonize the energy mix and to increase the share of renewable energy sources in European islands. As part of the project, long-term prospective modelling will contribute to the realisation of energy transition. The results will enable municipalities to consider different regulatory policies to achieve the energy transition of the territory. Moreover, as Hinnøya and Procida are representative of completely different European contexts, the results obtained in this study will not be limited to these two demonstration sites, but other islands could benefit from the analysis.

The main results from the study are summarized below:

- When local variable renewables deployment is coupled with the storage technologies, the system becomes more cost-effective and reduces its dependency to imports. For instance, the results for Procida, show that the use of batteries allows to decrease the electricity imports at peak hours, when the grid is more subjected to congestion problems. However, the results also showed that in the long-term the use of photovoltaics alone is not enough to cope with the increase of electricity consumptions. Additional solutions should then be considered, such as policies supporting energy efficiency.
- Storage technologies are powerful in managing the electricity supply especially in cases of intermittent renewable energy. The use of these devices is strictly related to the amount of renewable energy integrated in the energy system, as the investments in these devices increase with the share renewable energy.
- Integrating renewable energy-based electricity to decarbonize sectors is facilitated by flexibility solutions as they present one way to manage the additional load and avoid creating peaks with the electrification of emissive sectors. This is the example of sector coupling made possible by electrifying the transport sector in the Norwegian island. The analyses focused on the transport passenger cars where charging control is necessary to avoid additional peak or to shift them in time according to low values of electricity prices and demand. In fact, the results for this sector at year 2035 show that 58% of the mix will be electrified till reaching 100% electrification in year 2050. However, both national policies and technology advancement have a great impact on the choice of electric vehicles: the first one with associating a taxation of the emissions of the fuel used by this sector and the second, with the reduction of the investment costs through the horizon.
- The option of self-consumption implemented in the Italian island decreases the dependency on the grid especially in marginal locations like the case of islands that are connected to the mainland. Combined with dynamic prices of electricity applied to all sectors studied (public, residential, tertiary) it enhanced the investments of storage in the most energy intensive sectors namely the tertiary and residential, which reduced the imports of electricity at peak moments of the day but not as the level at the energy system. Therefore, in terms energy dependency, it is better to have tariffs that are adapted to the sector where they are implemented, i.e according to the load time variation of the respective sector.
- Dynamic prices of electricity can be used for valley-filling where the objective is to flatten the demand curve on a diurnal basis. This would provide incentive to the electric vehicle owner to participate in charging control strategies. However, the impact will not be noticed unless the transport sector constitutes an important demand of electricity.
- Public and tertiary sectors are another source of demand-side flexibility on the islands as noticed by the use of the energy management system. The trend towards relying on electricity in the activities of these economic sectors is leading to harnessing the existing or new possibilities of flexible load. In general, this requires an increasing roll-out of smart meters, grid connected devices and the introduction of decentralized renewable energy and storage technologies, so that demand-side and thus "prosumers" (consumers that become producers) participation is enhanced.

- National and local authorities play an essential role in the deployment of low emission technologies for the energy transition: we noticed for instance, that the electrification of the transport is supported by the national authorities in Norway and is reflected on the island since shares the same context of the mainland. However, the context of Procida differs from the country of Italy, mainly due to its limited surface, where possibilities are constrained.

Footnotes

[1] https://iea-etsap.org/

References

[1] UN Environment, "Mitigation," *UNEP - UN Environment Programme*, Sep. 14, 2017. http://www.unep.org/explore-topics/climate-action/what-we-do/mitigation (accessed Jun. 24, 2021).

[2] IRENA, "Renewable Power Generation Costs in 2019," International Renewable Energy Agency, Abu Dhabi, Jun. 2020. [Online]. Available: https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019

[3] European Commission, "Renewable energy targets," *Energy - European Commission*, Jul. 08, 2021. https://ec.europa.eu/energy/topics/renewable-energy/directive-targets-and-rules/renewable-energy-targets_en (accessed Jul. 31, 2021).

[4] European Union, "Clean energy for all Europeans." Publications Office of the European Union, Jul. 26, 2019. Accessed: Nov. 15, 2020. [Online]. Available: http://op.europa.eu/en/publication-detail/-/publication/b4e46873-7528-11e9-9f05-01aa75ed71a1/language-en

[5] European Commission, "Clean Energy for Islands Initiative." 2018. [Online]. Available: https://ec.europa.eu/energy/topics/renewable-energy/initiatives-and-events/clean-energy-eu-islands_en?redir=1

[6] C. Ray and F. Bradley, "Energy autonomy in sustainable communities—A review of key issues," 2012. https://reader.elsevier.com/reader/sd/pii/S1364032112004716?token=1876C4B2092D6C1E53B-F7EBD3C380353BE3194989C96404986600BBA40524D0FADF6EEE4C-C7A21FFEE5D5B14C4F11248 (accessed Mar. 13, 2021).

[7] M. Drouineau, E. Assoumou, V. Mazauric, and N. Maïzi, "Increasing shares of intermittent sources in Reunion Island: Impacts on the future reliability of power supply," *Renew. Sustain. Energy Rev.*, vol. 46, pp. 120–128, Jun. 2015, doi: 10.1016/j.rser.2015.02.024.

[8] J. Cochran *et al.*, "Flexibility in 21st Century Power Systems," NREL/TP-6A20-61721, 1130630, May 2014. doi: 10.2172/1130630.

[9] IEA, "Status of Power System Transformation 2019," p. 32, May 2019.

[10] O. M. Babatunde, J. L. Munda, and Y. Hamam, "Power system flexibility: A review," *Energy Rep.*, vol. 6, pp. 101–106, Feb. 2020, doi: 10.1016/j.egyr.2019.11.048.

[11] "Electric Utility Demand-Side Management." https://www.eia.gov/electricity/data/eia861/dsm/ (accessed Jun. 19, 2021).

[12] K. Knezović, "Active integration of electric vehicles in the distribution network – theory, modelling and practice," p. 229, 2016.

[13] R. Loulou, G. Goldstein, A. Kanudia, A. Lettila, and U. Remme, "Documentation for the TIMES Model - Part I." Jul. 2016.

[14] S. Selosse, S. Garabedian, O. Ricci, and N. Maïzi, "The renewable energy revolution of reunion island," *Renew. Sustain. Energy Rev.*, vol. 89, pp. 99–105, Jun. 2018, doi: 10.1016/j.rser.2018.03.013.

IAEE

International Association for
ENERGY ECONOMICS