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DESIGN OF ELECTRIC MICROGRIDS IN PUBLIC BUILDINGS

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Distributed grid architectures are acquiring a role increasingly important as alternative solutions to the centralized power grid, that faces new challenges and needs of restructuring. Among these architectures are the electric microgrids, low voltage distribution systems constituted by loads and distributed energy resources that, coordinated in an efficient way, allow to optimize the operation of the whole system. As part of current projects for the development of microgrids, this Master Thesis is a preliminary study for the design and sizing of an electric microgrid in the School of Engineering of the University of Seville. The first part of the project consists on collecting literature of the state of the art of the design of microgrids and their technical connection requirements to the grid. The second part of the project consists on studying the current generation resources of the building, that are a solar cooling plant and a back up generator set, its yearly consumption pattern and sizing additional renewable resources, concretely a photovoltaic system and a storage system, to obtain a possible generation scenario that makes possible the operation of the building as a microgrid.

Keywords: *Electric microgrids; integration of renewable energies; distributed generation; design of electrical systems*

DISEÑO DE MICRORREDES ELÉCTRICAS EN EDIFICIOS PÚBLICOS

Las arquitecturas de red distribuidas están adquiriendo un papel cada vez más relevante como soluciones alternativas a la red eléctrica centralizada, que enfrenta nuevos retos y necesidades de reestructuración. Entre dichas arquitecturas se encuentran las microrredes eléctricas, sistemas de distribución de baja tensión constituidos por cargas y recursos de energía distribuidos que, coordinados de forma eficiente, permiten optimizar la operación de todo el sistema. Como parte de los proyectos actuales para el desarrollo de microrredes, este TFM es un estudio preliminar sobre el diseño y dimensionamiento de una microrred eléctrica en la Escuela Técnica Superior de Ingeniería de la Universidad de Sevilla. La primera parte del proyecto consiste en recoger literatura del estado del arte del diseño de microrredes y de sus requerimientos técnicos de conexión a red. La segunda parte del proyecto consiste en estudiar los recursos de generación actuales del edificio mencionado, que son una planta de refrigeración solar y un grupo electrógeno, su patrón anual de consumo y dimensionar otros recursos renovables adicionales, concretamente una planta fotovoltaica y un sistema de almacenamiento, para obtener un posible escenario de generación que posibilite el funcionamiento del edificio como una microrred.

Palabras clave: *Microrredes eléctricas; integración de energías renovables; generación distribuida; diseño de sistemas eléctricos*

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1. Introduction

Currently, there is an electric energy system that is mostly centralized, in which electricity is transmitted from powers generation plants to consumers through an electric macrogrid (Zhang, 2013). In fact, the electrical network is defined by the U.S. National Academy of Engineering as the “most complex machine ever developed by humankind” (Wolf, 2015). However, more and more, alternative electric power systems to centralized generation systems are emerging in response to the new challenges and needs of restructuring that the current electric network faces, due to the increase of electricity demand and global emissions of greenhouse gases (C.M. Colson & M.H. Nehrir, 2009).

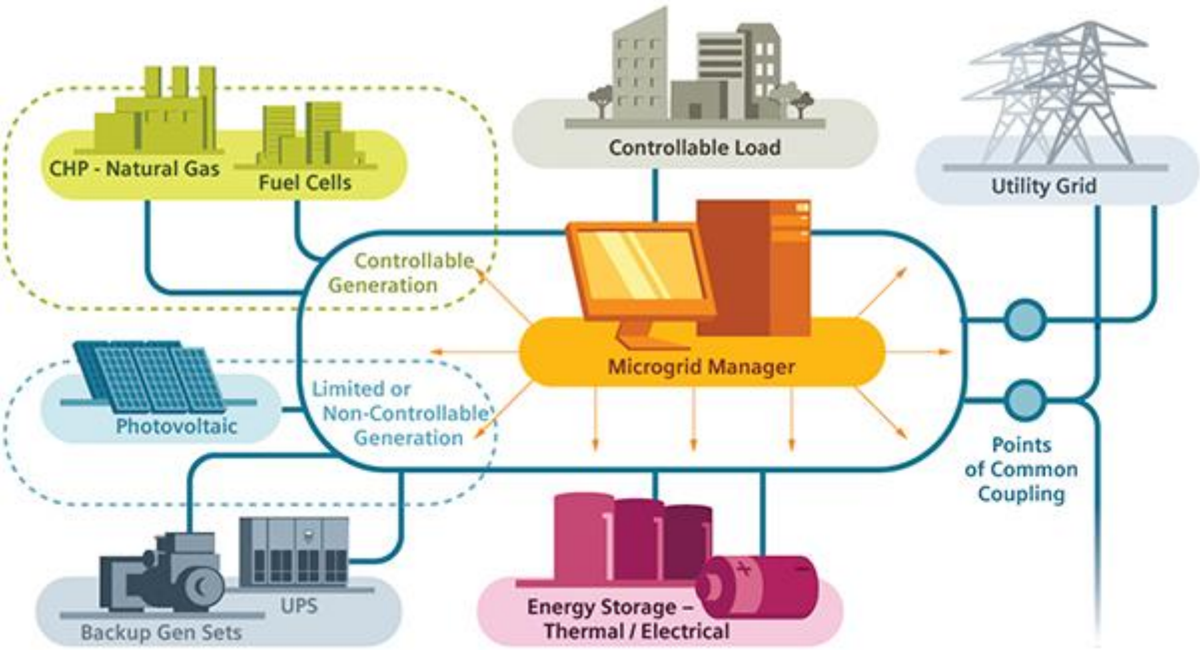
The increase of electricity demand and the requirement of a better quality of supply have led the electric network to reach their limits in both size and complexity. As a result, the current electrical infrastructure is facing problems such as security, reliability and quality of power supply (Wolf, 2015).

On the other hand, the current efforts to combat the climate change pursue a more sustainable electric network and, precisely, the new distributed grid architectures give the possibility of installing distributed resources based on renewable energies.

One of these distributed electric generation systems are microgrids. About the year 2000, people started to talk about microgrids as alternative solutions to centralized generation. Today, microgrids constitute a good solution for critical infrastructures, campuses, remote communities, island networks or single buildings as factories, shopping malls or faculties (Hatziargyriou, 2014).

According to several EU research projects (Hatziargyriou, 2014) “a microgrid comprises low voltage (LV) distribution systems with distributed energy resources (microturbines, fuel cells, photovoltaics (PV), etc.) together with storage devices (flywheels, energy capacitors and batteries) and flexible loads. Such systems can be operated in a non-autonomous way, if interconnected to the grid, or in an autonomous way, if disconnected from the main grid. The operation of microsources in the network can provide distinct benefits to the overall system performance, if managed and coordinated efficiently”. Next, Figure 1 shows a scheme of a microgrid. As it can be seen, the microgrid is constituted by loads (one part of them are controllable loads) and by a serial of Distributed Resources (DRs), including generation and energy storage technologies. All these resources are controlled by a microgrid controller to optimize the operation of the system based on a specific objective.

Figure 1 General Organization of a Microgrid (Siemens, 2017)



Since microgrids are new architectures subject to an intense analysis and pilot project implementations, there are not only technical challenges but also regulatory barriers or lack of regulation that difficult the deployment of microgrids (Amad Ali et al., 2017). In fact, there is not specific regulation about microgrids at the country level, as in Spain, thus, in case of being necessary, regulations that could be applied to the American network and not to the European, should be consulted.

Currently, microgrids are common research topics in the United States, Canada, Japan and Europe in where many studies have been carried out in order to demonstrate the operation of a microgrid (Hatziargyriou, 2017). As part of this common tendency for the development of microgrids, this project is a preliminary study of the requirements for the design and sizing of a microgrid.

2. Objective

The objective of this project is to carry out a preliminary study for the design and sizing of an electric microgrid in the School of Engineering of the University of Seville.

To design a microgrid requires a broad study that addresses the requirements of loads, DRs and the Electric Power System (EPS). This study focuses on analysing the generation capability required for the building to function as a microgrid. The generation capability planning study is addressed in the IEEE Standard 1547-4 (IEEE, 2011) as part of the necessary studies to assure the quality of service that a microgrid provides to its customers. Mainly, this study comprises the following parts:

- To examine real power capability of microgrid DRs.
- To compare generation capability with consumption needs to see if they are compatible.

This study should be carried out when the microgrid is operating in both non-autonomous and autonomous way. In this project, the generation capability planning study has been performed by considering the microgrid works in an autonomous way (when it does not count with the EPS support), the most unfavourable case.

Applying the previous study to the building object of study, the following tasks have been defined:

- To analyse current generation resources of the building to determine their rated power and their annual generation pattern.
- To analyse the yearly consumption pattern of the School to obtain representative daily load curves that allow to compare generation and consumption.
- To propose and size other distributed generation resources that, together the current generation resources, allow to cover the consumption needs of the school to work in an autonomous way.

3. Study Case

The building object of study is the School of Engineering (known in Spanish as ETSI, "Escuela Técnica Superior de Ingeniería"). This institution belongs to the University of Seville and is located in "Isla de la Cartuja" campus. The study is focused on the main building of the faculty, without taking the building workshop and laboratories into account (auxiliary buildings to the main building of the ETSI).

3.1. Type of microgrid

In relation to the classification of the Microgrid Institute (Microgrid Institute [MI], 2015) about types of microgrids, that depends on autonomous operation and network magnitude of the microgrid, the School of Engineering working as a microgrid would be a Nanogrid. A Nanogrid is formed by a single building that, in this case, is the main building of the faculty. It is the smallest microgrid network with the capability of operating independently (Wolf, 2015).

3.2. Stakeholders involved

The potential stakeholders (Hatziargyriou, 2014) who would be involved in the School of Engineering are:

- Consumer: is the entity that has a contract with a supplier company. This agent would be the University of Seville.
- Distribution generator owner/operator: The University of Seville owns the current and future generation distributed resources.
- Distribution system operator (DSO): is the agent responsible for the operation, maintenance and development of the distribution network. It is "Endesa Distribución" company.
- Energy service company (ESCO): is the agent that makes possible the participation of microgrid DRs in local energy markets. This agent would be the University of Seville that, by itself, would look for a supplier of electricity or a local energy market.
- Microgrid operator: is the agent responsible for the operation, maintenance and development of the local EPS that constitutes the microgrid. This agent would be the University of Seville.

3.3. Distributed resources

Currently, the ETSI counts on two generation distributed resources: a Solar Cooling Plant and a backup generator set. Both DRs are going to be studied to know what it is their rated power, how they operate, and any other information that serves to characterize their generation pattern.

In order to reach enough generation capability, other DRs will be proposed and sized. Specifically, a photovoltaic plant and a storage system will be designed so that they cover, together current DRs, consumption needs of the ETSI.

4. Methodology and Results

This chapter has several sections that are divided in two parts: one dedicated to consumption and another dedicated to generation (in turn, this part is divided in current and new DRs). The purpose of this chapter is to explain the methodology used to analyse each resource and to show results obtained.

4.1. Load Planning

To study generation capability needs of the ETSI is necessary to know the pattern consumption of the building. For that, we count on an Excel spreadsheet that contains active and reactive power measurements of the ETSI, taken every five minutes throughout 2003 (recent consumption information of the ETSI is difficult to get).

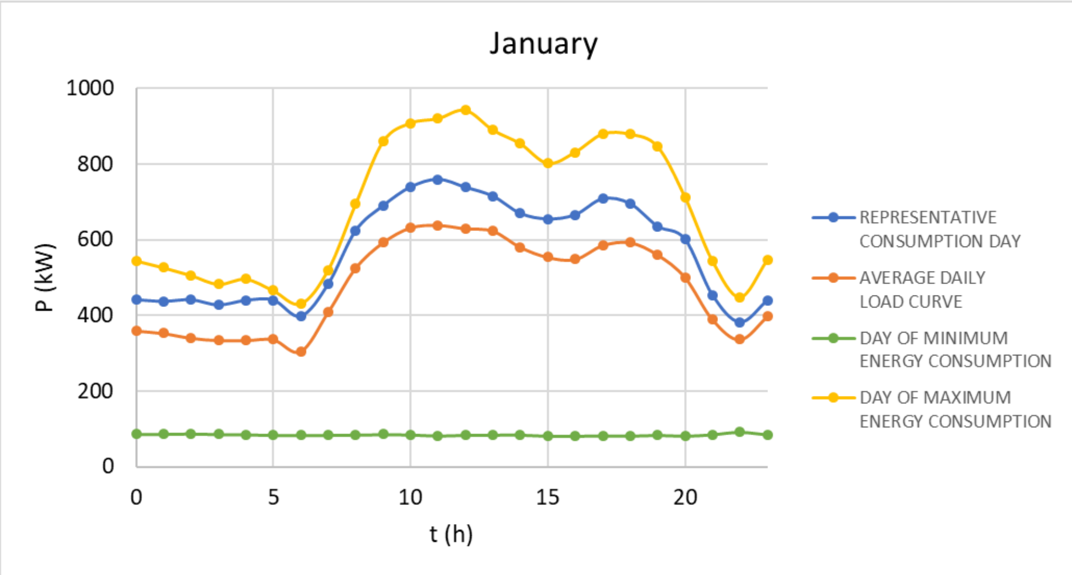
To compare generation and consumption in a simple way, a representative daily load curve for each month is going to be obtained. Since this building is a faculty, consumption on weekdays is different from consumption on weekend days. Thus, for each month, four daily load curves are obtained:

- Two active power daily load curves: one for weekdays and another for weekend days.
- Two reactive power daily load curves: one for weekdays and another for weekend days. Reactive power demands will not be used in this preliminary study, but they have been obtained for future works.

It should be mentioned that each representative daily load curve is a real daily load curve of a specific day: the day whose daily load curve shape looks more like the average daily load curve of a specific month. Doing that, a very important information is not lost: the consumption of one hour is related with the consumption of the next hour.

As an example, Figure 2 shows the active power daily load curve of weekdays of January. The average daily load curve is depicted in orange and the representative daily load curve in yellow. In addition, to assess dispersion of data, the day of maximum and minimum energy consumption are also shown.

Figure 2 Example of consumption pattern: active power daily load of weekdays of January



4.2. Analysis of the Solar Cooling Plant

In this section, one of the current generation resources of the School of Engineering will be characterized: The Solar Cooling Plant (SCP).

This DR is a pilot project of “Gas Natural” to demonstrate the viability of this technology for the air conditioning of buildings. This technology takes advantage of solar energy to produce cool or heat using a Fresnel type collector (shown in Figure 3). The pilot plant works in parallel with the cooling system of the School. The information of this resource has been taken from (Romero, 2012) and (Ramírez, 2013).

Figure 3 Fresnel type collector of the SCP (Romero, 2012)

We want to know how much energy this DR saves for the ETSI. This energy will depend on the season: it works in cooling mode in summer and in heating mode in winter. To obtain this information, the following steps are going to be followed:

- To obtain the average cooling energy the Solar Plant produces on a typical summer day and the average heating energy it produces on a typical winter day.
- To obtain the average number of hours the Plant works on a typical summer day and on a typical winter day.
- Having the previous values, the average cooling and heating power produced by the Solar Plant can be obtained.
- To consult the COP of a reversible heat pump (refrigerating machine of the ETSI) with the cooling and heating power previously obtained. Doing that, the electric energy the heat pump would consume to produce the same energy that the Solar Plant supplies is obtained. And, that electric energy consumption is, approximately, the electric energy the Solar Plant saves for the School.

The average cooling energy produced by the SCP on a typical summer day is 147 kW for 7 hours and the average heating energy produced on a typical winter day is 58 kW for 5 hours. The COP of a reversible heat pump has been consulted in a Daikin Catalogue (Daikin AC Spain, 2014): COP=3.2, EER=2.84, where the EER is the quotient between the cooling power produced and the electric power consumed in cooling mode and the COP is the quotient between the heating power produced and the electric power consumed on heating mode.

From the above information it can be obtained that the daily electric energy the SCP saves for the School is 388,5 kWh in cooling mode and 90 kWh in heating mode, approximately.

4.3. Analysis of the Backup Generator Set

In this section, the other generation resource that the ETSI counts on will be characterized: the generator set. As opposed to the previous case, there is no information about the generator set of the School, thus it will be necessary to make suppositions.

Based on the consumption pattern defined, it is considered that there is a backup generator set of a rated power of 500 kW, that would be a power enough to cover emergency loads.

One of the most important features of this DR is that when the microgrid works on island mode, this DR will act as the voltage and frequency source of the facility, that is, it will energize the system when the microgrid is not supply by the main network.

4.4. Sizing of the Photovoltaic Plant

Since the School of Engineering has to count on enough distributed resources that let it works in island mode, a PV Plant that covers part of the consumption needs of the School is going to be designed. For that, the program *PVsyst* will be used, a very powerful software to design and study PV plants.

The PV plant will be of the grid-connected type for self-consumption of all the electricity produced. Two situations will be considered:

- PV plant without storage. In this scenario, the PV plant supplies the School without ever surpassing the consumption of the building, that is, without the need of exporting energy to the grid. For that, the PV plant is going to be designed taking as a reference the representative daily load curve of the month with the lowest consumption during solar hours. In addition, two sub-scenarios will be considered: one in which the SCP works and another in which the SCP does not work.
- PV plant with storage: in this scenario, besides the PV plant, the School counts on storage resources. Hence, when the generation of the PV plant surpasses the consumption of the School, the surplus will be injected on the storage system.

Next, the methodology followed in each case is detailed:

- PV plant without storage: This study has been carried out with two data sources: monthly and hourly data. To use both data sources to compare results has been decided, since hourly data are more accurate but, from the beginning, the idea was to compare representative monthly data. The methodology followed is:

  1. To assign a rated power (Pn) to the PV plant. Start with a small rated power.
  2. To obtain the estimated annual energy production of a PV plant with that Pn from PVSyst.
  3. To match up generation and consumption data.
  4. If negative net consumption (consumption minus generation) does not exist, go back to step 1.

  The methodology consists on a trial and error test in which, starting from a small PV plant, the rated power that covers the maximum possible consumption without making the net consumption negative will be obtained.

- PV plant with storage: To design the storage system, it makes more sense to use hourly data because with monthly data the information is too synthesised. Different storage system sizes will be obtained, one per each PV plant size (obtained in the previous scenario). The chosen storage system will be the one with a reasonable size-cost trade-off and this one will determine the PV plant size that will be finally chosen. This study will be carried out in next subsection.

The necessary steps to design a PV plant in PVsyst are briefly summarized: to define the type of study, to define the plant location (to charge meteorological data), to define orientation and inclination of PV modules, to select system elements (PV modules and inverters) and to obtain the estimated hourly annual production of the plant.

Next, results obtained for the PV plant without storage and taking as a reference August (month of less consumption) are collected.

- Using monthly data, the following results are obtained:
  - The rated power of the PV plant when the SCP is not working is 350 kW. As an example, Figure 4 shows the daily generation and consumption curves of August. It can be seen that the net consumption reaches zero without being negative.
  - The rated power of the PV plant when the SCP is working is 300 kW.
- Using hourly data, the following results are obtained:
  - The rated power of the PV plant when the SCP is not working is 100 kW.
  - The rated power of the PV plant when the SCP is working has not been studied but, without doubt, it will be lower than 100 kW.

  In addition, the percentage of hours the net consumption is negative has also been obtained (see Table 1) for the different PV plant sizes.

Figure 4 Generation and demand in August with a PV plant of 350 kW and no SCP.

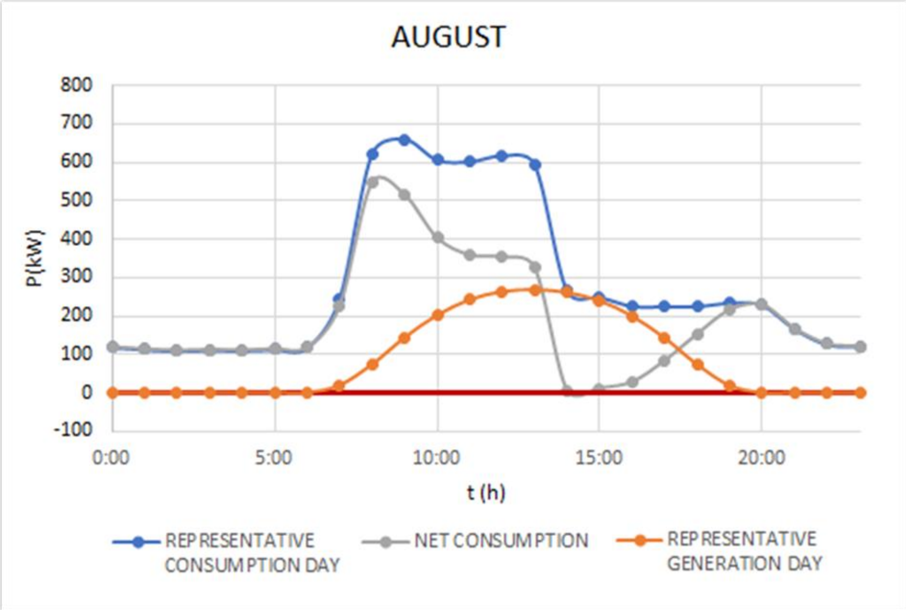


Table 1 Percentage of hours the net consumption is negative using hourly data

Pn (kW)	Hours (%)
100	0
200	4,18
300	6,65
350	7,23
400	8,21

4.5. Sizing of the Storage System

Counting on a storage resource implies that the microgrid can manage its generation or consumption. Among the possible cases for which the storage can be used, this study focuses on the use of storage for managing the surplus of generation. This situation can occur during solar hours, in days of low consumption and high generation.

Considering that for the sizing of the storage system the hourly data are going to be used and having the information presented in Table 1, a storage system will be necessary when PV plant size is greater than 100 kW.

For the different PV plant sizes of the prior section, the storage system necessary to absorb the surplus of generation of each case has been sized. Results are shown in Table 2.

Table 2 Energy and power of the storage system needed for each PV plant size

Pn (kW)	E (kWh)	P (kW)
100	0	0
200	456	84
300	1047	166
350	1344	207

From Table 2, it can be concluded that the storage capacity required for PV plants equal to or greater than 300 kW is very large and, therefore, very expensive. The storage system for a PV plant of 200 kW seems more reasonable.

Among the possible storage technologies (chemical, potential, kinetical or thermal energy), chemical storage has been selected, in particular, batteries of Li-Ion. As an example, two modules of TESLA battery “PowerPack” (used for utility grid applications), whose rated power is 100 kW and its rated energy is 220 kWh, could be used to manage the surplus of generation with a PV plant of 200 kW.

5. Conclusions

First, and giving a response to the objective defined in this project, a possible generation scenario for the operation of the ETSI as a microgrid has been obtained. Attending to the need of increasing the current generation capability of the building, it has been designed a PV plant that can go from lesser to greater rated power and, in this way, to cover more or less power demand, but with storage system, the solution is more limited.

Regarding the study performed, the following conclusions have been obtained:

- As in any study, the available information is very important for the reliability of results obtained. In numerous occasions, to make suppositions due to the lack of information has been necessary but, these considerations are reasonable for this type of project: a draft or preliminary study.
- In the consumption study, the available data, although old, have allowed to obtain a representative daily load curve for each month. This simplified consumption pattern is very useful to make comparisons with generation and to have a general idea of the way to consume in the building.
- The study of the Solar Cooling Plant has allowed, besides to obtain the daily electric energy save provided by this resource to the School, to learn about an experimental technology based on solar energy for the air conditioning of buildings.
- After the trial and error tests for the design of the PV plant, it is concluded that the study with hourly data is more reliable and more useful because gives an idea of the number of hours per year that the generation surpass the consumption and, in addition, allows to size the storage system that would be necessary to manage the surplus of generation.
- The scenario in which is considered the use of storage is much more interesting than the case in which is not used because, besides the main functionality for which has been conceived, it can be used for other interesting purposes such as the optimization of the daily load curve.

6. Bibliography

Ali, A., Li, W., Hussain, R., He, X., Williams, B.W. & Memon, A. H. (2017). Overview of Current Microgrid Policies, Incentives and Barriers in the European Union, United States and China. doi:10.3390/su9071146

Colson, C.M. & Nehrir, M. N. (2009, July). A review of challenges to real-time power management of microgrids. 1-8. Calgary, AB, Canada. doi:10.1109/PES.2009.5275343

Daikin AC Spain, S. (2014). Tarifa Daikin 2017. Precios de venta recomendados. Retrived from http://idaikin.es/catalogos/tarifa-abril-2017/mobile/tarifa_general_2017.pdf

Hatziargyriou, N. (2014). Market Models for Microgrids. In *Microgrid: Architectures and Control* (pp. 12-22). Available at https://www.wiley.com/en-us/Microgrids%3A+Architectures+and+Control-p-9781118720684

Hatziargyriou, N. (2014). Preface. In *Microgrids Architectures and Control.* Athens, Greece. Available at https://www.wiley.com/en-us/Microgrids%3A+Architectures+and+Control-p-9781118720684

Hatziargyriou, N. (2014). The Microgrids Concept. In *Microgrids Architectures and Control* (pp. 1-7). National Technical University of Athens, Greece. Available at https://www.wiley.com/en-us/Microgrids%3A+Architectures+and+Control-p-9781118720684

Hatziargyriou, N. (2017). Pilot Sites: Success Stories and Leanrt Lessons. In *Microgrid Architectures and Control.* Athens, Greece. Available at https://www.wiley.com/en-us/Microgrids%3A+Architectures+and+Control-p-9781118720684

IEEE. (2011, July). IEEE Std 1547.4 - Guide for Design, Operation, and Integration of Distributed Resources Island Systems with Electric Power Systems. 30. New York, USA. doi:10.1109/IEEESTD.2011.5960751

MI. (2015). *Community Microgrid Models.* Retrieved from http://www.microgridinstitute.org/about-microgrids.html

Ramírez, J. R. (2013). Evaluación de una instalación de refrigeración solar por absorción con captadores Fresnel. Sevilla. Retrieved from http://bibing.us.es/proyectos/abreproy/70510/fichero/PFM_131128_v2.0.pdf

Romero, J. M. (2012). Análisis energético de una planta de producción de frío solar mediante tecnología Fresnel. Sevilla. Retrieved from http://bibing.us.es/proyectos/abreproy/5179/fichero/An%C3%A1lisis+energ%C3%A9tico+de+una+planta+fr%C3%ADo+solar+mediante+tecnolog%C3%ADa+fresnel%252F1-Portada.pdf

Siemens. (2017). *Siemens USA. Smart Grid Solutions. Microgrids*. Retrieved from https://w3.usa.siemens.com/smartgrid/us/en/microgrid/pages/microgrids.aspx

Wolf, G. (2015, October). Microgrids are everywhere. Available at http://www.tdworld.com/grid-optimization/microgrids-are-everywhere

Wolf, G. (2015, December). The Name Game: Is 'Microgrid' Correct? Retrieved from http://www.tdworld.com/commentaries/name-game-microgrid-correct

Zhang, D. (2013). Optimal Design and Planning of Energy Microgrids (Thesis, University College London). 11. Retrieved from http://discovery.ucl.ac.uk/1418705/1/Thesis_Di%20Zhang.pdf