Luis A. M. Barros, João L. Afonso, P. Ferreira, M. Araújo and J. G. Pinto, "Study on The Technological and Economic Viability of Introducing Energy Storage Systems with Solar Photovoltaic Panels" in 4th International Conference on Energy and Environment: bringing together Engineering and Economics, Guimarães, Portugal, 16-17 May 2019.

4th International Conference on Energy and Environment: bringing together Engineering and Economics
Guimarães, Portugal
16-17 May, 2019

STUDY ON THE TECHNOLOGICAL AND ECONOMIC VIABILITY OF INTRODUCING ENERGY STORAGE SYSTEMS WITH SOLAR PHOTOVOLTAIC PANELS

Luis A. M. Barros[1*], João L. Afonso[1], P. Ferreira[1], M. Araújo[1] and J. G. Pinto[1]

[1] ALGORITMI Research Centre, University of Minho, Portugal

* Corresponding author: lbarros@dei.uminho.pt, University of Minho, Azurém Campus, 4800-0588 Guimarães, Portugal

KEYWORDS
Battery Energy Storage System, Economic Viability, Renewable Energies, Solar Photovoltaic.

ABSTRACT

Solar photovoltaic represent one of the most promising technologies for generating electrical energy from renewable sources. In fact, as a result of the technological advances in the field of microelectronics and power electronics, photovoltaic systems have reached historic lows in terms of costs, surpassing the other types of renewable energy sources. The potential of the solar photovoltaic systems is enormous, being capable of meeting the energy needs of today, without compromising future needs, and allowing a sustainable development. With this in mind, several incentives and, consequently, legislations have been implemented around the world. In the Portuguese case, depending on the type of contract, for photovoltaic solar installations with value of power up to 1500 Wp the production surplus is injected into the power grid without any financial compensation. Considering the high investment, particularly regarding the photovoltaic panels, the support structure and the power electronics converters, it could be interesting to implement a system capable of storing the surplus energy for later use by the owner of the photovoltaic installation. This paper presents a study on the viability of energy storage systems in photovoltaic installations up to 1500 Wp. For this study, different consumer profiles, types of installations and geographic locations were considered, in order to perceive the technological and economic viability of this solution.

INTRODUCTION

Solar energy became the promising renewable electricity generation source, growing 30 % a year, reaching in 2017 a total of 405 GWp of Photovoltaic (PV) installation and being expectable to achieve the mark of 1 270 GWp in 2022. As consequence of strong investments in the research and development in the subject, solar energy is becoming the cheapest and lowest environmental impact power generation source, reaching a low price world record of 0.0234 USD/kWh in a 300 MWp installation in Saudi Arabia (Rossi & Schmela 2018). Furthermore, this type of energy source has very attractive characteristics under the point of view of today's environmental problems, being a clean energy, unlimited and easy accessible.

Portugal is in a privileged position to explore and implement innovative solutions related to renewable energies, in particular solar PV energy. At the Portuguese surface, arrives a yearly global average irradiation equivalent to 1800 kWh/m^2, reaching a peak value of more than 2100 kWh/m^2, considering a PV modules optimum exposure (Commission 2017). However, in order to reach its full potential, is needed a paradigm change in energy production and distribution, emerging a full-decentralized Power Grid (PG). In this way, it is possible to implement emerging concepts such as micro-grids and smart-grids. This new paradigm provides a range of new challenges and opportunities where multiple systems can collaborate and exchange energy with each other. An example of this is the introduction of Battery Energy Storage System (BESS) in order to store the surplus energy for later use (Barros et al. 2017; Chakraborty & Chattopadhyay 2016).

PV modules appear to be a very attractive solution for the energy needs of today. However, together with the PV modules it is necessary to install power converters in order to extract the maximum power from the PV modules and to interface the PG or the loads. Considering all the existing solutions, the microinverters are a very attractive solution to interface the PVs modules with the PG, being a modular solution and mitigating the problems caused by the shadow effect over the PV Modules (Barros et al. 2017; Rezaei et al. 2016; Humada et al. 2014). Additionally, with emerging concepts such as smart grids and microgrids, the integration of an Energy Storage System (ESS) has been raising interest in the investigation of new converter topologies capable of doing this interface and enable new functionalities such as bidirectional energy flow (Kouro et al. 2015; Karimi et al. 2017; Zeraati et al. 2018; Sikkabut et al. 2016; Merabet et al.

2017; Barros et al. 2017). However, some factors need to be taken into account in order to realize the economic viability of these systems with the existing BESS technologies.
Before the installation of the PV modules, it is necessary to deal with some legal procedures to get the mandatory authorizations to proceed. In the Portuguese case, where the installed PV capacity reached 474 MWp in the middle of 2018, the legislation is very restricted. In case the user wants to install the PV modules, whose installation is not connected to the PG (islanded applications), a prior communication of exploitation is sufficient. Considering the connection to the PG, for installations with peak power lower than 200 Wp, no authorization or notification is required. For peak powers between 200 Wp and 1500 Wp, it is necessary a prior communication of exploitation. However, the energy produced and not consumed by the user (surplus energy), follows to the PG without payback. To obtain a remuneration for the energy injected into the PG, beyond the notification, it is necessary a special registration, the installation of an additional energy meter and a full inspection of the installation. In this case, the remuneration of the energy sold is 90 % of the value resulting from the simple arithmetic mean of the closing prices of the Iberian Energy Market Operator (OMIE) for Portugal, for the month in question, in €/kWh (ENERGIA 2014). In 2018, the OMIE value was 0,058354 €/kWh, almost 3 times less than the home user acquisition cost. For powers above 1500 Wp, all the installations are subject to registration, reinspection and periodic inspection taxes. Considering these legal frameworks there is an interesting possibility consisting in installations up to 1500 Wp (tax free) with a local ESS to store the surplus energy. This concept enables the user to control the consumption or storage of the energy from PVs. This paper presents a complete study about the technological and economic viability of introducing BESS with PVs, considering different climatic localizations as well as different user consumption profiles.

METHODOLOGY

The main objective of this work consists in studying the technical and economic viability of use energy storage systems in PVs installations up to 1500 Wp. The idea beyond this concept consists in the storage of the surplus energy for later consumption. Figure 1 shows an example of consumption profile, showing not only the power consumed, P_{Cons}, along the day but also the power produced, P_{PV}, from solar PV installation. Figure 1 intends to explain the energy shift concept here presented, with the surplus of production stored in BESS for later consumption.

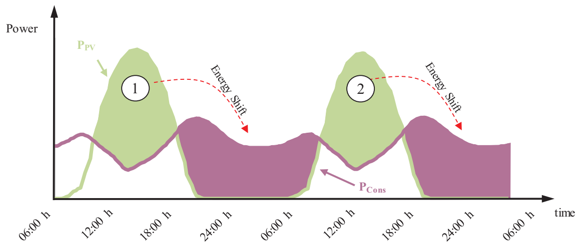

Figure 1: Example of the principle of operation of energy shift for a Battery Energy Storage System (BESS).

Once familiarized with this concept, from the technical point of view, it is necessary to confirm the existence of equipment that allows the implementation of this strategy. For this task, an exhaustive research was done considering the main manufacturers of equipment for PV installations to identify the best equipment for this purpose. Subsequently there are identified different sellers to confirm the equipment availability in Portugal and to obtain the reliable retail prices. From the economic point of view, it is necessary to study if the benefits of applying the BESS devices compensates for the additional cost of installation. In this way, different consumption profiles, different types of installations and different geographic locations were considered in order to perceive the viability of this solution.
In relation to consumption profiles, three different profiles were considered in this study, obtaining representative sample data of residential consumers available from the Portuguese transmission grid operator (REN). This data includes the 15 minutes average energy consumption for each day of the year, totaling 35 040 points for each profile. Thus, it becomes imperative to acquire the energy produced in periods of 15 minutes, with the intention of carrying out a more detailed study of the viability of the energy storage, increasing the sensibility of the perception of the energy produced as well as the time duration that it occurs. Taking this into account, the PV energy production information was obtained from the Photovoltaic Geographical Information System (PVGIS) portal for different geographic locations (Commission 2017). The data achieved from PVGIS was interpolated in order to get the 15 minutes average PV energy production for each day of the year. By combining the consumption with the production data it is possible to calculate, for each installation, the energy consumed directly by the user and the surplus energy that is injected into the PG. This data also enables the sizing of a BESS to be installed in each site to store the surplus energy to be later consumed by the user.
For the BESS dimensioning, it is necessary that the storage capacity is higher than the surplus energy for each day. So, for each day of the year it is necessary to compare the production and consummation profiles in order to determine the required storage capacity. The battery must be sized for the day with biggest surplus energy. In terms of graphical interpretation, the battery should be able to store the energy correspondent to the area 1, in green, in Figure 1.

CASE STUDY

For this study was considered a PV installation with 1 400 Wp, slightly below the maximum allowed in legislation of 1500 Wp. The PV panel can be installed in a fixed support with a given orientation or in a solar tracker system in order to maximize the sun exposure and, consequently, the energy production. Regarding the BESS, GEL batteries was selected since they are the most applied for this type of applications, having a life cycle superior to conventional lead-acid batteries. In fact there are different battery technologies that can be used in this application with better performance, however these new technologies are still not being marketed by vendors of PVs installations (Yang et al. 2018). Thus, considering this scenario, in order to make the study as realistic as possible GEL batteries were considered. For the battery pack, 12 V GEL lead-acid batteries with capacity of 120 Ah were considered. The manufacturer recommends maximum deep of discharge, p, of 30 % in order to preserve the state of health of the batteries, totaling 1 800 cycles (University 2019). In other words, considering a cycle per day over a year, the battery has a life time of approximately 5 years. Taking this into account, a budget was made for the main constituents of the solar photovoltaic installation considering the different configurations. The prices of the installation main components presented in Table 1 where obtained, in January of 2019, from different PV equipment sellers in Portugal, being presented the best solutions with the smaller sale price to the public.

Table 1: Prices and characteristics of the installation main components (January of 2019).

	Characteristics	Unit Price	Quantity	Total Price
PV module	280 W	147 €	5	735 €
Solar tracker	-	2 310 €	1	2 310 €
Fixed support	-	327 €	1	327 €
Main inverter	1500 W	735 €	1	719.74 €
Batteries converter	-	466.77 €	1	466.77 €
Batteries	120 Ah; 12 V	224.99 €	x	224.99 x €

For this case of study, three different users profiles where considered. Figure 2 shows the evolution of energy consumption for each one of these profiles, as well as the energy produced by an installation with solar tracker ($E_{PV\_Tracker}$) and without (E_{PV_Fixed}), located in Guimarães along the year, since it corresponds to the city with lower annual energy production.

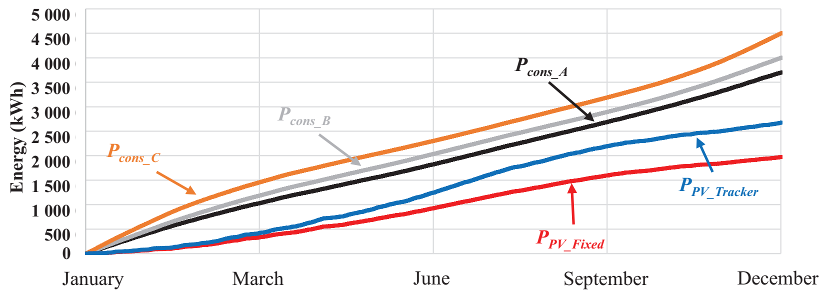

Figure 2: Evolution of the energy production with ($E_{PV\_Tracker}$) and without (E_{PV_Fixed}) solar tracker and the energy consumption considering three different users profiles in Guimarães during a year.

For this case study, six different geographic locations were considered, giving good representativeness of the country regions. For each site, it was considered a fixed installation, where it was taken into consideration the best slope and azimuth for the localization, and also an installation with solar tracking system. In Table 2 are presented de sites location and the predicted energy production for a 1400 Wp PV installation with and without solar tracker system.

Table 2: Prediction of energy production with a PV solar installation of 1400 Wp in different geographic locations [information taken from (Commission 2017)].

Cities	Coordinates	Elevation (m)	Without Solar Tracker			With Solar Tracker
			Slope (◦)	Azimuth (◦)	kWh	kWh
Guimarães	41.452; -8.291	200	35	4	2 010	2 730
Bragança	41.793; -6.752	808	35	0	2 120	2 940
Oporto	41.169; -8.684	9	36	6	2 130	2 890
Coimbra	40.222; -8.460	25	35	5	2 090	2 840
Lisbon	38.716; -9.187	136	33	5	2 220	3 070
Beja	38.012; -7.846	210	33	0	2 270	3 140
Faro	37.050; -7.927	18	33	3	2 420	3 370

Analyzing the data obtained, it can be verified that there is a variation of the energy production with the geographic location, with a tendency to increase as it approaches the south of the country. The elevation also influences the energy production. In addition, it can be seen that with a solar tracker, the energy production increases up to 39 %.
In order to show in more detail the energy production and consumption profiles, the information related to four different weeks of the year is presented in Figure 3. The selected weeks are spaced from three months intervals to get a good overview of the different climatic conditions along the year. As it is possible to see, the energy production and consumption changes over the day, verifying that at hours of higher production the energy consumption is usually low. This phenomenon may justify the adoption of BESS technology to prevent that during these time intervals the energy surplus flows to PG without any payback. In addition, it can be seen that energy production with solar tracker is significantly higher.

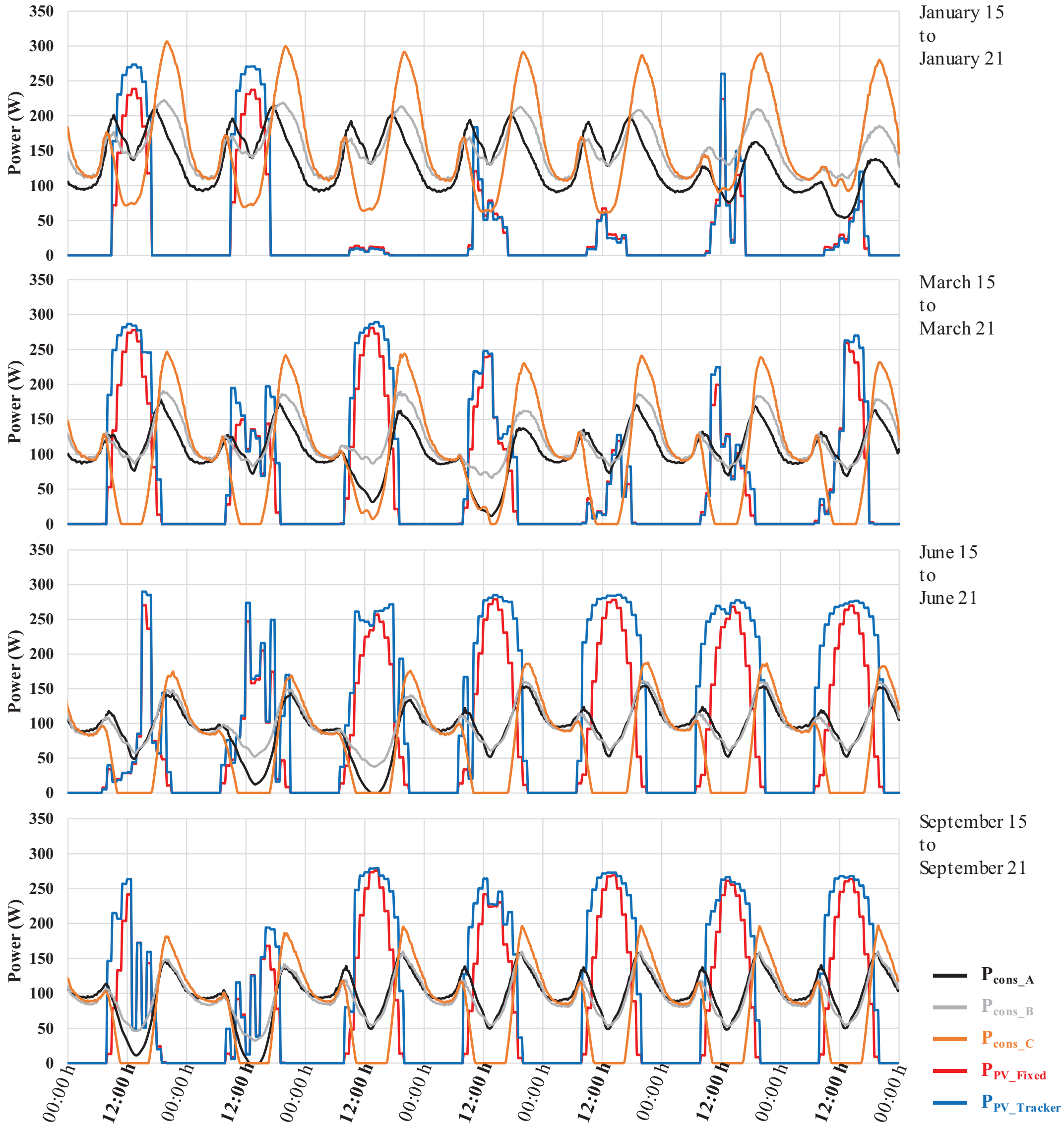

Figure 3: Representative graph of the consumed power (P_{Cons}) by a given consumer, and the evolution of the produced power with fixed support (P_{PV_Fixed}) and with solar tracker ($P_{PV\_Tracker}$) in different periods of the year.

Once all the necessary data were collected, it was processed and consequently analyzed in order to obtain the viability of the different types of PV solar installation, with the main focus being the system with the BESS. The final results are presented in Figure 4 which is representative of the evolution of the investment and the financial return (savings) during periods of 5 years up to 20 years, for each type of installation, consumption profile and geographical location. All the procedures explained below are based on the case of user "A" with fixed PV solar system located in Guimarães.
Thus, the first step was to determine the surplus energy for each day in order to dimension the BESS. For the case of the user "A" located in Guimarães and without solar tracker, the maximum surplus energy was calculated as 7 616 Wh for the 1 of May, requiring 18 batteries to store this energy. After that, it was possible to calculate the total annual surplus

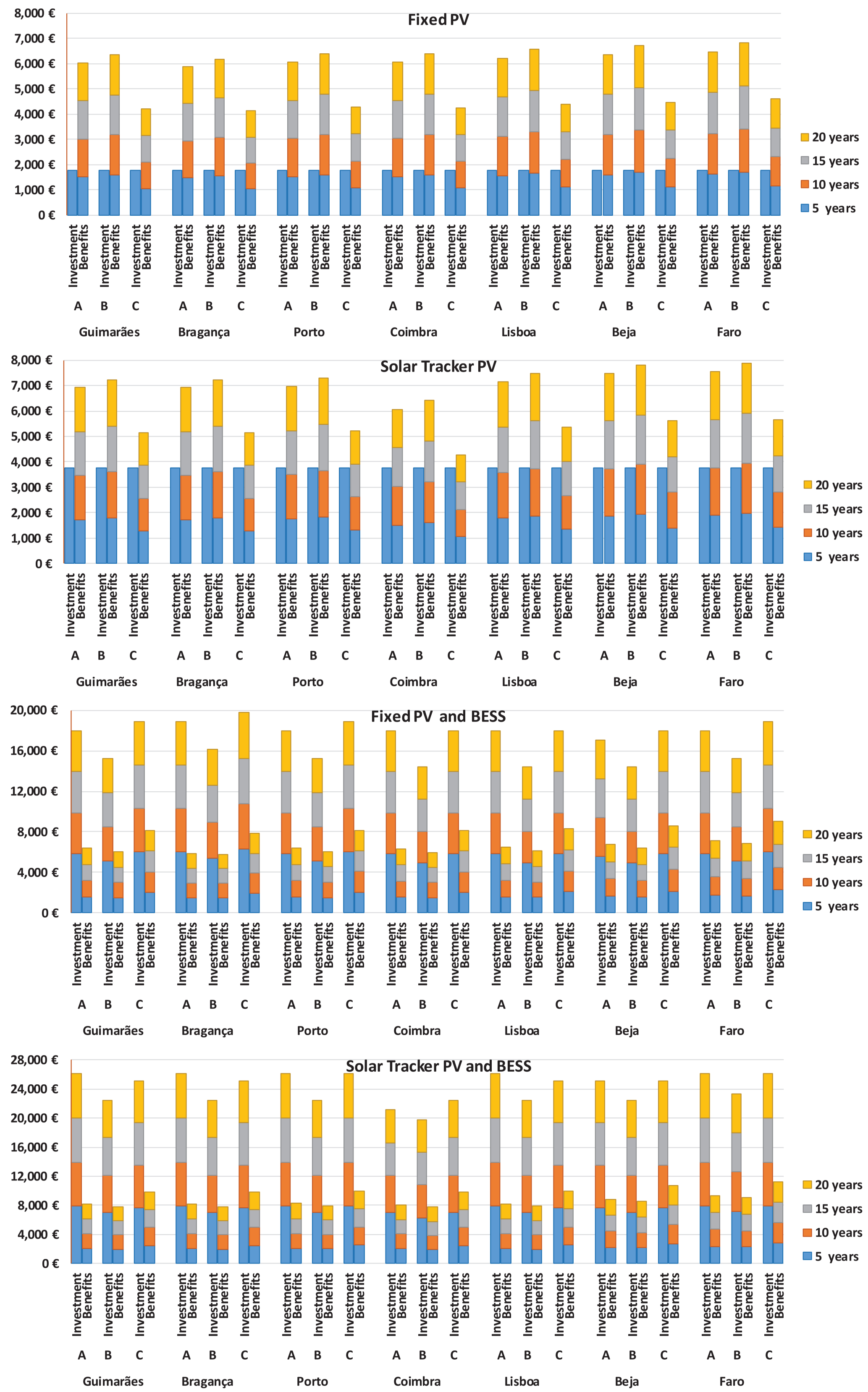

Figure 4: Graph representing the evolution of investment and economic benefits for periods of 5, 10, 15 and 20 years, for each consumption profile (A, B and C), in different geographic locations and for different types of installations, such as: (a) solar PV in fixed support; (b) solar PV with solar tracker; (c) solar PV in fixed support and BESS; (d) solar PV with solar tracker and BESS.

energy (1 030 kWh), the annual energy consumed directly from the PVs (944 kW) and the energy consumed from the PG (1 729 kW). Subsequently, these values where multiplied by the energy price in order to obtain the associated costs and benefits. If the user "A" did not have a BESS and had to buy energy in the hours of lesser production, it would have to spend 301.65 €. On the other hand, in the hours where the energy produced by the PV panel is locally consumed, allows the user to save 496.01 €. Once the values of the energy costs were obtained, it is necessary to calculate the cost of the equipment. The cost is equal for each installation type with the exception of the number of batteries necessary to store the energy surplus in each site. For the exemplary case, the user spends 5 831.56 € with the fixed PV system and BESS, saving 1 589.35 € after 5 years. After this period, taking into account the battery life time, the user would have to buy a new battery pack for BESS, spending more 4 049.82 €. Considering this values, the investment is always higher than the benefits, making impossible to obtain financial profits from this system.
In general, the benefits from solar system without BESS exceed the investment at the end of 6.5 years (on average), in the case of a fixed PV system, and at the end of 11.9 years (on average), in the case of a PV system with solar tracker. On the other hand, in the case of the PV solar system with a BESS, the investment is always higher than the benefits. In this way, the investment in BESS considering the actual technology and prices is not recommendable. A good alternative to improve the benefits from solar PV systems consists in shifting at the maximum the consumption to the hours with more PV production.

CONCLUSIONS AND FURTHER RESEARCH

This paper presents a study on the technological and economic viability of introducing Battery Energy Storage Systems (BESS) together with solar photovoltaic (PV) installations up to 1500 Wp. In order to obtain more credible results and to perceive the variables with greater influence, different geographic locations and consumption profiles were considered. According to the obtained results, it could be seen that the installation at the south of Portugal produces more energy, enhancing the possible benefits. The obtained results also shows that, in the best configuration, the benefits from the PV installations exceed the initial investment after 6.5 years, on average, making it an interesting investment. As the most important aspect of this study, it is found that taking advantage of surplus production for later use based on battery energy storage is not economically advantageous. Taking into account these results, it can be concluded that the investment in Battery Energy Storage Systems (BESS) for solar PV applications up to 1500 Wp, in Portugal, is not feasible, considering the actual battery technologies, battery prices and electrical energy prices. This scenario can be very different in a near future as consequence of the improvements in the battery technologies. As further research, it would be interesting to consider an optimization of the PV installation maximum power, according to the consumption profile, in order to maximize the benefits.

ACKNOWLEDGEMENTS

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2019. This work is financed by the ERDF – COMPETE 2020 Programme, and FCT within project SAICTPAC/0004/2015-POCI-01-0145-FEDER-016434 and FCT within project PTDC/EEI-EEE/28813/2017. Mr. Luis A. M. Barros is supported by the doctoral scholarship PD/BD/143006/2018 granted by the Portuguese FCT agency.

REFERENCES

Barros, L.A. et al., 2017. New multifunctional push-pull converter operating with MPPT and integrated energy storage system for PV micro-inverter applications. In *IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society*. pp. 7807–7812.

Chakraborty, S. & Chattopadhyay, S., 2016. A multi-port, isolated PV microinverter with low decoupling capacitance & integrated battery charger. In *Energy Conversion Congress and Exposition (ECCE), 2016 IEEE*. pp. 1–8.

Commission,E.,2017. PV Geographical Information System. Available at:http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP [Accessed 1–3, 2019].

ENERGIA, M.D.T.E., 2014. Decreto-Lei n.º 153/2014 de 20 de outubro. *Diário da República*, 1.ª série(— N.º 202), pp.5298–5311.

Humada, A.M. et al., 2014. Modeling of photovoltaic solar array under different levels of partial shadow conditions. In *Power Electronics and Motion Control Conference and Exposition (PEMC), 2014 16th International*. pp. 461–465.

Karimi, Y. et al., 2017. Decentralized method for load sharing and power management in a PV/battery hybrid source islanded microgrid. *IEEE Transactions on Power Electronics*, 32(5), pp.3525–3535.

Kouro, S. et al., 2015. Grid-connected photovoltaic systems: An overview of recent research and emerging PV converter technology. *IEEE Industrial Electronics Magazine*, 9(1), pp.47–61.

Merabet, A. et al., 2017. Energy management and control system for laboratory scale microgrid based wind-PV-battery. *IEEE Transactions on Sustainable Energy*, 8(1), pp.145–154.

Rezaei, M.A., Lee, K.-J. & Huang, A.Q., 2016. A high-efficiency flyback micro-inverter with a new adaptive snubber for photovoltaic applications. *IEEE Transactions on Power Electronics*, 31(1), pp.318–327.

Rossi, R. & Schmela, M., 2018. Global market outlook for solar power 2018-2022. *SolarPower Europe*.

Sikkabut, S. et al., 2016. Control of high-energy high-power densities storage devices by Li-ion battery and supercapacitor for fuel cell/photovoltaic hybrid power plant for autonomous system applications. *IEEE Trans. on Ind. Applications*, 52(5), pp.4395–4407.

University, B., 2019. Battery University. Available at: https://batteryuniversity.com/ [Accessed 1–3, 2019].

Yang, Y. et al., 2018. Integrated size and energy management design of battery storage to enhance grid integration of large-scale PV power plants. *IEEE Transactions on industrial electronics*, 65(1), pp.394–402.

Zeraati, M., Golshan, M.E.H. & Guerrero, J.M., 2018. Distributed control of battery energy storage systems for voltage regulation in distribution networks with high PV penetration. *IEEE Transactions on Smart Grid*, 9(4), pp.3582–3593.