20th International Conference on Renewable Energies and Power Quality (ICREPQ'22)
Vigo (Spain), 27th to 29th July 2022
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.20, September 2022

Local reactive power management using solar pumping in isolated electrical systems

B. González-Díaz[1], D. Rodríguez-Urrego[1], J. F. Gómez-González[1], O. García-Afonso[1], R. Guerrero-Lemus[2] and J. A. Méndez-Pérez[3]

[1] Departamento de Ingeniería Industrial, Escuela Superior de Ingeniería y Tecnología, Universidad de La Laguna (ULL), 38200, La Laguna, Tenerife, Spain.
Phone: +0034 922 316502 EXT 6252, e-mail: bgdiaz@ull.edu.es
[2] Departamento de Física, Facultad de Ciencias, Universidad de La Laguna (ULL), 38200, La Laguna, Tenerife, Spain.
[3] Departamento de Ingeniería Informática y de Sistemas, Escuela Superior de Ingeniería y Tecnología, Universidad de La Laguna (ULL), 38200, La Laguna, Tenerife, Spain.

Abstract. In this work, a new analysis of the solar pumping as a source to provide secondary regulation and local reactive management strategies into low-voltage grid, is addressed. Based on real generation data and the capabilities of a commercial solar inverter, the control and management of the different work modes of the power electronics is proposed to analyse the viability of the use of solar pumping systems to be active agents in the flexibility market. Finally, some regulatory issues are presented to evaluate the feasibility of this proposal.

Keywords. Solar power, water-energy nexus, reactive power management.

1. Introduction

The current world population is estimated in more than 7.2 billion, but with the exponential increase it is expected to raise by 2.2 billion over the next 30 years [1]. For this reason, the demand for the three natural building blocks, cropland, freshwater and fossil fuels, has tripled in the last 50 years and will continue to increase by 2050. Consequently, increased exploitation of primary energy and water resources to meet the basic needs of today's communities is not sufficient. Approximately 66% of the population does not have these means to live, which is why there is currently a high deficit in food, energy and water security worldwide [2], representing a high risk in terms of population sustainability.
The supply of fresh water is related to the availability of energy use in pumping from water wells, desalination, reclaimed water, wastewater treatment, transportation, and distribution, which are energy-intensive processes [3].
In the case of isolated territories, the dependence of external resources to obtain energy and water is critical due to the availability of internal resources [4]. Indeed energy-water systems must be analysed and optimized together [5] try to reach an integral solution to provide the adequate services. Solar pumping systems can plan a central role on it [6], [7].
Incorporation of solar distributed systems to obtain well water, could apport new technical solutions to adequate and stabilize the electrical grid [8]–[10] by means of the reactive power available at the low-voltage grid level [11].

In this work, a commercial photovoltaic installation of 5kWp, with a hybrid inverter able to work in grid connected or islanded modes has been used to power a water pump. Using the obtained real data, the control loops and reactive power capabilities from the inverter have been simulated and analysed to use the whole system to provide active and reactive power as demanded by the grid requirements.

2. Local reactive power

The introduction of power electronics in networks has brought a large number of new issues that have to be managed to improve the grid stability and to increase the share of renewable energy injected.
Moreover, the incorporation of power electronic devices has driven new challenges to regarding power quality, such as problems in a microgrid, voltage harmonics, voltage swells, voltage unbalance, current harmonics, etc [12].
Moreover, the actual power electronic devices, adapted to the Regulation UE 2016/631 [13] have the capability to manage and dispatch reactive power, without any internal modification. The reactive power management has been revelated as very attractive approach to reduce power losses and costs [14], and therefore, increase the grid stability inside of the systems.
Among the different reported strategies, the adaptation of the power factor according to the active energy injected (cos φ (P)) and the management of the reactive energy as a function of the local voltage of the network (Q(V)) have arisen as the most feasible strategy for the smart inverters. In both cases, the photovoltaic (PV) inverter is operating inside of the established voltage limits when an outsider reference voltage value from the grid is detected. In this moment, the inverter is capable of injecting reactive power to adjust the voltage at the connection

point to the network. Nowadays, commercial smart inverters present this capability and can vary its operating point in order to introduce reactive power to the grid. However, the reactive power is a function of the generated active power (Figure 1), limiting its operation [15]. From the technical point of view, the local management of the reactive power can improve the grid operation with an adjustment of the voltage level in a line, when the appropriate control loop and signal are sent to the smart inverters [16].

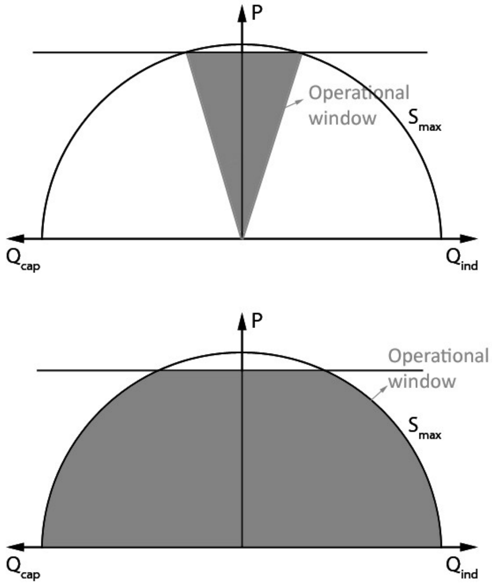

Fig.1. Operational window of cosφ (P) control (up) and Q(V) control (down).

3. Photovoltaic installation

Data obtained from a 5kWp photovoltaic installation coupled to a water pump, located in San Cristóbal de La Laguna, Tenerife, Spain (Figure 2), have been used to analyse the solar pump conditions and requirements.

Fig.2. Aerial view of the photovoltaic installation.

The system is composed by 15 polycristalline solar modules of 335 Wp provided by ZNSHINE Solar, connected by two strings to X3-Hybrid solar inverter from Solax Power. A X3 EPS Box is used to provide an automated changeover solution for the inverter's EPS off-grid output function. A DT/SSU666 from Chint Electrics is used for monitoring the grid absorbed energy and a CVM-A1500 spectra analyser from Circutor is used to analyse the grid values. Due to the contactors inside of an EPS box, the system can be used either connected to the grid or in islanded mode, depending on the operation needs. A frequency variator model S100 from LS is used on a 1.5CV electrical motor jointed to a servo brake to simulate different pumping configurations.

4. Simulation model

A Simulink® model based on a previous reported work [17] has been developed to simulate the operation modes of the PV system coupled with the water pump.

The model is composed by four subsystems: (i) the PV solar field, where the 15 solar panels and the array configuration has been modelled, and the inputs for the irradiance and temperature are introduced; (ii) PV inverter, adapted from the described model in [18], based on 3 IGBTs bridge. The inverter is linked to low-frequency filters to avoid the harmonics produced by the high frequency commutation [19], to habilitate frequency-reactive power controller. The inverter has a maximum power point tracking (MPPT) system, based on ΔP/ΔV strategy; (iii) a water pump connected with a frequency variator and constant torque control; (iv) a grid connection thought a 0.4/20 kV YΔ transformer. The Total Harmonic Distortion (THM) of the system has been limited to 15%. The model and the input control parameters has been adjusted and validated with real operation data available.

Three different scenarios have been evaluated: (i) the usual operation regime, where the solar pumping system is working is working isolated from the grid f; (ii) hybrid configuration, with the capability to absorb energy from the solar field and from the grid, with the active power surplus injection to the grid; and (iii) adapted system with a new control entry to support Q demand from the grid to adjust the voltage level consigned by the grid. In all cases, the irradiance profile has been used to evaluate the system response. The simulation model has been run on a computer with a computer with Intel (R) Core (TM) i7-10700 CPU @ 2.90GHz and 32GB of RAM.

5. Results and discussion

In order to check the accuracy of the PV array model, a simulation of the PV production has been carried out and compared with the experimental results.

Figure 3 shows the simulated intensity-voltage and power-voltage curves of the solar array, under different irradiation levels. The obtained results are in concordance with the real measured data, with an error below 3% of the PV production. This discrepancy between the simulated results and the data obtained might be attributed to losses in the cables from the PV array to the inverter, where the data is collected.

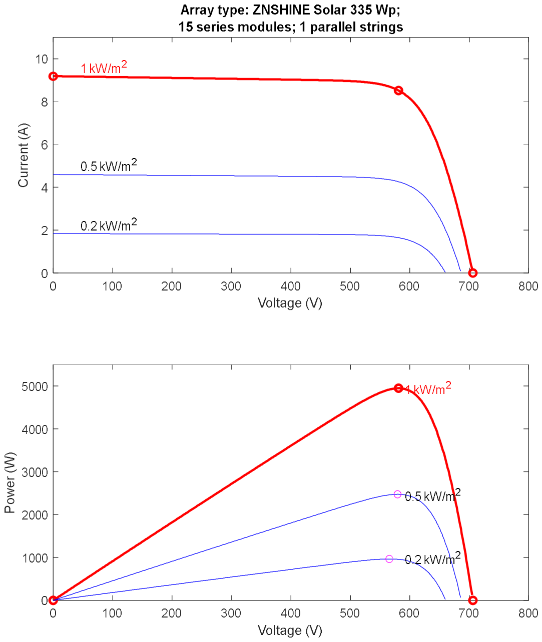

Fig.3. IV curves (up) and power-voltage curves (down) simulated under different irradiation levels. The red curves are using an irradiation level of 1000W/m² and the blue curves are with irradiation of 500 and 200 W/m2.

A. Solar pump performance islanded from the grid.

To understand the different modes of the solar pumping system with its components, a simulation of the operating conditions has been carried out using a radiation profile. This profile presents a rapid drop from the optimum values and a rapid rise to the initial levels, in order to simulate a rapid ramp due to the presence of clouds. The irradiation profile with and PV power in DC are shown in Figure 4.

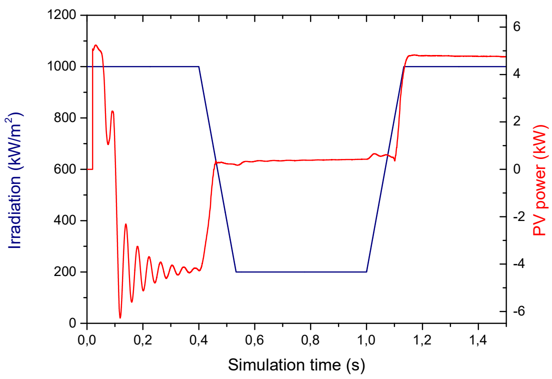

Fig.4. Irradiation profile (blue) and DC PV power (red) of the coupled solar pump system islanded from the grid.

A transient power generation due to the frequency variator and torque control is observed in the first steps of the simulation, in accordance with the expected behaviour. These results are interpreted as the voltage and current controllers included in the MPPT unit of the inverter are able to optimize the PV production, according to the irradiation profile. During this period, a peak of 8% THM has been obtained.
In this case, the inverter current is directly injected to the frequency variator (Figure 5), which control pump motor torque adjusted to a constant mechanical load regime. A reduction of the current is detected during the irradiation drop period.

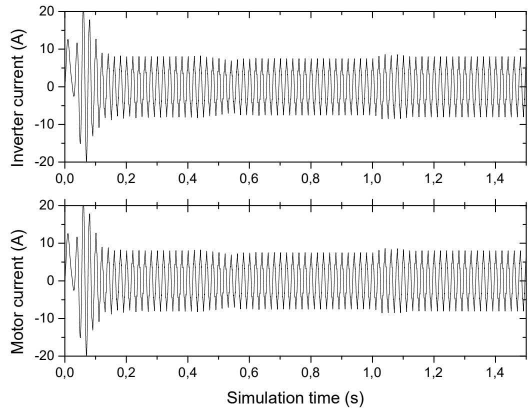

Fig.5. Inverter and motor current during the simulation time.

B. Solar pump performance in hybrid mode with active power injection to the grid.

In this configuration, the pump operation is prioritized, regardless of solar resource availability. Therefore, to maintain the programmed torque level, the pump is primarily powered by the photovoltaic system, but in the absence of solar resource, the system can draw power from the grid.
In Figure 6, the irradiation profile and PV power in DC are shown when the system is connected to the grid.

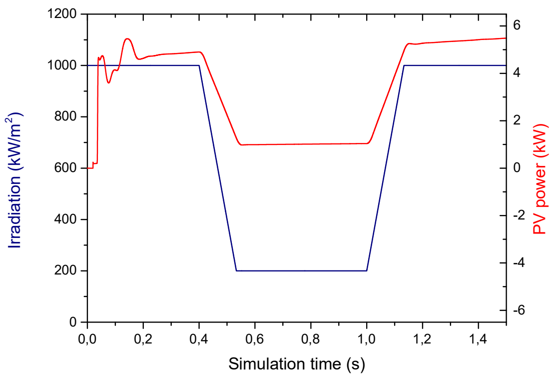

Fig.6. Irradiation profile (blue) and DC PV power (red) of the solar pump connected to the grid with active power injection.

In concordance to the previous case, a transient phase due to the pump has been detected. However, in contrast to the previous configuration (Figure 3), the transient period is partially reduced, mainly due to the absorption of the grid current during the starting time. After the irradiation recovers its initial level, the MPPT system continue increasing the power to reach the required level.
An analysis of the inverter, motor and grid single phase currents are shown in Figure 7. During the first steps, the inverter feeds the pump, at the same time that additional current is demanded from the grid. After this period, once the pump reaches nominal torque conditions, the surplus current is directly injected to the grid. That is to say solar pump operation mode is not affected by the reduction of the irradiation.

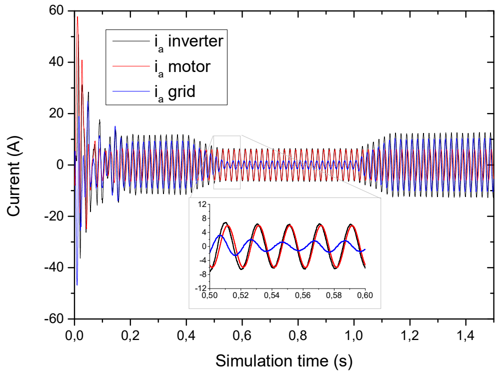

Fig.7. Inverter, motor and grid current during the simulation time for the solar pump connected to the grid with active power injection.

Figure 8 includes the THD over the simulated period. After the initialization stage of0.2s, THD peaks are observed related to the pump rotation start ramp, where the system is reaching the nominal conditions. The other two peaks' series are intrinsically related with the reduction and the following increase of the irradiance values. After returning to the stable irradiation regime, the THD decrease below 1% distortion.

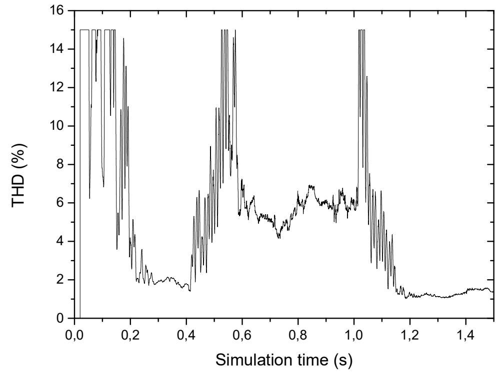

Fig.8. THD evolution during the simulation time for the P injection into the grid.

C. Demand of inductive reactive power

As it has been mentioned previously smart inverters can perform the Q (V) strategy in a broad band operation. In this case, the inverter can run with a power factor from 0.8 inductive to 0.8 capacitive. To analyse the system response, these two limit cases have been implemented and simulated.

In figure 9, the irradiation profile and the DC power for the maximum available inductive Q are shown. Under this strategy, the characteristic transient due to the pump is reduced.

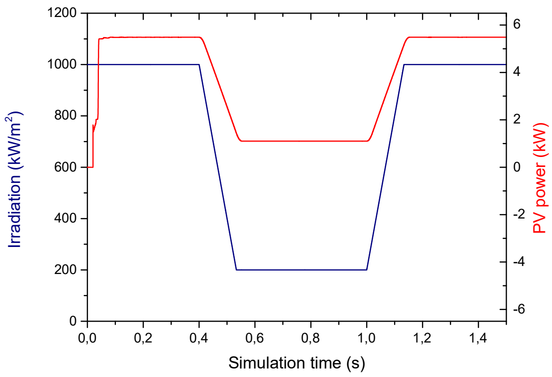

Fig.9. Irradiation profile (blue) and DC PV power (red) of the solar pump connected to the grid with active power injection and inductive reactive demand.

To evaluate this transient shortening, the currents by phase from the inverter, motor and grid are compared in Figure 10. During the transient, as the grid is demanding inductive Q, the pump nominal conditions are reached in a shorter time frame. However, the waveform detected implies that the current is near to the magnetization border in the hysteresis cycle.

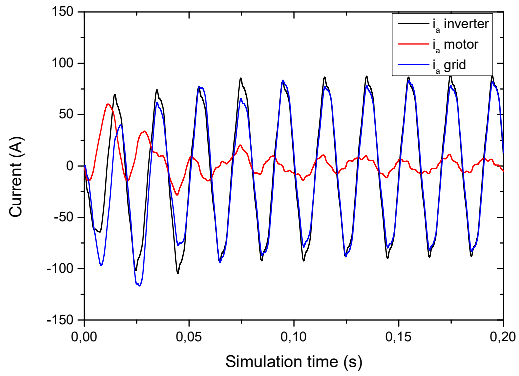

Fig.10. Inverter, motor and grid current during the simulation time for the solar pump connected to the grid with active power injection and inductive Q demanded by the grid.

However, the motor reaches the nominal rotation speed and the demanded torque. The THD in this operation mode (Figure 11) reveals a fast reduction after the pump start-up. There is not THD due to the variation of the irradiance levels. This result is interpreted as the demanded amount of reactive power favours the development of proportional integrators within the MPPT algorithm.

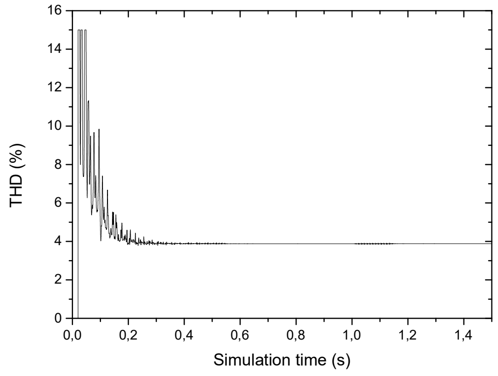

Fig.11. THD during the simulation time of the grid connected system with P injection and inductive Q demanded by the grid.

D. Demand of capacitive reactive power

Figure 12 shows the irradiation profile and the DC power for the maximum available capacitive reactive. In this strategy, the combination between the frequency variation, the proportional integrators from the MPPT algorithm and the capacitive reactive demand from the grid produces a non-convergence of the control system from the inverter and it is not possible to supply the adequate power to the pump, producing a malfunction.

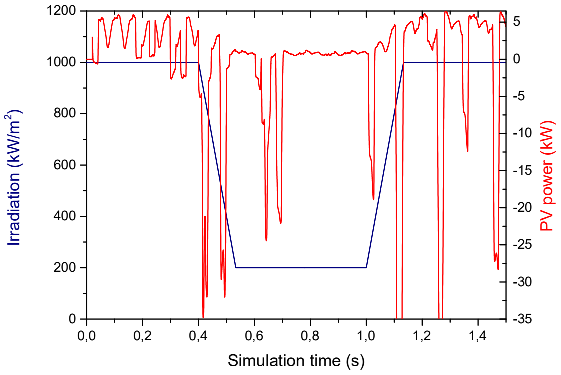

Fig.12. Irradiation profile (blue) and DC PV power (red) of the solar pump connected to the grid with active power injection and inductive capacitive demand.

The inverter, motor and grid currents per phase (Figure 13) analysis reveal that the demanded Q produces a failure in the pump operation and the current injection do not meet the grid requirements to an adequate active power injection. The THD shown in Figure 14 reinforce the interpretation that the inverter not being able to follow the Q(V) strategy.

This result points out the need to a multi-agent strategy to provide the adequate requirements to the solar pump, at the same time that the reactive power demand from the grid is fulfilled [20]. According to the literature, the introduction of a battery and the adequate management of the frequency control could assist to provide the adequate power to the solar pump without compromising the grid requirements [19].

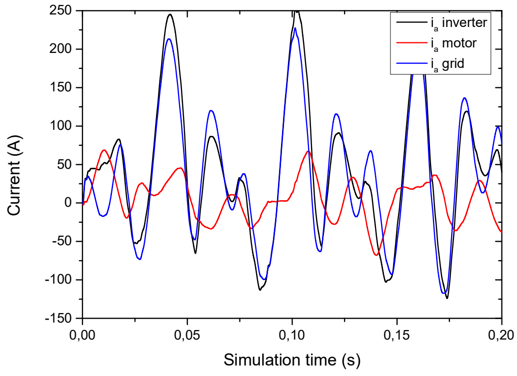

Fig.13. Inverter, motor and grid current during the simulation time of the grid connected system with P injection and capacitive Q demanded by the grid.

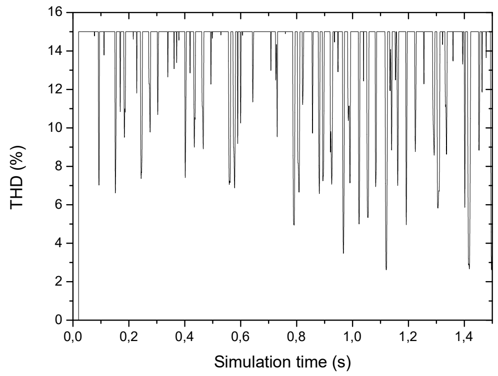

Fig.14. THD during the simulation time of the grid connected system with P injection and capacitive Q demanded by the grid.

E. Regulatory challenges

Connected solar pumps are arising as an interesting alternative to obtain water in islanded systems, from a sustainable perspective of the water-energy nexus [3]. The solar pump working in parallel to the grid can provide active power without compromising the pump working conditions. In contrast, additional technical questions must be addressed to demand reactive power in safety operational conditions.

Moreover, from the regulatory point of view, new challenged has come up to develop the adequate framework to habilitate the secondary regulation from the solar pump systems, inside of the small grids and islanded systems, improving the sustainability of the territories.

6. Conclusions

In this work, different operation modes of a solar pump system have been modelled and compared against the obtained values from a real facility

Islanded mode and active power injection of the energy excess of the system into the grid are completely feasible with the control strategies from the commercial inverter.

For the Q(V) strategy, when capacitive Q is demanded from the grid to adjust the voltage levels, the results reveal the presence of the pump is interfering with the control loops, being impossible to establish an effective system to keep the pump running and injecting the reactive power required by the grid, without any additional strategy or devices.

Acknowledgement

This research was funded by the CajaCanarias Foundation (grant number 2019SP25).

References

[1] United Nations, "Population in the World," 2022. [Online]. Available: https://www.un.org/es/global-issues/population. [Accessed: 20-Feb-2022].

[2] D. Pimentel and M. Burgess, "World Human Population Problems," in *Encyclopedia of the Anthropocene*, D. A. Dellasala and M. I. Goldstein, Eds. Oxford: Elsevier, 2018, pp. 313–317.

[3] D. Rodríguez-Urrego, D. Cañadillas-Ramallo, B. González-Díaz, and R. Guerrero-Lemus, "Analysis of the Water-Energy Nexus Applied to an Insular System: Case Study of Tenerife," *Sustainability*, vol. 14, no. 3, p. 1653, Jan. 2022.

[4] A. Hafeez *et al.*, "Solar powered decentralized water systems: A cleaner solution of the industrial wastewater treatment and clean drinking water supply challenges," *J. Clean. Prod.*, vol. 289, 2021.

[5] P. Cabrera, J. A. Carta, H. Lund, and J. Z. Thellufsen, "Large-scale optimal integration of wind and solar photovoltaic power in water-energy systems on islands," *Energy Convers. Manag.*, vol. 235, 2021.

[6] J. Vishnupriyan, P. Partheeban, A. Dhanasekaran, and M. Shiva, "Materials Today : Proceedings Analysis of tilt angle variation in solar photovoltaic water pumping system," *Mater. Today Proc.*, no. xxxx, 2022.

[7] S. Verma *et al.*, "Solar PV powered water pumping system - A review," *Mater. Today Proc.*, vol. 46, pp. 5601–5606, 2020.

[8] N. Habib Khan, R. Jamal, M. Ebeed, S. Kamel, H. Zeinoddini-Meymand, and H. M. Zawbaa, "Adopting Scenario-Based approach to solve optimal reactive power Dispatch problem with integration of wind and solar energy using improved Marine predator algorithm," *Ain Shams Eng. J.*, vol. 13, no. 5, p. 101726, 2022.

[9] D. Cañadillas, H. Valizadeh, J. Kleissl, B. González-Díaz, and R. Guerrero-Lemus, "EDA-based optimized global control for PV inverters in distribution grids," *IET Renew. Power Gener.*, no. December 2019, pp. 382–396, 2021.

[10] S. Jashfar and S. Esmaeili, "Volt/var/THD control in distribution networks considering reactive power capability of solar energy conversion," *Int. J. Electr. Power Energy Syst.*, vol. 60, pp. 221–233, 2014.

[11] B. González-Díaz, J. F. Gómez-González, D. Cañadillas-Ramallo, J. A. Méndez-Pérez, and R. Guerrero-Lemus, "Reactive power management to enhance solar energy penetration in small grids: Technical and framework approaches," *Renew. Energy Power Qual. J.*, vol. 17, no. 17, pp. 583–588, 2019.

[12] R. Passey, T. Spooner, I. MacGill, M. Watt, and K. Syngellakis, "The potential impacts of grid-connected distributed generation and how to address them: A review of technical and non-technical factors," *Energy Policy*, vol. 39, no. 10, pp. 6280–6290, 2011.

[13] Comisión Europea, "Reglamento (UE) 2016/631 de la Comisión de 14 de abril de 2016 que establece un código de red sobre requisitos de conexión de generadores a la red," *D. Of. la Unión Eur.*, no. 112, 27 de abril, 2016.

[14] S. X. Chen, Y. S. F. Eddy, H. B. Gooi, M. Q. Wang, and S. F. Lu, "A centralized reactive power compensation system for LV distribution networks," *IEEE Trans. Power Syst.*, vol. 30, no. 1, pp. 274–284, 2015.

[15] S. Souri, H. M. Shourkaei, S. Soleymani, and B. Mozafari, "Flexible reactive power management using PV inverter overrating capabilities and fixed capacitor," *Electr. Power Syst. Res.*, vol. 209, no. March, p. 107927, 2022.

[16] V. Calderaro, G. Conio, V. Galdi, and A. Piccolo, "Reactive power control for improving voltage profiles: A comparison between two decentralized approaches," *Electr. Power Syst. Res.*, vol. 83, no. 1, pp. 247–254, 2012.

[17] S. Keawthai and S. Po-Ngam, "Simplified active power and reactive power control with MPPT and islanding detection for three-phase grid-connected photovoltaic inverters," *ECTI-CON 2015 - 2015 12th Int. Conf. Electr. Eng. Comput. Telecommun. Inf. Technol.*, 2015.

[18] N. Bhujel, "Grid connected PV inverter," *MATLAB Central File Exchange*, 2022. [Online]. Available: https://es.mathworks.com/matlabcentral/fileexchange/66600-grid-connected-pv-inverter. [Accessed: 10-Jan-2022].

[19] S. Aminzadeh, M. Tarafdar Hagh, and H. Seyedi, "Reactive power management for microgrid frequency control," *Int. J. Electr. Power Energy Syst.*, vol. 120, no. March, p. 105959, 2020.

[20] A. M. Abdulmohsen and W. A. Omran, "Active/reactive power management in islanded microgrids via multi-agent systems," *Int. J. Electr. Power Energy Syst.*, vol. 135, no. August 2021, p. 107551, 2022.