Study of Ancillary Service of Island Operation Capability in a Deregulated Market: a system dynamics approach

Juan David Marín Jiménez
Department of Electrical, Elecrtonic and Computer Engineering
Universidad Nacional de Colombia
Manizales, Caldas
Email: jdmarinj@unal.edu.co

Josep M. Guerrero
Senior Member, IEEE
Institut for Energiteknik
Aalborg University
Email:joz@et.aau.dk

Sandra Ximena Carvajal Quintero
Member, IEEE
Department of Electrical, Elecrtonic and Computer Engineering
Universidad Nacional de Colombia
Manizales, Caldas
Email: sxcarvajalq@unal.edu.co

***Abstract*—Island Operation Capability is a future ancillary service that would allow safely operate a smart grid in isolation of the interconnected grid in order to maintain electrical supply following a partial or complete blackout. This paper discusses a payment proposal for Island Operation Capability in the Colombian electricity sector. It presents the technical issues of the service and the economical proposal with based on welfare of stakeholders into Colombian electrical power system.**

***Index Terms*—Ancillary Services, Island Operation Capability, Microgrids, System Dynamics.**

I. Introduction

THE blackouts around the world raised fundamental questions about the appropriateness of the rules, regulations and system operating practices governing electrical system security. Management of system security needs to keep improving to maintain reliable electricity services in more dynamic operating environment. System operating practices need to give greater emphasis to system- wide preparation to support flexible, integrated real-time system management [1]. Real- time coordination, communication and information exchange, particularly within integrated transmission and distribution systems spanning multiple control areas, can and must be improved [2]. Recently, similar major power system disturbances have occurred in USA, Italy, Germany and UK interconnections that in terms of intensity, extent and duration, have caused multi-billion USD damages to the utilities and their customers.

In 1995, Federal Energy Regulatory Commission (FERC) of USA defined ancillary services as “those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those areas to maintain reliable operations of the interconnection system.” [3]. At the present, ancillary services typically include: AGC/Regulation, Spinning/Operating Reserve, Voltage/Reactive Power support and Black-start [3].

Currently, these services are offered by large plants centrally dispatched generation, without possibility of being offered by Distributed Energy Resources (DER) [4]. Island Operation Capability (IOC) is not a new service from the conceptual point of view, since in the last decade, several authors and businesses around the world have advanced on recognize the need for Island Operation capabilities but might not be able to determine its availability or current performance [5]. However, it is in the currently where consolidation is projected by the new paradigm of operation of active distribution systems on smart grid [6].

The service IOC payment can be paid by availability, operation or both [7]. The restoration process normally account with plans that include the general premises and additionally mind some of the possible scenarios of restoration, but in most cases have no strict applicability in practice by the same dynamic systems and random failures and events that may occur in a power system [8].

This study is an attempt to evaluate a global welfare to implement Island Operation Capability for the Colombian electrical power system, using the system dynamics methodology.

II. Minigrids and Island Operation Capability

A. Minigrids

A Minigrid (mG) also referred as MicroGrid, is defined as a fraction of the Electric Power Systems (EPS) which consists of the following characteristics: (i) Distributed Energy Resources (Distributed Generation, storage elements and controllable demand), (ii) have the ability to disconnect from and parallel with the area EPS, (iii) include the local Electric Power Systems (EPS) and may include portions of the area EPS, and (iv) are intentionally planned [9], [10]. The basic operation of a mG can be seen in Fig. 1, the blue box limits the planning area mG, and inside there are elements as elements of generation, storage and loads Center Control (CC), Generation Control (GC) Circuit Breaker (CB) and Circuit Sectionalizer Breaker (CSB) [11], [12].

978-1-4673-6605-2/15/$31.00 ©2015 IEEE

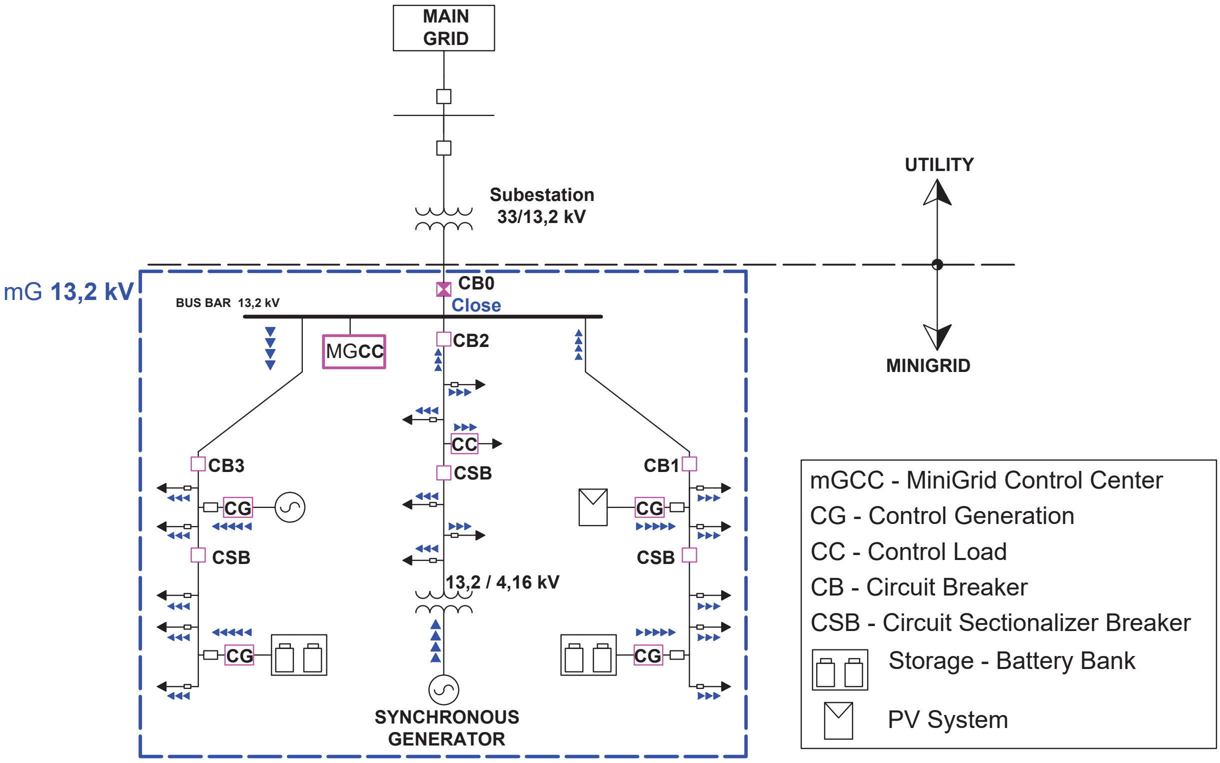


Fig. 1. Basic scheme for a MiniGrid operation

B. Island Operation Capability

Island Operation Capability (IOC) is defined as the ability to Supply a Grid Area in isolation of the synchronous grid over extended periods of time, autonomously and with the aid of a Generating Unit, in Order to maintain operation within the permitted operating parameters [13].

This AS is centrally managed by the Transmission System Operator (TSO), which receives signals from the control center of the Islands formed or mG and thus the reset process previously planned in case of a power outage.

The Ancillary Service of IOC is closely related with operating systems mGs. However, it should highlight the conceptual differences that need to use both terms. mG operation relates to the ability of a fraction of an electrical system (regardless of the capacity or voltage level) to continue its normal operation against a fault event or maintenance [14]. Ancillary Service of IOC relates to the ability of a fraction of the Distribution System, Sub-transmission or transmission to isolate the EPS in the event of a local failure or power outage. In this case the Restoration process begins with a reference in the islands formed which will serve for starting large power plants, thus the islands that contribute to the process of restoration must have a generating capacity above 5 MW (according to requirements of the Transmission System Operator) because otherwise many signals have different islands, making it difficult resynchronization and signal processing control [15], [16].

III. Discussion for the Implementation of Ancillary Service of IOC in a Deregulated Market

The analysis of the implementation of AS of IOC will take place through the methodology of System Dynamics (SD). SD is a method which applies a variation of control theory to managerial and design problems, with an emphasis on feedback and delays, relaying on simulation rather than a closed form solutions to gain insight into the system as most of these systems are nonlinear [17]. It was developed in the sixties and has been used since in a variety of different contexts [18], [19]. In deregulated electricity markets applications includes among others, in [20] that analyze the English market; in [21] analyzes the potentiality of cycles in generation capability in California; in [22] analyses regulation, learning and strategy in Colombia.

The standard system dynamics approach to modeling start by establishing the feedback and delay in the system to be investigated, followed by a stock and flow diagram and finally the formal equations using differential equations. This formalization allows for the simulation of the system. For a detailed description and discussion of system dynamics modeling, formalization and verification see Sterman [18].

A. Systemic Problem Statement

In deregulated markets, the AS are offered by large power plants centrally dispatched [23]. Currently a new paradigm in the operation of electric power systems, through the integration of SmartGrids concepts, installation and implementation DER Asset Distribution Systems arises. DER penetration without adequate control systems leads to a reduction in the reliability, quality and security of supply.

B. Dynamic Hypothesis

In Fig. 2 a part of flow and level diagram is presented. The main variables that relate to determine the time behavior of the electrical system restoration process when considering AS of IOC observed.

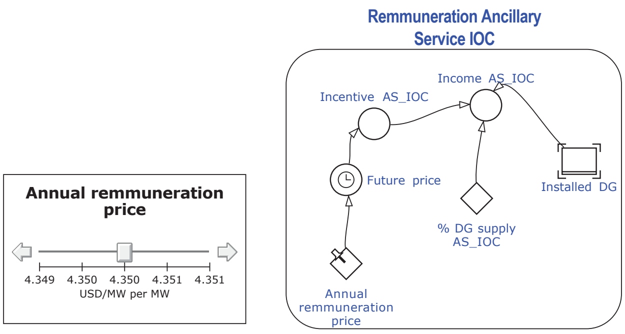


Fig. 2. Causal Loop Diagram for Study AS of IOC in Restoration Process

The variable to optimize the reset process is time, but should ensure the security, quality, reliability, flexibility and economics, which is achieved by having speed in decision making, reducing uncertainty about the impact these decisions may have on the control variables of the power system [8].

C. Costs involved for provide the ancillary service IOC

Compensation and remuneration of ancillary services it is related to the identification and quantification of taxes extra costs of providing the same [24]. These costs are shown in Eq. (1)

$$Cost_{AS} = Inv + C^{Fixed}_{O\&M} + C^{Var}_{O\&M} + P_{Losses/C.O} \quad (1)$$

Where, Inv it is related to recovery of investment resulting of implementationadaptation of installation that enable the provision of the Services Ancillary. In the case of AS IOC, modernization of electrical distribution systems to adapt to allow operation by mG.

You can recognize two possible situations in the return to investment. The first comes from the new facility infrastructure. In this case, offset should be the total investment of the installation application. The second possibility is the installation or adaptation existing. In this case, the compensation should have its value calculated with based on the depreciation of a new installation, considering the relationship between the lifetime and the use time of same.

$C^{Fixed}_{O\&M}$, it is related with the investment return of costs Operation and Maintenance fixed, related to the instant that installation is available to provide service. This amount can be paid in annual instalments by, in most cases, do not represent a great value financial [24].

$C^{Var}_{O\&M}$, it is related with the investment return of costs Operation and Maintenance Variable, and is related to the instant wherein plant is providing the service effectively. This portion may in some cases be paid in by annual instalments, do not represent a great value financial.

$P_{Losses/C.O}$, it is related with the investment return of costs resulting from the measurement of the increase in power losses actively involved in the provision of Ancillary Services (e.g. IOC) andor from the measurement of the opportunity cost (cost avoided). This portion may have different treatment depending on the given Ancillary Service

Therefore, following the analysis of the variables that influence the implementation of AS IOC in the process of restoring the system in a deregulated market.

1) Stakeholders for implementation of Ancillary Services: Island Operating Capability : So far, not presented in the literature methodology or standard to quantify the potential benefits of the Ancillary Service of Island Operating Capability.

Table I summarizes the main research works of authors who have developed studies providing AS through mGs and DER. This segmentation is done considering specific and particular studies of each AS, ie technical, economic assessments, regulatory or market analysis, which illustrate the progress and studies of AS around the world.

TABLE I
OVERVIEW ANCILLARY SERVICES MG AND DER

Ancillary Services	Microgrid	DER
Frequency Control (FC)	[16]	[25]–[29]
Voltage Control (VC)	[30], [31]	[27], [29], [32]–[35]
Stability Services (Transient Stability)	[34]	[36]
Improvement of Voltage Quality		[29], [36], [37]
Black Start Capability	[38]–[40]	[29], [36]
Islanded Operation Capability	[40]	
Peak shaving		[36]
Reactive power compensation	[31]	[29], [41]

Some authors have studied the subject of Islands Operation, determining benefits, issues and barriers in their operation, control, planning and implementation [10], [42], [43]. However, the study od AS of IOC is subject to the market and the availability of an Active Distribution System or SmartGrid that integrates elements of mGs and DER.

In Fig 3 the main applications of AS of IOC in the EPS are presented as a support service to electrical transmission and distribution systems. These advantages largely unexplored countries require be exploited to promote and entered the new paradigm of active operation Asset Distribution Systems and SmartGrids.

Following an analysis of the different variables studied in the dynamic model for the determination of a potential benefit is presented.

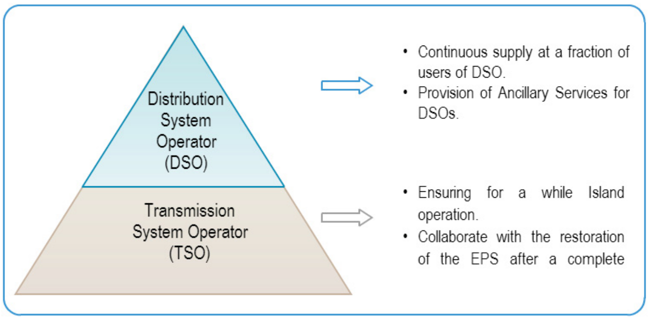


Fig. 3. Aplications of Island Operating Capability

2) Utilities - Distribution Systems Operators Viewpoint: For utilities, the operation of islands is presented as a given that its electrical infrastructure has control elements and traditional operation and thus is not feasible to provide the AS of IOC challenge. On the other hand, have installed on your system DER distribution are controlled by users, causes high risk of equipment failure and compromise personal safety [44], [45].

A very important for power distribution companies is the reliability aspect, the AS of IOC enabling users involved in the planning of the island will increase their reliability indices, which in turn reduces economic losses Energy Not Supplied. Finally, consider the remuneration of AS of IOC may encourage the modernization of infrastructure and implementing Asset Distribution Systems. It is notable that the IOC applies to nearby islands with capacity of 5 MW, thus an electric distribution company may have one of its substations authorized to provide such AS.

3) Transmission Systems Operators Viewpoint: After a partial or total blackout of the power system, the TSO require executing a reset process that sometimes presents great difficulty and requires a time which is sometimes indeterminate [6]. The AS of IOC has a benefit given to the TSO since the number of users involved in a blackout is reduced, as is possible to reduce the times of restoration of the system after a power outage been submitted [40].

4) DER Owners Viewpoint: When considering remuneration for AS of IOC DER owners have an additional incentive that does not have at present, increasing competitiveness and reducing the bias caused by the economy of scale when compared to large power plants [46]. Thus the AS of IOC maximize the benefits attributed to the installation of DER on the distribution network.

5) Customers Viewpoint: Customers are within the planning of the operation by islands, presented an increase in supply reliability. Since the AS of IOC can offer a continuous supply in case of a scheduled maintenance, a local fault on the distribution system or a general blackout Power System.

IV. Results and Discussion

In Fig. 4 Profitability (Capex and Opex) implementation AS of IOC presents, this simulation does not consider remuneration. The balance point where Opex and Capex are equal in the first half of 2021, with a price of 700.000 USD. The stabilization point Opex presented in 2035 in a value close to $ 1.7 million, the initial investment is $ 1.5 million potential depends only on the first year Generation.

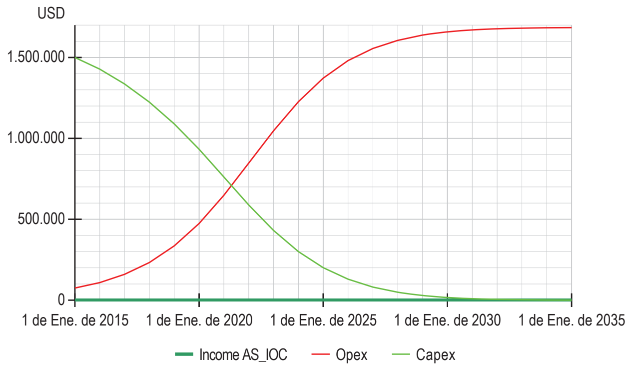


Fig. 4. Profitability of AS of IOC without remuneration

In Fig. 5 Profitability (Capex and Opex) implementation AS of IOC presents, this simulation consider with restore remuneration. The balance point where Opex and Capex are equal in the first half of 2022, with a price of 780.000 USD. The stabilization point Opex presented in 2035 in a value close to $ 1.78 million, adding to a value income AS IOC (dark green line). The initial investment is $ 1.7 million depends on the installation of generation adequacy more investment in AS IOC (restore remuneration only).

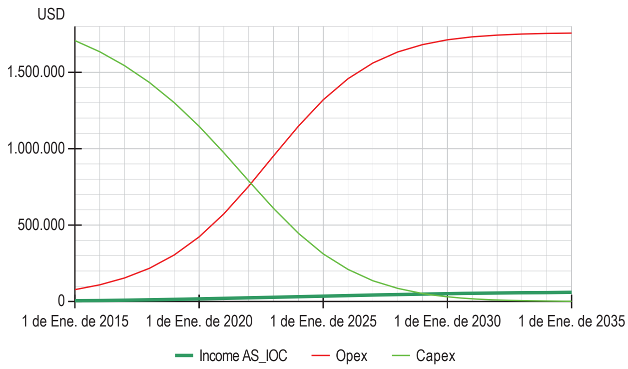


Fig. 5. Profitability of AS of IOC with restore remuneration

In Fig. 6 Profitability (Capex and Opex) implementation AS of IOC presents, this simulation consider with increase reliability remuneration. The balance point where Opex and Capex are equal is in the second half of 2023, with a price of 840.000 USD. The stabilization point Opex presented in 2035 in a value close to $ 1.83 million, adding to a value income AS IOC (dark green line). The initial investment is $ 1.92 million depends on the installation of generation adequacy more investment in AS IOC (reliability remuneration only).

In Fig. 7 Profitability (Capex and Opex) implementation AS of IOC presents, this simulation consider with increase

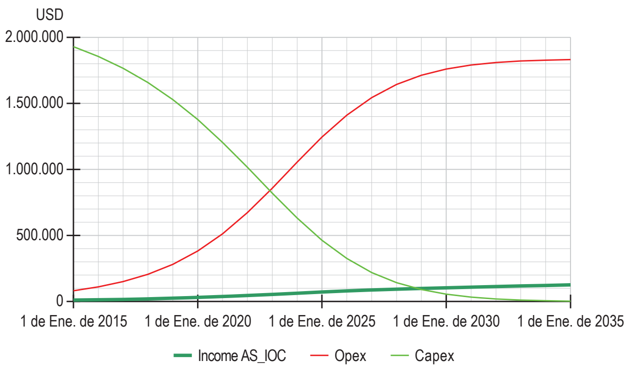


Fig. 6. Profitability of AS of IOC with increase reliability remuneration

reliability and restore remuneration. The balance point where Opex and Capex are equal in the first half of 2024, with a price of 920.000 USD. The stabilization point Opex presented in 2035 in a value close to $ 1.92 million, adding to a value income AS IOC 400.000 USD (dark green line). The initial investment is $ 2.32 million depends on the installation of generation adequacy more investment in AS IOC (reliability and restore remuneration).

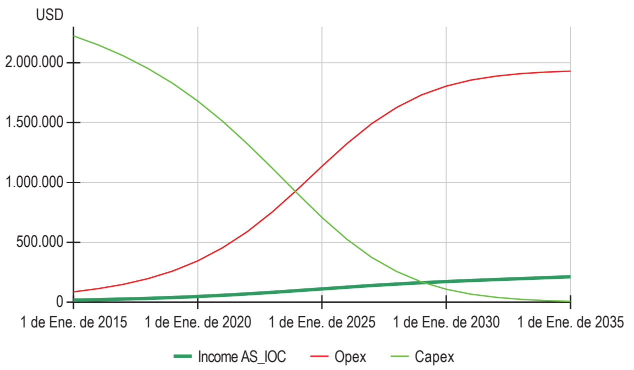


Fig. 7. Profitability of AS of IOC with increase reliability and restore remuneration

V. Conclusion

Modern economies are becoming increasingly dependent on reliable and security electricity services. Development and deployment of new and existing technologies has considerable potential to improve system operating tools to enhance electrical power system. Island Operation Capability permit more flexible operation of electrical power systems and more effective real time responses to alleviate congestions, manage emergency situations, and enable timely service restoration. Furthermore, it offers the potential to facilitate real-time coordination and more holistic management of system security in distributions and transmission systems spanning multiple control areas.

A dynamic relationship between the different variables of the model determines technical and economic behaviours that affect the restoration process, being able to quantify the contribution of AS IOC in reducing the time variable. In addition to the restoration process, may be determined the behavior of local variables of the Distribution System Operator.

Currently the economic benefits attributed to generation through DER come purely from the sale of energy (kWh). A regulatory or economic incentive for the provision of AS of IOC through network allows respond to the requirements of quality, safety and reliability of a liberalized market. Thus, the IOC becomes a link between DER capabilities that have not been explored and the needs of the operators of electrical systems.

References

[1] J. Feltes and C. Grande-Moran, "Down, but not out: A brief overview of restoration issues," *Power and Energy Magazine, IEEE*, vol. 12, no. 1, pp. 34–43, 2014.
[2] S. C. Savulescu, *Real-time stability in power systems: techniques for early detection of the risk of blackout*. Springer, 2014.
[3] S. Stoft, "Power system economics: Designing markets for electricity," *Wiley-IEEE*, vol. 14, p. 496, 2002.
[4] J. D. Marín-Jiménez, S. X. Carvajal-Quintero, and A. Arango-Manrique, "Discusión de la implementación en colombia del servicio complementario capacidad de operación por islas," *Directora-Editora*, vol. 43, pp. 99–108, 2014.
[5] E. Agneholm, N. Krantz, M. Emanuelsson, H. Hermansson, S. Ab, S. Kraftnät, and V. A. Elproduktion, "Solvsim power station – a new safe way of testing the frequency control and island operation capability of power stations," 2002. [Online]. Available: http://pscc.ee.ethz.ch/uploads/tx_ethpublications/s06p06.pdf
[6] N. Hatziargyriou, *Micrograds : architectures and control*. Chichester, West Sussex, U.K: Wiley, 2014.
[7] M. H. Bollen, "The smart grid: Adapting the power system to new challenges," *Synthesis Lectures on Power Electronics*, vol. 2, no. 1, pp. 1–180, 2011.
[8] R. A. U. Ramŕrez and X. C. D. E. E. MERCADO, "Restablecimiento de sistemas de potencia usando teorta de grafos," *Revista CIER N*, vol. 53, p. 4, 2009.
[9] IEEE Std 1547.4, "IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems," *IEEE Std 1547.4-2011*, pp. 1–54, 2011.
[10] F. P. Sioshansi, Ed., *Smart Grid: Integrating Renewable, Distributed & Efficient Energy*. Waltham: Academic Press, 2011.
[11] H. Mohamad, H. Mokhlis, A. H. A. Bakar, and H. W. Ping, "A review on islanding operation and control for distribution network connected with small hydro power plant," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 8, pp. 3952 – 3962, 2011.
[12] H. Zeineldin and M. M. A. Salama, "Intentional islanding of distributed generation," *IEEE Power Engineering Society General Meeting*, vol. 2, pp. 1496–1502, 2005.
[13] ENTSO-E, "Glosaty: Island operation capability," ENTSO-E Metadata Repository, Tech. Rep., 2015. [Online]. Available: https://emr.entsoe.eu/glossary/bin/view/ENTSO-E+Common+Glossary/Island+Operation+Capability
[14] S. X. C. Quintero and J. D. M. Jiménez, "Impacto de la generación distribuida en el sistema eléctrico de potencia colombiano: un enfoque dinámico," *Tecnura*, vol. 17, no. 35, pp. 77–89, 2013.
[15] ENTSO-E, "Supporting document for the network code on emergency and restoration," ENTSO-E AISBL, Tech. Rep., 2015.
[16] S. Granfors, "Online testing of generating units on their ability to regulate frequency during restoration of an islanded grid," in *Power and Energy Society General Meeting, 2010 IEEE*, July 2010, pp. 1–5.
[17] J. M. García, *Teoría y ejercicios prácticos de dinámica de sistemas*. Barcelona: Juan Martín García, 2003.
[18] J. D. Sterman, *Business dynamics: systems thinking and modeling for a complex world*. Irwin/McGraw-Hill Boston, 2000, vol. 19.
[19] J. W. Forrester, "Industrial dynamics," *Journal of the Operational Research Society*, vol. 48, no. 10, pp. 1037–1041, 1997.

[20] D. W. Bunn and M. Martoccia, "Unilateral and collusive market power in the electricity pool of england and wales," *Energy Economics*, vol. 27, no. 2, pp. 305–315, 2005.

[21] A. Ford, "Waiting for the boom:: a simulation study of power plant construction in california," *Energy Policy*, vol. 29, no. 11, pp. 847–869, 2001.

[22] S. Arango, I. Dyner, and E. R. Larsen, "Lessons from deregulation: Understanding electricity markets in south america," *Utilities Policy*, vol. 14, no. 3, pp. 196–207, 2006.

[23] B. Olek, "Deployment of energy storages for ancillary services," in *European Energy Market (EEM), 2014 11th International Conference on the*, May 2014, pp. 1–5.

[24] T. Sousa, C. M. V. Tahan, J. A. Jardini, J. A. O. Rosa, A. Feltrin, and J. Manso, "A new approach to remuneration of ancillary services provided by generation agents in brazil," *Latin America Transactions, IEEE (Revista IEEE America Latina)*, vol. 8, no. 1, pp. 38–44, 2010.

[25] L. Kılıç and A. B. Arsoy, "Evaluation of frequency control application for distributed generation in turkey," *International Journal of Electrical Power & Energy Systems*, vol. 67, no. 0, pp. 501 – 509, 2015.

[26] F. Alsokhiry and K. Lo, "Distributed generation based on renewable energy providing frequency response ancillary services," in *Power Engineering, Energy and Electrical Drives (POWERENG), 2013 Fourth International Conference on*, May 2013, pp. 1200–1205.

[27] P. Kotsampopoulos, N. Hatziargyriou, B. Bletterie, and G. Lauss, "Review, analysis and recommendations on recent guidelines for the provision of ancillary services by distributed generation," in *Intelligent Energy Systems (IWIES), 2013 IEEE International Workshop on*, Nov 2013, pp. 185–190.

[28] A. Rueda-Medina, A. Padilha-Feltrin, and J. Mantovani, "Active power reserve for frequency control provided by distributed generators in distribution networks," in *PES General Meeting — Conference Exposition, 2014 IEEE*, July 2014, pp. 1–5.

[29] M. Braun, *Provision of ancillary services by distributed generators: Technological and economic perspective*. kassel university press GmbH, 2009, vol. 10.

[30] A. Madureira and J. P. Lopes, "Ancillary services market framework for voltage control in distribution networks with microgrids," *Electric Power Systems Research*, vol. 86, no. 0, pp. 1 – 7, 2012.

[31] M. H. Gomes and J. T. Saraiva, "Allocation of reactive power support, active loss balancing and demand interruption ancillary services in microgrids," *Electric Power Systems Research*, vol. 80, no. 10, pp. 1267 – 1276, 2010.

[32] K. Kashyap and B. D. Reddy, "Ancillary services and stability analysis of distributed generation system," *SYSTEM*, vol. 3, no. 3, pp. 247–251, 2013.

[33] R. Strzelecki, G. Benysek, M. Jarnut, R. Smolenski, and B. Maciejewski, "Ancillary services to grids provided with distributed generation," in *Compatibility and Power Electronics, 2009. CPE'09.* IEEE, 2009, pp. 29–34.

[34] F. Alsokhiry, G. Adam, and K. Lo, "Contribution of distributed generation to ancillary services," in *Universities Power Engineering Conference (UPEC), 2012 47th International*, Sept 2012, pp. 1–5.

[35] V. Calderaro, V. Galdi, F. Lamberti, and A. Piccolo, "A smart strategy for voltage control ancillary service in distribution networks," *Power Systems, IEEE Transactions on*, vol. 30, no. 1, pp. 494–502, Jan 2015.

[36] J. Campbell, "Ancillary services provided from der," ORNL, Tech. Rep., 2005.

[37] B. Olek and M. Wierzbowski, "Ancillary services provided by renewable energy sources," in *Power in Unity: a Whole System Approach, IET Conference on*, Oct 2013, pp. 1–7.

[38] O. Palizban, K. Kauhaniemi, and J. M. Guerrero, "Microgrids in active network management – part ii: System operation, power quality and protection," *Renewable and Sustainable Energy Reviews*, vol. 36, no. 0, pp. 440 – 451, 2014.

[39] J. Li, J. Su, X. Yang, and T. Zhao, "Study on microgrid operation control and black start," in *Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), 2011 4th International Conference on*, July 2011, pp. 1652–1655.

[40] J. P. Lopes, C. Moreira, and F. Resende, "Control strategies for microgrids black start and islanded operation," *International Journal of Distributed Energy Resources*, vol. 1, no. 3, pp. 241–261, 2005.

[41] W. Brignol, A. Barin, L. Canha, A. Santos, A. Abaide, and M. De Carli, "Analysis of the distributed generation for ancillary services support in distribution networks," in *Power Engineering Conference (UPEC), 2014 49th International Universities*. IEEE, 2014, pp. 1–5.

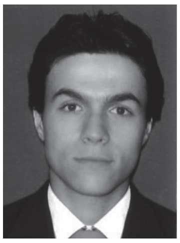
[42] S. X. Carvajal Quintero, J. D. Marin Jimenez, and S. Arango Aramburo, "Feasibility of intentional islanding operation with small hydropower plants," in *Transmission and Distribution: Latin America Conference and Exposition (T& D-LA), 2012 Sixth IEEE/PES*, 2012, pp. 1–6.

[43] S. P. Chowdhury, P. Crossley, and S. Chowdhury, *Microgrids and Active Distribution Networks*. Institution of Engineering and Technology, 2009.

[44] D. Zhu, R. P. Broadwater, K.-S. Tam, R. Seguin, and H. Asgeirsson, "Impact of dg placement on reliability and efficiency with time-varying loads," *Power Systems, IEEE Transactions on*, vol. 21, no. 1, pp. 419–427, 2006.

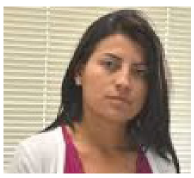
[45] IEEE Std 1547, "IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems," *IEEE Std 1547-2003*, pp. 0 1–16, 2003.

[46] S. X. Carvajal and J. D. Marín, "Impacto de la generación distribuida en el sistema eléctrico de potencia colombiano: un enfoque dinámico," *Tecnura*, vol. 17, no. 35, pp. 77–89, 2013.



Juan David Marín Jiménez Master's in Electrical Engineering, Universidad Nacional de Colombia. Student of Doctorate in Engineering, Universidad Nacional de Colombia. His special fields of interests include: Distributed Generation and MiniGrids.

Josep M. Guerrero (S'01-M'03) received the B.S. degree in telecommunications engineering, the M.S. degree in electronics engineering, and the Ph.D.degree in power electronics from the Universitat Politècnica de Catalunya, Barcelona, Spain, in 1997, 2000, and 2003, respectively. From 1998 to 2004, he was an Assistant Professor in the Department of Automatic Control Systems and Computer Engineering, Universitat Politècnica de Catalunya. In 2004, he became a Senior Lecturer at the same university, where he teaches digital signal processing, control theory, and microprocessors. Since 2004, he has been the Responsible of the Sustainable Distributed Generation and Renewable Energy research group at the Escola Universita d'Enginyeria Tècnica Industrial de Barcelona (EUETIB). He has organized and chaired sessions at several IEEE IECON, APEC, and PESC Conferences. He is listed in Marquis' *Who's Who in the World and Marquis' Who's Who in Science and Engineering.*



Sandra Ximena Carvajal Quintero She is Associate Professor at Universidad Nacional de Colombia. She is Master and PhD of the same University. Her publications are in journals such as Energy Policy, International journal of Electrical Power & Energy Systems and national journals. Her research interests include the study of MicroGrids and ancillary services.