A Proposal for Microgrids Control Architecture as Aggregator

Alonso de Jesús Chica Leal
Universidad Central
Universidad Distrital FJDC
Bogotá, Colombia
Email: achical@ucentral.edu.co

César Trujillo Rodríguez
Universidad Distrital FJDC
Bogotá, Colombia
Email: cltrujillo@udistrital.edu.co

Francisco Santamaría Piedrahita
Universidad Distrital FJDC
Bogotá, Colombia
Email: fsantamariap@udistrital.edu.co

***Abstract*—This paper presents a review of microgrid control architectures, and it proposes a decentralized control architecture for multiple microgrids operating as a power aggregator in demand response. This architecture consists of four control levels. The interrelationships of the hierarchical levels in the proposed architecture are described, and the operation models of control architectures for each microgrid and for multiple microgrids operating as aggregator are presented. Finally, some comments about the proposal are presented.**

I. Introduction

Distributed Energy Resources (DER) for Demand Response (DR) are essential components in the future of smart grids [1], seeking to integrate Renewable Energy Resources (RER) to keep the balance between energy demand and supply. Microgrid (MG) is a subsystem of the distribution grid, which comprises generation capacities, storage devices, and controllable loads, operating as a single controllable system either connected or isolated from the utility grid [2]–[4]. Furthermore, as a group of DER, MGs can provide flexibility to the distribution system to get a faster response to energy demand, and improve the capacity to reduce distribution network losses [3],[5].

Microgrids can be AC, DC, AC/DC, or high frequency [3]–[5] and can operate in both modes, island mode and grid-connected mode [6]–[8]. The requirements for each operation mode are different as well as the specifications for stability and control [4]. MGs are controlled systems that can operate as a load or an aggregated generator, and they can act as power sources incorporated into the network or as a means to provide ancillary services [9], [10].

In a distribution system, hundreds of DER units can be available to propose an aggregated load to the main grid. This leads to a smart distribution system that requires real-time information about each DER unit and load [11]. On the other hand, the complexity problem of control is reduced to control all DER units for MGs dispatch. In this sense, MGs are smart systems that can respond to energy demand by increasing their local generation or by turning off non-critical loads or shifting their use in time.

This paper presents a proposal for a decentralized control architecture for multiple microgrids, acting like a power aggregator in demand response. The possibility of aggregated MGs having a contract with the distribution grid operator to supply energy for demand response is analyzed.

In Section II, a review of microgrid control architectures is presented. In Section III, the concept of power aggregator using MGs is explained. Proposed MGs control architecture including a power aggregator level is presented in Section IV. Finally, in Section V some comments about the proposal are presented.

II. Review of microgrid control architectures

Depending on the control architecture, it is necessary to have the set points available to local controllers of power generators, storage devices and smart loads, as well as the island and grid operation modes [12]. There are mainly three MG control architectures: centralized, decentralized and multilayer. The last architecture is also called hierarchical control levels [13]-[16].

In centralized control, architecture sources are controlled by a central control system, located remotely, in a Mater-Slave configuration as depicted in figure 1. In this architecture, the Microgrid Central Controller (MCC) optimizes power interchanges between MG and the main grid, which maximizes the local generation, depending on security and market prices restrictions. This is possible with control points to DER and controllable loads into MGs.

In this architecture the use of bidirectional communication networks between MCC and each Local Controller (LC) is necessary. This communication can be done by using telephone lines, power line communication, serial lines, or wireless communication [17], [18], being Serial and TCP Modbus and Control Area Network (CAN) the most used [19].

In decentralized control, the individual sources share the load according to their characteristics and capacities of individual power control without any communication between them. In this concept, most drivers follow a droop control scheme, either for operation in island mode or grid connected mode [20]-[22]. Figure 2 depicts the independence of the drivers and the absence of a central controller. Real–time economic dispatch optimization and the use of sources under several operation conditions are not possible using this approach.

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

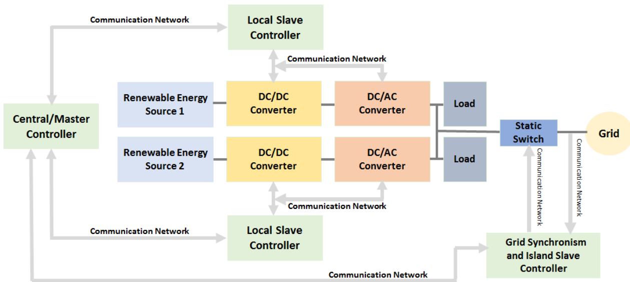

Fig. 1: Centralized control architecture, modified from [15]

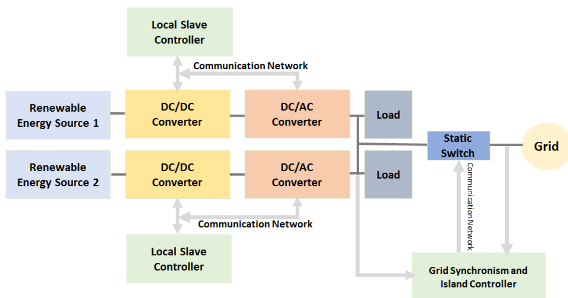

Fig. 2: Decentralized control architecture, modified from [14]

The multilayer control or hierarchical control, combines the best characteristics of the centralized and decentralized control architectures [14]. This concept is used in MGs from experience of hierarchical control of dispatch for large-scale power systems, where voltage amplitude and frequency deviations are limited, and therefore system quality, stability and reliability are improved [19]. In [22], a level of control is included to correct these deviations. Moreover, a control strategy without communication networks is proposed, which could be appropriated for high-performance paralleled inverters [23].

Supervisory control in MGs is proposed in [15], by means of three hierarchical control levels. In the top level or grid level, there are both, a controller of Distribution Network Operator (DNO) and a Market Operator (MO). At the management level, there is a MCC for each MG and, at the field level or bottom level, LC of DER and the controlled loads are working for each MCC (See figure 3).

Depending on MG control architecture, LC has a different intelligence level. In centralized operation, each LC receives the set points of the corresponding MCC. In a decentralized operation, each LC makes a decision locally.

The discussion on problems of microgrid controls include multiples generators and energy storage, compensation of power quality problems and the inclusion of AC, DC, AC/DC MGs, among others. Advanced control strategies, such as distributed and cooperative strategies have been considered. Several proposals involve multi- agents systems with local agents for local tasks and leading agents to coordinate local agents [24], [25].

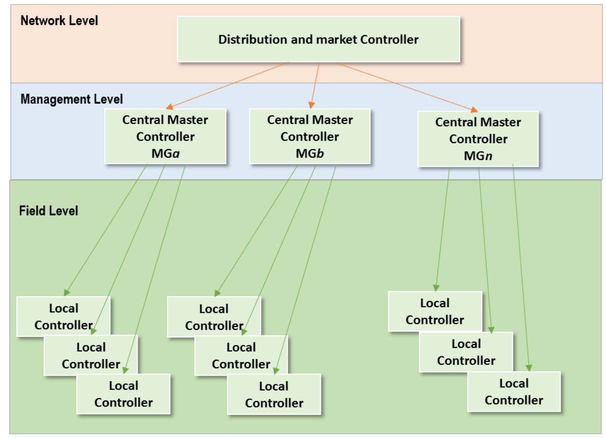

Fig. 3: Supervisory control

III. Microgrids as power aggregators

MGs in grid-connected operating mode can work as Demand Response Aggregators (DRA), and multiple grouped MGs can take part as client of Demand Side Management (DSM) [25]. However, DER in MGs are small loads with low capacity, and in most cases, they are not qualified for DSM. Therefore, it is necessary to check their role as DRA, analyzed as a Virtual Power Plant (VPP), using a business model for DRA, allowing them to participate in the wholesale energy market as flexible entities of DR. Multiple grouped MGs can operate as a great elastic load participating in DSM.

When MGs have non-dispatchable generators [26] such as photovoltaic and wind generators, or others using intermittent resources [30], [31], it is necessary to adapt the distribution system to provide flexible and effective response to MGs operation, ensuring power system reliability under the penetration of renewable energies and the growing of the temporal loads, as electric vehicles [32].

The current and future problem is associated to the organization of the dynamics of the energy markets, based on the next MGs in the rural region, cities, or near to cities. The main competitive advantage of the multiple grouped MGs is that it can quickly provide electric power to the main grid at a lower price than the the main grid spot market price [30]. Therefore, in the future, the organization of the energy market strategies must be based on MGs.

According to [31], an aggregator is an entity that collects generated energy for by one or several Distributed Generators (DG) and sells it to the utility [34]. Additionally, the DRA can get benefit by participating in pricing between demand and supply.

If a system operator requires a certain amount of power from a single or several DRAs at a minimum purchase price, a two stages communication from DRA begins. The first stage is to set price between the system operator and the DRA, and the other stage is to set the price between the DRA and the MGs

[31]. Figure 4 shows a conceptual architecture of several MGs and a single DRA, where there are n MGs, each one with DER units and loads operating locally. In addition, communications between the n MGs and the DRA node are performed, in order to carry out transactions with the wholesale and the retail market, participating in price fixing of aggregated power by MGs.

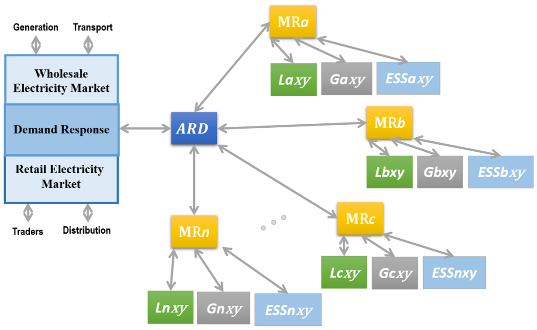

Fig. 4: Conceptual proposal of MGs as power aggregator

Smart transactions between the new load aggregator and the wholesale and complementary markets haves been already studied with multi-agent systems [32], [33]. This paper proposes a solution from the Model Predictive Control (MPC) approach.

IV. Proposed Control Architecture

Proposed control architecture is shown in figure 5. In this architecture, DRA is responsible for initiating all the local markets and making energy auction between the traders of different MGs and the main grid.

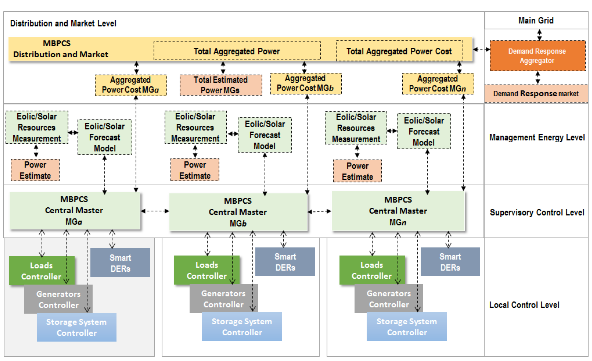

Fig. 5: Proposed architecture for MGs as power aggregator

A. *Electrical Power System*

In general, low-voltage distribution networks are radial topologies. However, to allow MGs participate as power aggregators, more flexible topologies are required, but those are not studied in this paper. Therefore, a radial low-voltage distribution grid and n radial MGs, each one with a set of n Distributed Generators (DG) Gn_{xy}, n energy storage systems ESS_{xy}, and n controllable loads Ln_{xy} with a specific geographic location xy are considered in the analysis.

DG can be wind, PV or diesel generators, the former ones are non-dispatchable generators and depend of the primary energy source (wind and solar radiation), while the last one is dispatchable, but with variable output power (1).

$$Gn_{xy} = \{Gn_{x_1y_1}, Gn_{x_2y_2}, \ldots, Gn_{x_ny_n}\} \tag{1}$$

For each $Gn_{x_ny_n} \in Gn_{xy}$, the power complex is:

$$S_g(t) = P_g(t) + jQ_g(t) \tag{2}$$

The set of distributed ESS for any MG is shown in (3)

$$SAn_{xy} = \{SAn_{x_1y_1}, SAn_{x_2y_2}, \ldots, SAn_{x_ny_n}\} \tag{3}$$

For each $ESSn_{x_ny_n} \in ESSn_{xy}$, the State-of-Charge (SOC) is estimated according to [39]:

$$SOC(t+k) = SOC(k) - \alpha(p_g(k)) \tag{4}$$

Where $SOC(k)$ is the actual $ESSn_{xy}$, state of charge, $P_g(k)$ is the power required from DERs in each MG to charge the ESS, and is the efficiency of charge/discharge of the ESS.

The set of distributed controllable loads in a MG is shown in (5).

$$Ln_{xy} = \{Ln_{x_1y_1}, Ln_{x_2y_2}, \ldots, Ln_{x_ny_n}\} \tag{5}$$

B. *Local control level (LCL)*

At local control level, each DER and controllable loads have a local controller (LC), and there is two-way communication with a Central Controller Master (CCM) of each MG, which coordinates the operation of DERs and controllable loads.

C. *Supervisory Control Level (SCL)*

DRA interprets the options of demand response proposed by load agents, who are monitoring the whole aggregate power of DER units and the power cost at Power Aggregator Level (PAL). In this level, PAL receives aggregate cost information for each MG, estimates the power for each MG aggregation and sends reference signals to the MGs controllers. Based on demand predictions and power generation costs, the Model Based Predictive Control Systems (MBPCS), evaluate MG participation in the sale of energy [35]. The MBPCS operates in a decentralized and distributed architecture and it is located at the Supervisory Control Level (SCL). At this level, control tasks are performed using the sliding horizon concept to develop predictions in a period determined by MG requirements.

At the supervisory control level, CCM uses a MBPCS to execute an optimization algorithm to minimize errors of the SOC estimation of each ESS. It assigns set-points of active and reactive power and sends signals for connection and disconnection of DERs. The optimization of energy flow between various resources in the MG is developed by the MBPCS each hour during the day, using the concept of sliding horizon.

MBPCS has a predictive controller based on model predictive control with the following function:

$$J = \sum_{k=1}^{N} [\gamma_i(SOC_i(t+k)) - SOC_i^{ref}] + \sum_{k=1}^{Nu} [\alpha_i P_i^2(t+k) + \beta_i \Delta P_i^2(t+k)] \quad (6)$$

where N is the prediction horizon and Nu is the control horizon [40]. The tracking error minimization between the value of $SOC_i(t+k)$ and the State-of-Charge of reference $SOC_i^r ef$ is presented in the horizon N, and error weights γ_i penalize tracking error. On the horizon Nu, both the use of DERs and their power variations are minimized, and those are penalized by error weights α_i and β_i, respectively. Values of N, Nu and α_i,β_i and γ_i are adjusted according to MG conditions [37].

At each time step, an optimal control problem in open loop based on measurement and prediction of the input and output variables proposed in the objective function is formulated. In the optimal solution, just the control action for the current period is sent to local controllers. This process is repeated at each time step, updating both the load-forecasting model and the short-time forecasting model of the power sources and their estimated costs. This type of controllers incorporates predictive models and restrictions [38], such as a power balance between generation and demand, inequality restrictions in the minimum and maximum power capacity, and the restriction of SOC limit of storage systems. The optimization problem can be solved by several methods, where quadratic programming and mixed integer programming are the most widely used.

D. Energy Management Level (EML)

In the Energy Management Level (EML) of each MG, DER power and availability are measured, forecasting and prediction models are constructed, and a MG demand prediction is developed.

At the level of energy management level, the MBPCS in each MG defines and solves an optimization problem for each MG. Aat each time step of time. In this sense, the controller must have take high-level decisions about: i) when to sStarting and stop of each generation unit; ii) how How much powerenergy each unit must produce each unit to meet cover the load demand at a minimal cost; iii) theThe amount of energy that has to be stored; iv) when to perform the The criteria for charging and discharging ESS cycles of energy storage systemESS; v) If When the MG is connected to the network, the quantity when and how much of energy that must be negotiatedbe (bought or sold) from to with the system operator and (when the MG is connected to the network); vi) load shedding reduction schedule.

To minimize the functional cost, which represents operating costs, an economic optimization must be performed in each MG. Therefore, a cost function that includes the costs associated with energy production and startup and shutdown decisions, profits and penalties is proposed.

Photovoltaic and wind generators are taken into account in the predictive control in each MG, from a forecasting model of energy resources and demand in the MG, and DERs power estimation. In [39] a comparison between load forecasting models using neural networks (NN) and fuzzy inference systems (FIS) is presented. Short time forecasting models for solar radiation (from few seconds to several minutes), two states model and the ARIMA model, are presented in [40], and other models are available in [41], [42] and [43].

In [44] a forecasting model using Multi-Layer Perceptrons (MLPs) and the radial basis function (RBF) NN for wind prediction are described. In [45] relevance vector machines are used for wind speed prediction, while reactive power dispatch is calculated by means of a genetic algorithm. For interested readers, in [46] a complete review of forecasting models for solar and wind power is presented.

E. Power Aggregator Level (PAL)

DRA interprets the options of demand response proposed by load agents, who are monitoring the whole aggregate power of DER units and the power cost at Power Aggregator Level (PAL). In this level, PAL receives aggregate cost information for each MG, estimates the power for each MG aggregation and sends reference signals to the MGs controllers.

In this level, the power in each MG is estimated, and based on that an aggregated power cost optimization process is developed. The total aggregated power and its cost per hour are also calculated. This information is sent to the DRA. The DRA must know directly the wholesale price of energy to participate in the DR programs, and simultaneously transfer price signals to end-user, with different risk price protection programs.

Power aggregator and DR aggregator take into account the MGs participation in the market, for example, following the Herfindahl index (H) calculated according to (7), where S_i is the market share of the i–th MG.

$$H = \sum_{i=1}^{n} S_i^2 = S_1^2 + S_2^2 + \ldots, S_n^2 \quad (7)$$

When H approaches zero, market is more competitive, and as it approaches one market is almost a monopoly. The use of aggregators increases competition and moves the Herfindahl index closer to zero. Thus, the active demand response, self-sufficiency and selling surplus is encouraged, and there are new opportunities with controlled interruptible loads.

After performing market transactions with DRA, PAL communicates with EML to define the lower reference values, maintaining a loop between control architecture levels. The MBPCS for PAL and MBPCS for SCL, have transition times and different prediction and control horizons, but they are synchronized every half hour. The control signals between the SCL and the LCL are reported in seconds

V. Final comments

Each MG can be dispatched whether locally or can be grouped with other MGs, to participate in DR market using power aggregators. Transactions between MGs, DRA and grid operator, depend on the costs and demand predictions.

MBPCS allows planning demand due to price variations or local generation. The proposal shows not only a way of starting a new market for existing MGs, but also enables the design of new MGs with existing or new DERs, as a form of business in energy markets for isolated areas.

Developing and consolidating a MGs market is not easy in the current regulatory, technical and financial framework [51] in countries like Colombia, where most attempts have been academic experiments. Therefore, further work on this approach is necessary.

References

[1] D.T. Nguyen, L.B. Le, Risk-Constrained Profit Maximization for Microgrid Aggregators with Demand Response, *Smart Grid, IEEE Transactions on*, vol. 6, no. 1, pp. 135146, 2015.

[2] Y.A. Muoz, Optimizacin de recursos energticos en ZNI mediante estrategias de suministro y consumo, Disertacin Ph.D., Dept. Eng. Elect., Univ. Politcnica de Valencia, 2012.

[3] T.S. Ustun, C. Ozansoy, and A. Zayegh, Recent developments in microgrids and example cases around the world - A review, *Renew. Sustain. Energy Rev.*, vol. 15, no. 8, pp. 40304041, 2011.

[4] I. Patrao, E. Figueres, G. Garcer, and R. Gonzlez-Medina, Microgrid architectures for low voltage distributed generation, *Renew. Sustain. Energy Rev.*, vol. 43, pp. 415424, 2015.

[5] H. Laaksonen, Advanced islanding detection functionality for future electricity distribution networks, *IEEE Trans. Power Deliv.*, vol. 28, no. 4, pp. 20562064, 2013.

[6] D. Velasco, C.T. Rodrguez, and J.H. Mora, Algoritmo de deteccin en modo isla de un inversor, basado en la medicin del segundo armnico, *Rev. Lasallista Investig.*, vol. 10, no. 1, pp. 6274, 2013.

[7] C.L. Trujillo, D. Velasco, D. Fuente, E.F. Amors, and G.G. Sanfeli, Anlisis de un mtodo activo para la deteccin de isla basado en la perturbacin de la fase en el pll y comparacin con otros mtodos activos, *Rev.Cientfica*, no. 12. pp. 113-124, 2010.

[8] H.A. Gabbar, A.A. Abdelsalam, Microgrid energy management in grid-connected and islanding modes based on SVC, *Energy Convers. Manag*, vol. 86, pp. 964972, 2014.

[9] R. H. Lasseter, Smart distribution: Coupled microgrids, *Proc. IEEE*, vol. 99, no. 6, pp. 10741082, 2011.

[10] M. Yazdanian, A. Mehrizi-sani, Distributed Control Techniques in Microgrids, *Smart Grid, IEEE Transactions on*, vol.5, no.6, pp.2901,2909, Nov. 2014.

[11] D.E. Olivares, A. Mehrizi-Sani, A.H. Etemadi, C.A. Caizares, R. Iravani, M. Kazerani, A.H. Hajimiragha, O. Gomis-Bellmunt, M. Saeedifard, R. Palma-Behnke, G.A. Jimnez-Estvez, and N.D. Hatziargyriou, Trends in microgrid control, *Smart Grid, IEEE Transactions on*, vol.5, no.4, pp.1905,1919, 2014

[12] R.G. Wandhare, S. Thale, and V. Agarwal, Design of a photovoltaic power conditioning system for hierarchical control of a microgrid, Photovoltaic Specialist Conference (PVSC), *2014 IEEE 40th*, pp. 31443149, 2014.

[13] S. Thale, R.G. Wandhare, and V. Agarwal, A Novel Reconfigurable Microgrid Architecture with Renewable Energy Sources and Storage, *Industry Applications, IEEE Transactions on* , vol.51, no.2, pp.1805,1816, 2015.

[14] E. Mojica-Nava, C.A. Macana, and N. Quijano, Dynamic Population Games for Optimal Dispatch on Hierarchical Microgrid Control, *Syst. Man, Cybern. Syst. IEEE Trans.*, vol. 44, no. 3, pp. 306317, 2014.

[15] F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, Microgrids management, *IEEE Power Energy Mag.*, vol. 6, no. june, pp. 5465, 2008.

[16] A.G. Tsikalakis and N.D. Hatziargyriou, Centralized control for optimizing microgrids operation, *IEEE Trans. Energy Convers.*, vol. 23, pp. 241248, 2008.

[17] B.A. Vaccaro, M. Popov, D. Villacci, and V. Terzija, An Integrated Framework for Smart Microgrids Modeling, Communication, and Verification, *Proc. IEEE*, vol. 99, no. 1, pp. 119132, 2011.

[18] R.H. Lasseter, MicroGrids, *Power Engineering Society Winter Meeting, 2002. IEEE*, vol.1, pp.305,308, 2002.

[19] C.K. Sao and P.W. Lehn, Control and power management of converter fed microgrids, *IEEE Trans. Power Syst.*, vol. 23, no. 3, pp. 10881098, 2008.

[20] J. Rocabert, A. Luna, F. Blaabjerg, and P. Rodrguez, Control of Power Converters in AC Microgrids, *Power Electronics, IEEE Transactions on*, vol. 27, no. 11, pp. 47344749, 2012.

[21] M. Hua, H. Hu, Y. Xing, and J.M. Guerrero, Multilayer control for inverters in parallel operation without intercommunications, *IEEE Trans. Power Electron.*, vol. 27, no. 8, pp. 36513663, 2012.

[22] J.M. Guerrero, J.C. Vasquez, J. Matas, L.G. De Vicua, and M. Castilla, Hierarchical control of droop-controlled AC and DC microgrids - A general approach toward standardization, *IEEE Trans. Ind. Electron.*, vol. 58, no. 1, pp. 158172, 2011.

[23] J.M. Guerrero and J. Miret, Inverters in Microgrids Using Resistive Output Impedance, pp. 51495154, 2006.

[24] H. Xin, Z. Qu, J. Seuss, and A. Maknouninejad, A self-organizing strategy for power flow control of photovoltaic generators in a distribution network, *IEEE Trans. Power Syst.*, vol. 26, no. 3, pp. 14621473, 2011.

[25] F. Rahimi and A. Ipakchi, Demand response as a market resource under the smart grid paradigm, *IEEE Trans. Smart Grid*, vol. 1, no. 1, pp. 8288, 2010.

[26] U.S.E.I.A, Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2015, U.S. Energy Information Administration, 2020 Levelized Costs AEO 2015, June, 2015.

[27] Y.M. Atwa, E.F. El-Saadany, M.M.A. Salama, and R. Seethapathy, Optimal Renewable Resources Mix for Distribution System Energy Loss Minimization, *Power Systems, IEEE Transactions on*, vol. 25, no. 1, pp. 360370, 2010.

[28] H.S.V.S.K. Nunna, and S. Doolla, Demand Response in Smart Distribution System with Multiple Microgrids, *Smart Grid, IEEE Transactions on*, vol. 3, no. 4, pp. 16411649, 2012.

[29] T. Dragicevic, J. Vasquez, J.M. Guerrero, and D. krlec, Advanced LVDC Electrical Power Architectures and Microgrids, *IEEE Electrif. Mag.*, vol. 2, no. March, pp. 5465, 2014.

[30] S.P. Chowdhury, S.P. Chowdhury, and P. Crossley, *Microgrids and Active Distribution Networks,* London, United Kingdom: The Institution of Engineering and Technology, London, United Kingdom, 2009.

[31] K. Hongseok and M. Thottan, A Two-Stage Market Model for Microgrid Power Transactions via Aggregators, *Bell Labs Tech. J.*, vol. 16, no. 3, pp. 101107, 2011.

[32] H.S.V.S.K. Nunna and S. Doolla, Energy management in microgrids using demand response and distributed storage - A multiagent approach, *IEEE Trans. Power Deliv.*, vol. 28, no. 2, pp. 939947, 2013.

[33] M. Ding and K. Luo, A multi-agent energy coordination control strategy in microgrid island mode, *Lect. Notes Electr. Eng.*, vol. 238 LNEE, no. 11511075, pp. 529536, 2014.

[34] A. Parisio and L. Glielmo, Energy efficient microgrid management using Model Predictive Control, *IEEE Conf. Decis. Control Eur. Control Conf.*, pp. 54495454, 2011.

[35] W. Shi, X. Xie, C. Chu, and R. Gadh, A Distributed Optimal Energy Management Strategy for Microgrids, in *IEEE SmartGridComm*, pp. 16, 2014.

[36] H. Tazvinga, B. Zhu, and X. Xia, Energy dispatch strategy for a photovoltaic wind diesel battery hybrid power system, *Sol. Energy*, vol. 108, pp. 412420, 2014.

[37] C. Bordons, F. Garca-Torres, and L. Valverde, Gestin ptima de la Energa en Microrredes con Generacin Renovable, *Rev. Iberoam. Automtica e Informtica Ind. RIAI*, vol. 12, no. 2, pp. 117132, 2015.

[38] J. Ma, S. Member, F. Yang, Z. Li, and S. J. Qin, A Renewable Energy Integration Application in a MicroGrid Based on Model Predictive Control, *Power Energy Soc. Gen. Meet. 2012 IEEE*, pp. 16, 2012.

[39] F. vila, D. Sez, G. Jimnez-estvez, L. Reyes, and A. Nez, Fuzzy demand forecasting in a predictive control strategy for a renewable-energy based microgrid, in *2013 European Control Conference (ECC)*, no. 1, pp. 20202025, 2013.

[40] [40] M. Paulescu, O. Mares, E. Paulescu, N. Stefu, A. Pacurar, D. Calinoiu, P. Gravila, N. Pop, and R. Boata, Nowcasting solar irradiance using the sunshine number, *Energy Convers. Manag.*, vol. 79, pp. 690697, 2014.

[41] M. Lipperheide, J.L. Bosch, and J. Kleissl, SE-D-14-00153 Review 15 march - Embedded nowcasting method using cloud speed persistence for a photovoltaic power plant, *Sol. Energy*, vol. 112, no. SE-D-1400153, p. 16, 2014.

[42] S.R. West, D. Rowe, S. Sayeef, and A. Berry, Short-term irradiance forecasting using skycams: Motivation and development, *Sol. Energy*, vol. 110, pp. 188207, 2014.

[43] H. Breitkreuz, M. Schroedter-Homscheidt, T. Holzer-Popp, and S. Dech, Short-range direct and diffuse irradiance forecasts for solar energy applications based on aerosol chemical transport and numerical weather modeling, *J. Appl. Meteorol. Climatol.*, vol. 48, no. 9, pp. 17661779, 2009.

[44] M. Lydia and S.S. Kumar, A comprehensive overview on wind power forecasting, *IPEC 2010 Conf. Proc.*, vol. Singapore, pp. 268273, 2010.

[45] T. Brandt, N. DeForest, M. Stadler, and D. Neumann, Power Systems 2.0 Designing an Energy Information System for Microgrid Operation, in *Proceedings of 2014 International Conference on Information Systems (ICIS 2014)*, pp. 118, 2014,

[46] Y. Ren, P.N. Suganthan, and N. Srikanth, Ensemble methods for wind and solar power forecastingA state-of-the-art review, *Renew. Sustain. Energy Rev.*, vol. 50, pp. 8291, 2015.

[47] C.A. Ramrez Escobar, Los Precios Del Mercado Mayorista de Electricidad como Expresin de la Participacin Activa de la Demanda: Aplicacin de la Economa Experimental, Disertacin PhD, Dto. Ing. Electr., Universidad Politcnica de Valencia, 2008.

[48] L. Tao,C. Schwaegerl, S. Narayanan, and J.H. Zhang, From laboratory Microgrid to real markets Challenges and opportunities, *eighth Int. Conf. Power Electron. - ECCE Asia "Green World with Power Electron.*, ICPE 2011-ECCE Asia, pp. 264271, 2011.