Control Methods for Microgrids

Fabian Moehrke
Reiner Lemoine Institut
Berlin, Germany
fabian.moehrke@rl-institut.de

Johanna Myrzik
Technical University Dortmund
Dortmund, Germany
johanna.myrzik@tu-dortmund.de

Abstract- **This paper describes different approaches for controlling electrical components in a microgrid. Due to multiple targets for controlling those components, a variety of different approaches exists. A brief description of main approaches is given and discussed.**

***Index Terms*—power systems operations and controls, microgrids, voltage control, control methods**

I. Introduction

The installed capacities of Distributed Energy Resources (DERs), especially volatile renewable energy sources such as photovoltaic plants and wind turbines, have risen throughout the last decade significantly. Drivers of this development are mainly the need to substitute fossil fuelled power plants in order to reduce the greenhouse effect, and, to a lesser extent and depending on the location, urges for fossil fuel-independent power supply and economical long-term solutions for electricity generation.

However, in well-built grid areas, a diverse number of DERs and other power supply components, such as energy storages and combined heat and power (CHP) plants have been installed. Depending on the application, a technical and economical combination of DERs could be beneficial. Therefore, several concepts of aggregating DERs have been developed.

Among them, the microgrid (MG) approach for combining distributed energy resources (DER) has recently gained attention both in research and in industry.

A microgrid is an aggregation of DER, storage components such as flywheels, stationary batteries or electrolyzers, sheddable loads and non-sheddable loads in low-voltage distribution systems. The Consortium for Electric Reliability Technology Solutions (CERTS) provided a microgrid definition in [1].

A microgrid is connected to the main grid via a Point of common coupling (PCC). Furthermore, a microgrid is able to switch on and off to a Medium Voltage (MV) grid (islanding) in the case of e.g. grid faults.

The ability to switch to and off the overlying grid and thereby its inherent ability of being connected to the main grid via a PCC divides the microgrid aggregation concept from the Virtual Power Plant (VPP) concept. In a (commercial) VPP, units are not necessarily connected to the main grid via one PCC. Reference [2] differs the two concepts as "hardware-connected" (microgrids) and "software-connected" (VPPs). Furthermore, microgrids can be handled as one technical unit within a distribution grid, whereas VPPs are likely to exist of technical units which are distributed among the grid. Microgrids can be a part of VPPs; this topic is regarded in [2], [3]. However, definitions still have to be found; recently VPPs are divided into Technical (TVPP) and Commercial (CVPP) VPPs. TVPPs are very similar to the given microgrid definition. A workgroup of the Conseil International des Grands Reseaux Électriques (CIGRE) is working on definitions [4].

A common use of a microgrid is supplying electrical energy to remote areas, such as off-grid villages, islands or military compounds. However, due to its ability to switch on and off the main grid in case of faults (islanding), the microgrid concept has gained attention in well-built grid areas as well. For instance, in the city of Sendai, Japan, an installed microgrid continued operation after the Tsunami impact in 2011. Further examples of microgrids in well-built grid areas are:

- Kythnos Island, Greece [5]
- MVV Residential Demonstration, Mannheim, Germany [5]
- Continuon MV/LV microgrid, Netherlands [5]
- Micro Smart Grid EUREF, Berlin, Germany

CIGRE has developed a benchmark microgrid for research questions, which is shown in figure 1. A wide range of load types and microgrid technologies, e.g. wind turbines, photovoltaic power plants, fuel cells or flywheels is included.

The microgrid concept is still in the research stadium and has not been widely deployed in main grids.

A. Microgrid Variants

In terms of current, two versions of microgrids can be differed: AC microgrids, where dispersed generators are connected in the microgrid via an inverter or synchronous/asynchronous generators and DC microgrids, where electrical components are connected within the microgrid in absence of an inverter or additional generators, thereby avoiding additional equipment and losses for transforming the alternating current.

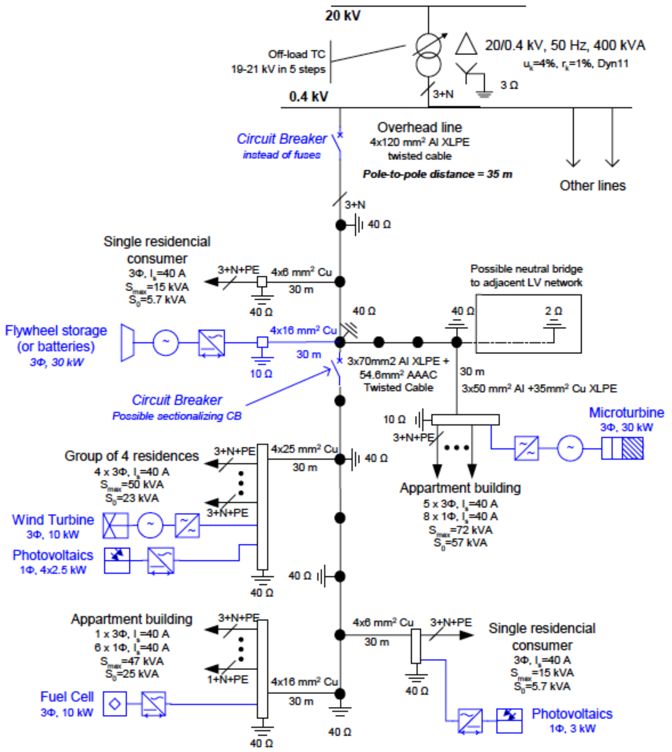

Fig. 1: CIGRE benchmark low-voltage microgrid [6]

According to [7], DC microgrids are suitable for microgrid applications where a high power quality is needed, due to the fact that AC power quality issues, e.g. flicker or unwanted current/voltage harmonics, are avoided.

B. Microgrid Situations

With regard to grid behavior, two different microgrid situations can be distinguished: grid-connected and not grid-connected (islanded). Especially the process of islanding and reconnection to the main grid creates high requirements on microgrid controls.

Different approaches and needs for data communication between microgrid components lead to microgrid variants with different degrees of communication between the components. This is accompanied by centralized and decentralized approaches, where in centralized approaches, commonly a high degree of data communication is implied, whereas in decentralized variants the communication between microgrid components is reduced. Some researchers regard fully decentralized approaches, where very few communication between components is suggested [8].

This paper focuses on control approaches and control levels within a microgrid. Currently, distributed electrical generators, such as photovoltaic or wind power plants, are mostly not controlled besides necessary grid stability purposes. In future, with the increasing number of distributed generators especially in distribution grids, sophisticated control concepts can improve microgrid operation with respect to one or multiple targets. Microgrid control can be differentiated from the Energy Management System (EMS) [9].

Different needs of communication technology within a microgrid are addressed in [8]. Other research fields in the microgrid area are short term generation scheduling [10], optimal design in autonomous (islanded) and grid-connected mode [11], short-term load forecasting [12] and generation scheduling [10], economic analysis of a microgrid installation [13] and provision of ancillary services from microgrids [3], [14], [15].

II. Control Purposes/Targets of Microgrid Controls

Due to the diverse microgrid variants and situations, a variety of different control purposes for a microgrid has to be regarded.

Targets of the microgrid can be divided into technical targets, where most research has been done, and economic targets. Main goals of the microgrid control are [1], [7], [9], [16]:

- Economic operation of the microgrid and its microsources
- Applicable load sharing and DER coordination,
- Ensuring a stable islanding and grid-reconnecting process
- Power flow control within the microgrid and from the microgrid to the main grid
- Improvements to microgrid efficiency
- Insure that the heat and electrical demands are met by the microsources
- Insure that the microgrid satisfies operational contracts with the bulk power provider
- Energy Storage System (ESS) should support the MG and increase the system's reliability and efficiency

Responsible for the technical goals within the microgrid is microgrid system operator or Independent System Operator (ISO) [9]. The Distribution Network Operator (DNO) is responsible for the distribution grid operation and is thus responsible for the microgrid behavior within the distribution system, i.e. the DNO is liable from the PCC on. The Market Operator (MO) is responsible for the economic operation of the microgrid within the energy market environment, thus the MO is considered to create schedules and to develop the portfolio management for the microgrid.

III. Control Approaches

The targets for microgrid control refer to different situations, e.g. islanding, and to different time scales, e.g. dispatch scheduling. Due to this fact, a variety of different control approaches has been developed, where hierarchical approaches are the main part.

Concepts regarding those architectures are described in the following section.

A. Hierarchical Controls

In the recent development of microgrid technologies and especially in the EU research project “Microgrid”, an hierarchical control architecture of three levels is considered [17]–[19].
Control types in this architecture are:

- Local Controllers (LC) or Microsource Controllers (MS),
- Microgrid Central Controller (MGCC),
- Distribution Network Operator/Market Operator (DNO/MO).

In this hierarchy, the DNO is responsible for the operation of the medium or low voltage area the microgrid is connected to. Additionally, one or more MOs are responsible for the economic operation of the microgrid. Furthermore, MOs could be able to enable the market participation of one or more microgrids, possibly creating schedules for the microgrid and thereby for its components.
DNO and MO are communicating with the microgrid and controlling microgrid operations via the MGCC [17]. The MGCC is mainly responsible for converting the DNO/MO commands to the LCs and thereby coordinates the microsources in the microgrid. Hence, the MGCC is responsible for the entire microgrids technical stability.
Each LC is responsible for keeping the technical behavior of its microsource within specified ranges. For example, in Germany the code of practice VDE AR 4105 [20] is applicable for DERs in low-voltage grids; according to this code of practice, short-term voltage deviations must not exceed 3% of the nominal voltage. Internationally, IEEE standard P1547.4 can be applied for DERs [9]. Further standards for power quality and low-voltage distortions, which could be applicable to microgrids, are EN 50160 and IEC 61000.

Local Controllers can have a double function concerning control strategies: On the one hand, the microsource has to be controlled within given limits; on the other hand, local controllers have to execute commands of the MGCC.
In some cases, Local Controllers play a major role in microgrid control, e.g. in case the MGCC is out of function, LCs have to ensure the stability of the microgrid.
In addition to this hierarchical architecture, recent studies have researched various aspects of microgrid control in detail. In [9], the international standard IEC/ISO 62264 is applied to microgrid control. The authors consider four control levels in total. In addition to the above mentioned hierarchy of three levels, an additional level between LC and MGCC is considered, the primary control level.
Hierarchical controls are mainly suitable for AC microgrids, but can be adopted with modifications to DC microgrids as well [7].

B. Decentralized Controls

Decentralized control approaches are usually used either when a centralized control (MGCC) is not necessary, not fast enough or too expensive to coordinate the microgrid components. In the case of e.g. islanding of the microgrid, a reaction of microgrid components in the area of milli- and microseconds is needed to guarantee a stable operation of the grid.
Moreover, decentralized control is ideally utilized in the case of different suppliers, i.e. different microsource operators which might pursue different economic and technical goals.
Decentralized energy management options regard the fact that often multiple MS owners act within a microgrid so that goals like system stability can only limitedly be handled by a system operator, but rather have to be regarded by every microgrid component.
Decentralized controls have to be set at the LCs and have to handle with available data, e.g. the grid voltage at the inverter, to set operation points for each component.

C. MAS-based control

Multi-agent systems (MAS) based approaches define agents for components or roles within the microgrid. Via MAS, it is possible to implement both centralized and decentralized microgrid management strategies. Approaches for a MAS-based microgrid management is presented in [17], [21], [22].
Furthermore, it is possible to combine centralized and decentralized control strategies to hybrid strategies, which could apply for particular situations of microgrid control, e.g. centralized control for market participation or decentralized control for islanding of the microgrid.

IV. CONTROL LEVELS

Based on [2], [7], [9], [23], microgrid control can be divided in three to four levels:

- Inner Control Loop (Level 0),
- Local Control Loop/Primary Level (Level 1),
- Secondary Control Loop (Level 2),
- Global Control/Tertiary Control Loop (Level 3)

Particularly, [9] recently investigated if the standard IEC/ISO 62264 would be applicable for microgrid control structures. As this is the most substantial and elaborate approach at hand which categorizes the microgrid control levels, this work will be mainly followed in this paper.

A. Inner/Internal Control Loop/Level 0

This control level is based at the component level (LC/MC). Target of this control level is to manage the power of MSs [9]. Reference [24] divides the voltage control principles in this level into:

- P/Q inverter control: The inverter provides a set point for both active and reactive power, and
- Voltage Source Inverter (VSI) Control: The inverter is controlled to feed the load with pre-defined values for voltage and frequency.

Inner control loop is set within the microgrid component and controls the microgrid behavior, e.g. a wind turbine is controlled by a LC which adapts rotor speed and pitch angle for maximum energy output of the turbine.

B. Primary Control Loop/Level 1

The primary control level is needed to pursue the following targets [7], [9], [25]:

- Adjust the frequency and amplitude of the voltage references that are fed to the inner current and voltage control loops (Level 0). So this control level's due is to ensure that operation points of the microgrid components are set in a way which ensures microgrid stability.
- Plug-and-Play Capability for DERs and proper sharing of active and reactive power between them, possibly without communication between the DERs
- Mitigating circulating currents that can cause over-current phenomena in the power-electronic devices.

In this level, energy balance between DGs and energy storage should happen. The Primary Control Level should have the fastest response of all control levels [2], [9]. This assumption is due to the behavior of power-electronic devices within the microgrid, which are wide-spread, as most DER components in AC grids are connected to the grid via inverters. If DGs with synchronous generators (SG), e.g. small wind turbines, are connected to the microgrid, maybe this constraint can be regarded with a lower priority, as the inertia from SGs could reduce the response time of the control mechanism by a certain amount.

Due to the high priority to technical and economical goals, the primary control level is a topic which is extensively researched in the literature.

Out of the relevant literature, [8] provides an extensive review about issues of the primary level and an overview of control strategies. Control strategies with communication are:

- Central Control/Concentrated Control. A central controller coordinates the power-electronic interfaces in order to maintain the balance in active and reactive power in steady-state conditions. Communication links between the central controller and the power-electronic devices are needed. Central control is simple and stable, but has a low reliability and redundancy.
- Master/Slave control: A master unit has voltage control, is responsible for voltage regulation and for current specifications of each inverter (slaves). This control method can be further distinguished in Master/Slave control with a central controller, without a central controller and Auto-master-slave control. A disadvantage of Master/Slave control is its dependence on the reliability of the Master component.

Further control methods with communication are Instantaneous Current Sharing, Peak-value Based Current Sharing, Circular Chain Control, Distributed Control, and Angle Droop.

Control strategies without communication are droop controls. A very common control method is the P/f droop control. P/f droop control is based on mimicking a synchronous generator, where the active power P of a microsource is controlled via the grid frequency f, e.g. via a characteristic curve. Another droop control is the P/V droop control. In low-voltage networks, line resistance has a higher share on the impedance than in high-voltage networks. This leads to a higher link between active power and the voltage difference. To address this matter, the P/V droop control is proposed for microgrid components.

C. Secondary Control Loop/Level 2

The main goal of the secondary control loop is to compensate errors of the primary control level [9], i.e. this control loop eliminates frequency and voltage deviations which remain after the primary control took effect. Reference [2] proposes a control method for secondary control, where remaining deviations of the primary control level are first balanced by storage devices. If the capacity of storage devices is reached or storage is not available, the secondary control could help restoring the set points of the components by activating demand response, thus conducting an adaptive control.

Reference [9] divides this control level in centralized and decentralized approaches.

In centralized control, the MGCC is obliged to secure the duties of the secondary control. This type of secondary control is especially suitable for certain small, manually controlled MGs, MGs with common goals or cooperative MGs [16].

By the decentralized secondary control, the microsources' maximum power has to be specified, considering the consumer needs and power increasing to the grid for market participation.

There could be a need to act simultaneously, as is the case when a microgrid participates in electricity markets. Therefore it could be useful if a combination of centralized and decentralized controls is available.

D. Tertiary Control Loop/Level 3

According to *[9]*, there are two main purposes of the tertiary level. In the case of connecting the microgrid to the main grid, voltage and frequency have to be measured and reference values for the secondary control loop have to be determined.

Furthermore, the tertiary level manages the power flow of the microgrid in grid-connected mode. Hence, this control loop manages voltage and frequency of the microgrid via the Point of Common Coupling (PCC). Reference *[9]* proposes that via measuring the active and reactive power at the PCC, values for P and Q could be set to a desired operation point and thereby the microgrid's active power can be controlled. This could have technical as well as economical benefits *[7]*.

Due to its nature to be only available in grid-connected mode and its minor importance on microgrid stability, this control level is assumed to have the slowest response time and could be overridden in case of occurrences of higher technical priority, e.g. grid faults and subsequent island of the grid or DERs faults and the subsequent necessity of a rearrangement of operation set points. Reference *[9]* assumes that in islanded mode, the secondary control is the highest control level, whereas in grid-connected mode the tertiary control level reinstates itself.

From an economic point of view, this control level could be the most interesting, as it is possible to generate economic benefits for the whole microgrid participants, e.g. the market operator (MO), aggregators or energy suppliers, by treating the microgrid as one combined technical unit.
Reference *[7]* points out that at the tertiary control loop a MAS control can be established for microgrid power management. This level is not a control level as it is not sending control signals to components, but is rather an economic layer which provides the tertiary control loop with necessary information about economic microgrid operation *[9]*. Fig. 2 summarizes the control concept from *[9]*.

V. Conclusion

In this paper, a review of microgrid situations, control purposes and control approaches for microgrids as well as new approaches to control levels within a microgrid is given.
A microgrid can contain diverse energy components, such as DER, storages or dispatchable loads. Microgrid definitions according to CERTS and CIGRE are given and differences to VPP concepts are discussed.
Microgrid applications include AC/DC microgrids, Islanded/Grid-connected microgrids and can contain multiple different suppliers and aggregators within a microgrid.
Therefore, different control approaches have been briefly presented, as hierarchical controls are the main concept which is found in the literature. Further control concepts are decentralized and MAS-based controls.
Based on hierarchical controls, several microgrid control levels can be distinguished. Inner control loop is set at the microgrid component and controls the microgrid behavior. In the primary control, set points for each microgrid component and therefore the power-electronic devices, by which the components are connected to the grid, are determined. In literature, the primary control level is extensively researched. Main approaches of the primary level are briefly presented, including droop control methods.
The secondary control mainly resets persisting deviations from the primary level, whereas the tertiary level is necessary for power flow management in the case of grid connection of the microgrid. The literature is not consistent about the duties of primary, secondary and tertiary level, sometimes combining different levels to one level.
Microgrid controls are researched in detail in the literature, whereas an extensive research on microgrid participation in

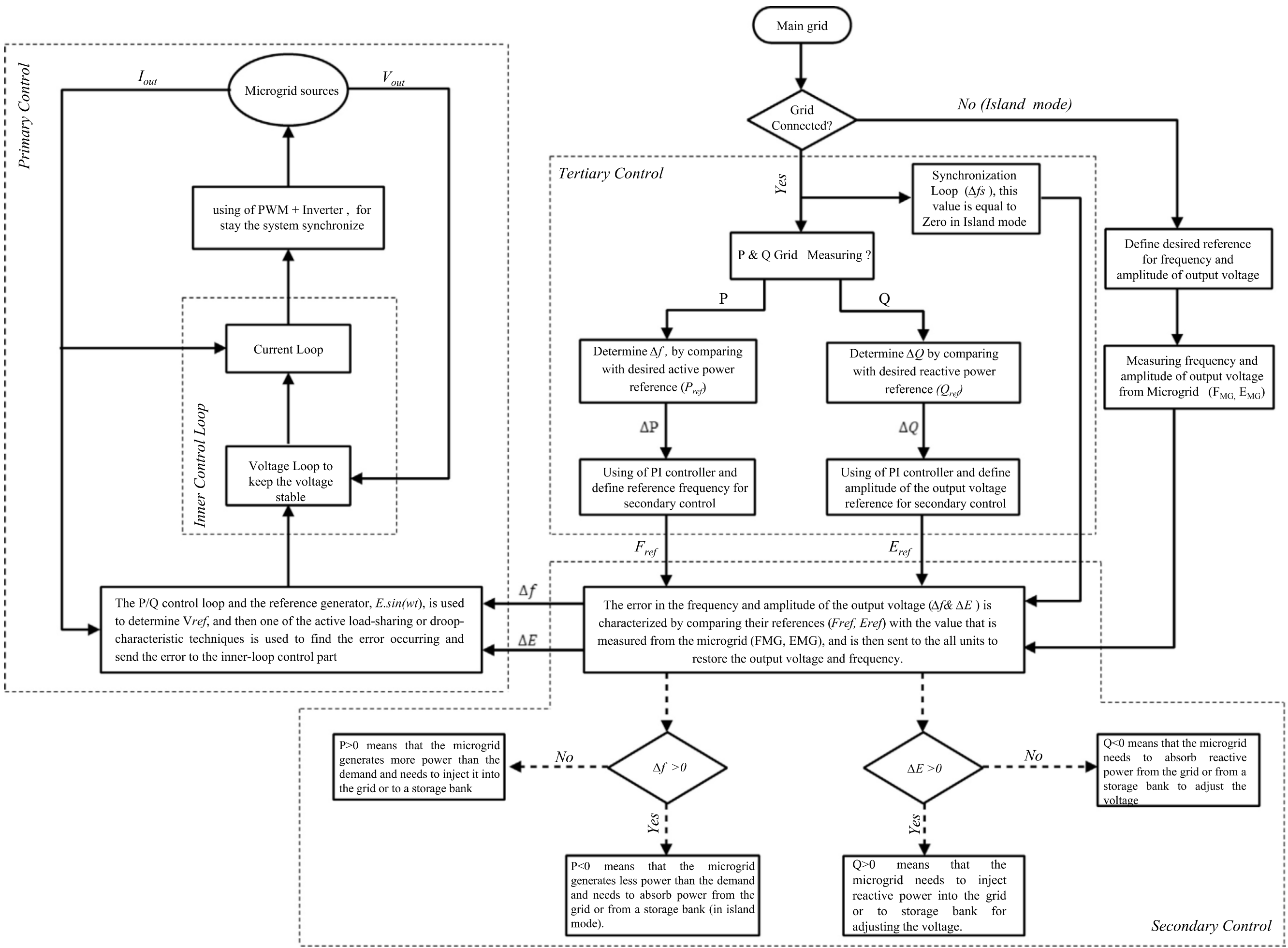

Fig. 2: Microgrid control levels, connections and duties as derived from IEC/ISO 62264 [8]

energy markets is an issue which will be regarded in future work.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the partial funding of this work by research project ”D3 – MSG EUREF” as a part of “Schaufenster Elektromobilität” research program.

REFERENCES

[1] R. Lasseter, A. Akhil, C. Marnay, J. Stevens, J. Dagle, R. Guttromson, A. Sakis Meliopoulous, R. Yinger, and J. Eto, *Integration of Distributed Energy Resources - The CERTS MicroGrid Concept*. 2002.

[2] T. L. Vandoorn, B. Zwaenepoel, J. D. M. De Kooning, B. Meersman, and L. Vandevelde, “Smart microgrids and virtual power plants in a hierarchical control structure,” *2011 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies*, pp. 1–7, Dec. 2011.

[3] C. Yuen, A. Oudalov, and A. Timbus, “The Provision of Frequency Control Reserves From Multiple Microgrids,” *IEEE Transactions on Industrial Electronics*, vol. 58, no. 1, pp. 173–183, Jan. 2011.

[4] “WG C6.22 Microgrids - Cigre.” [Online]. Available: http://c6.cigre.org/WG-Area/WG-C6.22-Microgrids. [Accessed: 16-May-2014].

[5] N. Hatziargyriou, H. Asano, R. Iravani, and C. Marnay, “Microgrids,” *Power and Energy Magazine, IEEE*, vol. 5, no. 4, pp. 78–94, 2007.

[6] S. Papathanassiou, N. Hatziargyriou, and K. Strunz, “A benchmark low voltage microgrid network,” in *Proceedings of the CIGRE Symposium: Power Systems with Dispersed Generation*, 2005, pp. 1–8.

[7] A. Bidram, S. Member, and A. Davoudi, “Hierarchical Structure of Microgrids Control System,” vol. 3, no. 4, pp. 1963–1976, 2012.

[8] T. L. Vandoorn, J. D. M. D. Kooning, B. Meersman, and L. Vandevelde, “Review of primary control strategies for islanded microgrids with power-electronic interfaces,” *Renewable and Sustainable Energy Reviews*, vol. 19, pp. 613–628, 2013.

[9] O. Palizban, K. Kauhaniemi, and J. M. Guerrero, “Microgrids in active network management—Part I: Hierarchical control, energy storage, virtual power plants, and market participation,” *Renew. Sustain. Energy Rev.*, pp. 1–13, Jan. 2014.

[10] T. Logenthiran and D. Srinivasan, “Short term generation scheduling of a Microgrid,” in *TENCON 2009 - 2009 IEEE Region 10 Conference*, 2009, pp. 1–6.

[11] M. A. Hassan and M. A. Abido, “Optimal Design of Microgrids in Autonomous and Grid-Connected Modes Using Particle Swarm Optimization,” *IEEE Transactions on Power Electronics*, vol. 26, no. 3, pp. 755–769, Mar. 2011.

[12] N. Amjady, F. Keynia, and H. Zareipour, “Short-Term Load Forecast of Microgrids by a New Bilevel Prediction Strategy,” *IEEE Transactions on Smart Grid*, vol. 1, no. 3, pp. 286–294, Dec. 2010.

[13] P. M. Costa and M. A. Matos, “Economic analysis of microgrids including reliability aspects,” in *Probabilistic Methods Applied to Power Systems, 2006. PMAPS 2006. International Conference on*, 2006, pp. 1–8.

[14] J. T. Saraiva and M. H. Gomes, “Provision of some ancillary services by microgrid agents,” in *Energy Market (EEM), 2010 7th International Conference on the European*, 2010, pp. 1–8.

[15] C. Yuen and A. Oudalov, “The Feasibility and Profitability of Ancillary Services Provision from Multi-MicroGrids,” *2007 IEEE Lausanne Power Tech*, pp. 598–603, Jul. 2007.

[16] R. Zamora and A. K. Srivastava, “Controls for microgrids with storage: Review, challenges, and research needs,” *Renew. Sustain. Energy Rev.*, vol. 14, no. 7, pp. 2009–2018, Sep. 2010.

[17] A. L. Dimeas, S. Member, N. D. Hatziargyriou, and S. Member, “Operation of a Multiagent System for Microgrid Control,” vol. 20, no. 3, pp. 1447–1455, 2005.

[18] H. Jiayi, J. Chuanwen, and X. Rong, “A review on distributed energy resources and MicroGrid,” *Renewable and Sustainable Energy Reviews*, vol. 12, no. 9, pp. 2472–2483, Dec. 2008.

[19] A. G. Tsikalakis and N. D. Hatziargyriou, “Centralized control for optimizing microgrids operation,” in *2011 IEEE Power and Energy Society General Meeting*, 2011, pp. 1–8.

[20] VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V., *VDE-AR-N 4105 Erzeugungsanlagen am Niederspannungsnetz – Technische Mindestanforderungen für Anschluss und Parallelbetrieb von Erzeugungsanlagen am Niederspannungsnetz*. 2011, pp. 80–80.

[21] G. Basso, V. Hilaire, F. Lauri, and D. Paire, “A Principled Approach for Smart Microgrids Simulation Using MAS,” pp. 193–207, 2013.

[22] C. M. Colson and M. H. Nehrir, “Comprehensive Real-Time Microgrid Power,” vol. 4, no. 1, pp. 617–627, 2013.

[23] J. J. Justo, F. Mwasilu, J. Lee, and J.-W. Jung, “AC-microgrids versus DC-microgrids with distributed energy resources: A review,” *Renew. Sustain. Energy Rev.*, vol. 24, pp. 387–405, Aug. 2013.

[24] J. A. P. Lopes, S. Member, C. L. Moreira, and A. G. Madureira, “Defining Control Strategies for MicroGrids Islanded Operation,” vol. 21, no. 2, pp. 916–924, 2006.

[25] J. M. Guerrero, S. Member, J. C. Vasquez, J. Matas, L. G. D. Vicuña, and M. Castilla, “Hierarchical Control of Droop-Controlled AC and DC Microgrids — A General Approach Toward Standardization,” vol. 58, no. 1, pp. 158–172, 2011.