Australian Journal of Basic and Applied Sciences, 9(33) October 2015, Pages: 56-63

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Robust Distributed Generation and Storage Unit Based On Co-Operative Control For A DC Microgrid

[1]Mrs. J.Karthika, [2]Dr.V.Subbiah and [3]Dr. S. Kanthalakshmi

[1]*Assistant Professor, Sri Krishna College of Engg and Tech, India)*
[2]*Associate Professor PSG College of Technology, India*
[3]*Visiting Professor, PSG College of Technology, India*

ARTICLE INFO

Article history:
Received 3 October 2015
Accepted 31 October 2015

Keywords:
ANFIS, Cooperative control, Distributed Generation, DC Microgrid, , droop control.

ABSTRACT

A Low voltage dc microgrids were widely used for supplying various loads, such as space crafts and data centres. Also, it is important to ensure redundancy and enough energy capacity in order to support various changes in load consumption. This is achieved by the addition of extra distributed energy storage units. However, using the distributed energy storage units in a system adds more challenges in microgrids control. However, the stored energy should be balanced in order to avoid deep discharge (DOD)and over-charge (SOC) in both the energy storage units. Voltage droop loops are used for interconnecting several different units in parallel to a microgrid. In this paper a new decentralized strategy based on ANFIS logic is used which ensures the stored energy balance for a low voltage dc microgrid with distributed battery energy storage systems by modifying the virtual resistances ofthe droop controllers in accordance with the state of charge of each energy storage unit. Also, the virtual resistance is adjusted in order to reduce the voltage deviation at the common dc bus. The units are self-controlled by using local variables. The MATLAB/SIMULINK is used to model the system and the simulation results are shown. The performance of developed control was assessed through experimental results.

To Cite This Article: Mrs. J.Karthika, Dr.V.Subbiah and Dr. S. Kanthalakshmi., Robust Distributed Generation and Storage Unit Based On Co-Operative Control For A DC Microgrid. ***Aust. J. Basic & Appl. Sci.,*** *9(33): 56-63, 2015*

INTRODUCTION

Due to technological advancement in power electronics for the past few decades has led to the condition where two or more renewable energy sources (RES) can be considered as a controllable by its natural phenomenon (Blaabjerg, F., 2004). Microgrids are the solution for integrating distributed energy resources (DER), loads and Energy Storage Systems (ESS) which may operate in grid-connected or even islanded mode, either in AC or DC configuration (Vandoorn, T., 2013). DC microgrids have no issues like Synchronization, Reactive Power Flow, Harmonics and Losses but are intrinsic in AC micro grids (Kakigano, H., 2013). The sporadic nature of RES added with unpredictable load fluctuations may cause instantaneous power unbalances that affect the operation of the microgrid. Hence it is decided to have more distributed ESS for providing redundancy and energy support; also it provides higher efficiency, more natural inference of RES, better compliance with consumer electronics, guaranteed reliability and power stability (Kakigano, H., 2013; Dragiˇcevi´c, T., 2013). The merging of small variable nature sources with an Energy Storage System (ESS) in to a single controllable entity that can work standalone or grid connected brought to a conceptnamed microgrid (Lasseter, R., 2002). Plenty of analysis has been done previously in improving the operation of ACMicrogrids (Pogaku, N., 2007; Li, Y.W. and C.N. Kao, 2009). However, the reactive power flow, power quality, and frequency control are not an issue in DC systems. The most common applications of DC MGs are electrical power supply of isolated systems like remote communication stations, telecom systems, vehicles or rural areas (Schneider, K., 2005; Valenciaga, F. and P. Puleston, 2005). When two or more ESS exist in a microgrid, a proper coordination is requires to safeguard stored energy balance among the units, in order to avoid deep-discharge in one of the energy storage unit and over charge in the others. Therefore during the process of charging, it is desirable to prioritize thecharge of the unit with the smallest state of charge (SOC), andsimilarly, during the process of discharging, the unit with thehighest SOC should provide more power to the microgrid thanthe others in order to ensure stored energy balance (Chen, Y.K.,

Corresponding Author: Mrs. J.Karthika, Assistant Professor, Sri Krishna College of Engg and Tech, India)
E-mail: karthikarajkumar11@gmail.com

2013; Vasquez, J., 2013).The droop control method is used commonly when two or more units are connected in parallel to the dc bus through a dc/dc converter, to ensure a current sharing feature among the units (Karlsson, P. and J. Svensson, 2003; Schonberger, J., 2006). In a worthy energy balance has been obtained by adjusting the virtual resistance (VR) in voltage droop controllers. A common centralized supervisory control is used but the voltage regulation is not strongly guaranteed. In (Lu, X., 2012) a new approach for adjusting the controller based on SOC in a distributed ESS has been proposed but it considers only when the batteries are supplying power to the load. But in author proposed a fuzzy based gain-scheduling algorithm to achieve good voltage regulation, energy balance in a distributed ESS and power sharing. Here the centralized fuzzy controller is used to modify the voltage reference for balancing the stored energy.

In this paper designing and implementation of ANFIS based supervisory controller is proposed for achieving good stored energy balance among several ESS.ANFIS combines the advantages of Fuzzy Logic and Neural Networks and hence deals efficiently with nonlinear behaviour of the model. This proposed controller is able to adjust the VR in accordance to the common DC bus voltage in order to reduce the voltage deviation and also for the energy management of ESS in microgrids. This paper is organised as follows. In section II DC Microgrid configuration, operation and control under isolated operation is described. Section III describes the design and operations of the proposed ANFIS controllers. Section IV shows the results under different operation modes. This proposed method is simulated using MATLAB/SIMULINK and the result shows the effectiveness of the proposed method. Section V represents conclusion and future works.

II Configuration, Operation and Control of the DC Microgrid:

A DC Microgrid is shown in Fig. 1. It is composed of PV Panels and Wind Turbine Generator, two battery banks, a common DC bus and variety of loads. The microgrid has a common bus voltage of about $48V_{dc}$where these kind of low voltage microgrids have been widely used for residential applications and in communication Networks (Li, W., 2012; McMenamin, D., 1998; White, R., 1988).

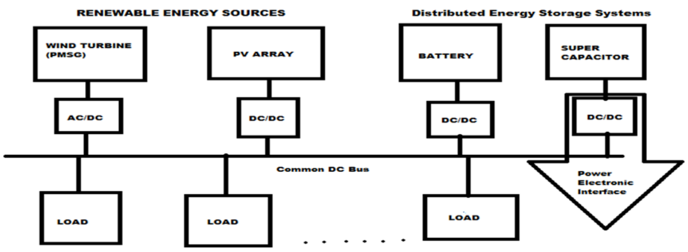

Fig. 1: General Structure of a DC Microgrid.

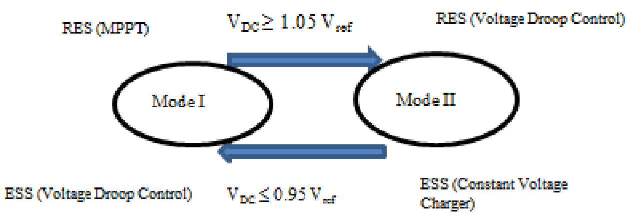

Fig. 2: (i) Mode I - regulated by Distributed ESS.

(ii) Mode II - regulated by Distributed RES:

In Islanded mode, the dc common bus regulation is based on the kind of distributed energy resources. It can be regulated in Two Modes as shown in Fig. 2. (i) Mode I - regulated by Distributed ESS (ii) Mode II - regulated by Distributed RES. This control strategy directs each energy storage unit and changes based on the SOC value of the battery in order to balance the power generated by the RES and the power consumption. The control strategy of the RES changes in accordance to the common DC bus voltage and in the same way it changes the mode of operation of the microgrid (Sun, K., 2011).

But the control strategy of DER requires two inner control loops in order to function under the two different modes and control states. The complete configuration of DC Microgrid with complete control scheme is shown in Fig. 3.The inner control loops in battery converter and in each RES converter are also clearly shown.Fig. 4 represents the Modes of operation.

A. *Mode I :*

In this mode, both Wind and Solar renewable energy sources operate under MPPT and it can be seen as Constant Power Sources (CPS) (Diaz, N., 2011; Errami, Y., 2012). Meanwhile, the converters of the battery work under droop control method and are responsible for regulating DC bus voltage. Fig. 4a represents the equivalent circuit for mode I. A constant power source (CPS) is represented by a resistor in parallel with a constant current source and the voltage source in series with the resistance R_d represents the voltage droop control of a battery.

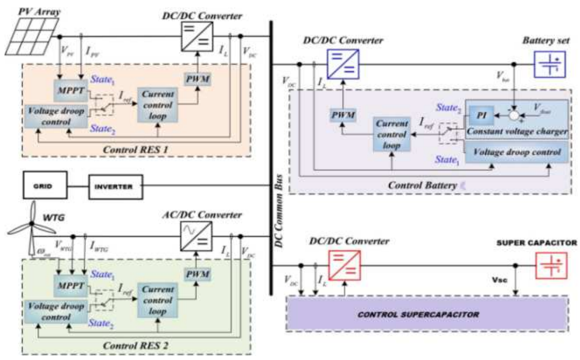

Fig. 3: DC Microgrid with control loops.

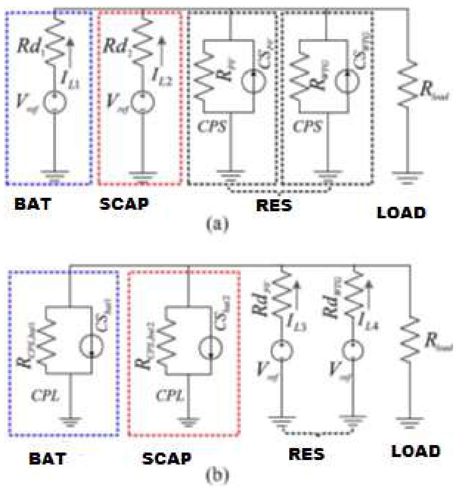

Fig. 4: Proposed microgrid operation (a) Mode I (b) Mode II.

In this mode the value of SOC of the batteries is maintained between 60% and 100%. The batteries can be charged or discharged based on the generated power and the load consumption (Zhang, Y., 2012). If the power generated by the RES is higher than the load consumption then the batteries are allowed to charge. On the contrary, if there is an unbalance between generated power and the consumed power, then the batteries are allowed to discharge. To avoid deep discharge levels (below 50%) it is important to implement a load shedding scheme so that the life time of the battery can be saved. The batteries are charged by a two stage procedure, current-limited followed by a constant voltage charger.

During the first stage of charge, the current is limited by droop control loops. When the voltage per cell reaches a value of 2.45±0.05 volts/cell, the voltage of the battery should be kept constant. This value is known as a floating voltage (V_{float}). At this stage, the current in the battery will approach to zero asymptotically, and once if it falls below a certain value, then the battery may be considered as fully charged. When the voltage of each battery reaches the reference value (V_{float})the control of the converter switches to a constant voltage charger for the battery, in which, the battery draws as much current as needed to keep its voltage at V_{float}. When both batteries reach the float voltage, the RES continues operating in MPPT until a voltage threshold (V_H= V_{ref} *1.05)is reached in the dc bus. Then, the RES changes their inner control loops from MPPT to a voltage droop control in which the power drawn from the RES is limited to the power consumption of the microgrid. At this moment, the microgrid is under operation mode II[see Fig. 4b].

B. *Mode II:*

In this mode, the RES are responsible for dc commonbus regulation, since both batteries are under constant voltage charge. For that reason, the batteries

Australian Journal of Basic and Applied Sciences, 9(33) October 2015, Pages: 56-63

will only take, as much current as necessary from the microgrid for keeping the batteries voltage regulated at (V_{float}). Then, batteries can be represented as constant power loads (CPL) (Rahimi, A. and A. Emadi, 2009). Fig. 4b. represents the equivalent circuit for mode II. The microgrid continues operating in this mode until a voltage threshold (VL = Vref ・0.95) is reached at the dc bus. This may occur whether the consumption of the load is bigger than the power generated by the RES. At this point, the microgrid changes to operation mode I.

C. Controllers Operation:

Decentralized finite state machines with two states are used for transition between controllers at each unit. In case of Energy storage System, the transition between state 1 to state 2 i.e. Voltage droop control to constant voltage charger is controlled by the battery voltage when $V_{bat} = V_{float}$.The transition between state 2 to state 1 is controlled by the common DC voltage when$V_{DC} \leq V_L$. In case of Renewable Energy Sources, the transition between state 1 to state 2 i.e. MPPT to Voltage droop control is controlled by the common DC bus voltage $V_{DC} \geq V_H$.The transition between state 2 to state 1 is controlled by the common DC bus voltage when$V_{DC} \leq V_L$.

III. ANFIS based Virtual Resistance:

The objective in designing of ANFIS system for adjusting the virtual resistances is to ensure the complete balance between the ESS and also to maintain the SOC value within the limits to avoid deep discharge and over charging of batteries. Also, the voltage deviation in the common dc bus is reduced. Since it is a decentralized method, only local variables are used for the adjustment of the virtual resistances. The voltage droop controllers are used by RES and ESS at different operating modes of the microgrid, a different ANFIS controller may be designed for DER and for ESS.

A. ANFIS for Battery Charge and Discharge:

During, charging and discharging of batteries the power is balanced by the droop control loops. The output voltage is represented as,

$V_{DC} = V_{ref} - I_{LI} * R_{di}$ ------ (i)

Where $V_{DC}$is the voltage at common dc bus, V_{ref} is the reference voltage of the common dc bus, $I_{LI}$is the output current at each converter, and Rdiis the virtual resistance at each droop control loop. (Guerrero, J., 2011; Nelson, L., 2014) the battery with small R_d will extract or inject more current in order to maintain a balanced power in the microgrid. Because of this reason the battery with lowest SOC is charged first in order to balance the stored energy. Hence smaller value of R_d has to assign to that battery. Likewise the battery with highest SOC is discharged first. In order to prevent deep discharge and also to balance the stored energy the battery with lowest SOC should be assigned with higher value of R_d.It is also important to prevent voltage deviation in the DC bus. To prevent the high voltage deviation at the DC bus, a small value for R_d is appropriate when $V_{DC}$is far fromV_{ref}.
However, a high value for R_d is appropriate when $V_{DC}$is near to V_{ref}.

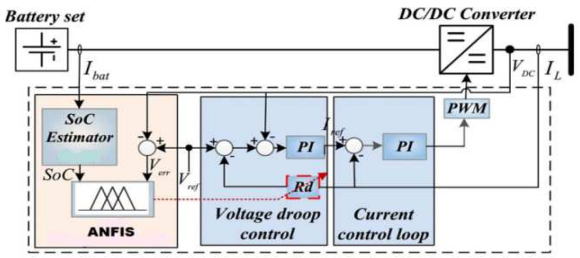

Fig. 5: Proposed ANFIS controller based virtual resistance for ESS under Mode I operation.

Artificial Neuro fuzzy inference system (ANFIS) can easily update all the above said qualitative knowledge. This controller can easily deal with different control objectives at the same time. In this case it controls the stored energy balance and DC bus voltage deviation. This system uses the knowledge of an expert and experience about the behaviour of the system to work out and find the virtual resistance value at each control loop. In this paper Artificial Neural Network and Mamdani FIS has been used for changing the virtual resistance value R_d at each battery converter system. This system uses the SOC and the voltage error (V_{err}) as inputs and the virtual resistance R_d as the output. The value of SOC is obtained by Ampere-hour (Ah) counting method.

$V_{err} = V_{ref} - V_{DC}$ ------ (ii)

$$SOC = SOC(0) - \int_0^t \frac{I_{bat}(\tau)}{C_{bat}} d\tau \quad ----- \quad -(iii)$$

Where SOC (0) represents the initial SOC value, C_{bat} represents the capacity of the battery and I_{bat} is the current of the battery. Fig. 5 represents the proposed ANFIS controller based virtual resistance for ESS under Mode I operation. This controller is used only when the battery is in voltage droop control mode in state 1.

Australian Journal of Basic and Applied Sciences, 9(33) October 2015, Pages: 56-63

Fig. 6 represents the Proposed ANFIS controller based virtual resistance for RES under Mode II operation. The value of virtual resistance is adjusted based on the expected behaviour of the system.

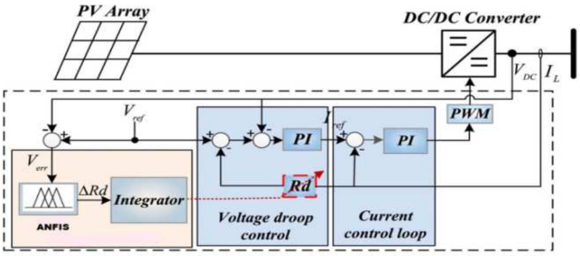

Fig. 6: Proposed ANFIS controller based virtual resistance for RES under Mode II operation.

The voltage deviation in the DC bus plays an important role in the performance of the system. ANFIS reduces the voltage deviation but not able to eliminate it.The R_d range in ANFIS can be determined by analyzing the circuit shown in Fig 4(a).

$$V_{DC} = \frac{\frac{V_{ref}}{R_{deq}} + \sqrt{\left(\left(\frac{V_{ref}}{R_{deq}}\right)^2 + 4P_{CPS}\left(\frac{1}{R_{deq}} + \frac{1}{R_{Load}}\right)\right)}}{2\left(\frac{1}{R_{deq}} + \frac{1}{R_{Load}}\right)}$$

Where R_{deq} and R_{CPS} are the equivalent Virtual Resistance and the equivalent resistance of RES. I_{CPS} is the equivalent current of the CPS.

B. ANFIS for Voltage Regulation under Mode II:

In Mode II RES is responsible for DC bus voltage regulation. At this point Both Wind and Solar RES operated under Droop control loops. The value of R_d is adjusted for reducing the voltage deviation. The adjustment of $R_d$is based on ANFIS system of which the output is an incremental signal (ΔR_d). Depending on the error value (V_{err}), the virtual resistance can be decreased or increased.

Table I: Parameters Of The Microgrid.

Parameter	Symbol	Value
DC bus voltage reference	V_{ref}	48V
Maximum Power from RES	P_{max}	300W
Maximum power in the load	$P_{Load\ max}$	250W
Floating Voltage	V_{float}	54V
Nominal Virtual Resistance	$R_{d\ nom}$	0.8Ω
Low voltage Threshold	V_L	45.6V
High voltage Threshold	V_H	50.4V
Nominal Battery Capacity	C_{bat}	0.02(Ah)

IV. Experimental Results:

The simulation time is divided into four stages in order to indicate the system performance clearly as shown in fig. 7. In the stage I (T1), the microgrid is operating under mode-I. The generated power of combined RES is 290W and the batteries are being charged. With the ANFIS controller, the SOC value of battery 2 approaches battery 1 asymptotically. At the end of T1, battery 1 reaches the floating voltage; therefore it changes from voltage droop control to constant voltage charger. We can see that the voltage deviation is only very small compared to other controllers. During stage II (T2), the battery 2 reaches its floating voltage; therefore it changes from voltage droop control to constant voltage charger. It can be seen that the total time taken to charge the battery (T1+T2) is very less compared to other controllers. During stage III (T3), RES operates in MPPT mode and the batteries are in constant voltage mode. The DC bus voltage starts to increase. While it reaches the value ($V_{DC} = V_H$), then the system changes to mode II (T4). During this transition the normal controllers will have big spikes in the output. But this controller reduces the spikes in the battery current during transition. During stage IV (T4), RES is operating in voltage droop control mode and batteries are in constant voltage mode. The current decreases exponentially and also the voltage deviation is smaller in the system using ANFIS controller.

Fig. 8 represents the performance of microgrid when the power generated by the renewable energy sources varies with respect to time, with the adjustment of virtual resistance using ANFIS controller. We can also see the performance of the proposed controller under charging and discharging of Batteries. Till the end of Stage III (T3), the microgrid operated in Mode I.RES and ESS operates under voltage droop control.

V. Conclusion:

The proposed ANFIS controller based adjustment of Virtual Resistance provides good energy storage balance and less voltage deviation in the DC bus. This method is more flexible and does not require a centralized control. This method can add new energy storage units without any modifications. This method proves that the batteries charges faster compared to the traditional methods. In addition, the ANFIS controller balances the stored energy and also reduces the voltage deviation. Also the controller has the advantage of changing the values of R_d. Hence, the microgrid can operate in a stable state under different situations without using communications.

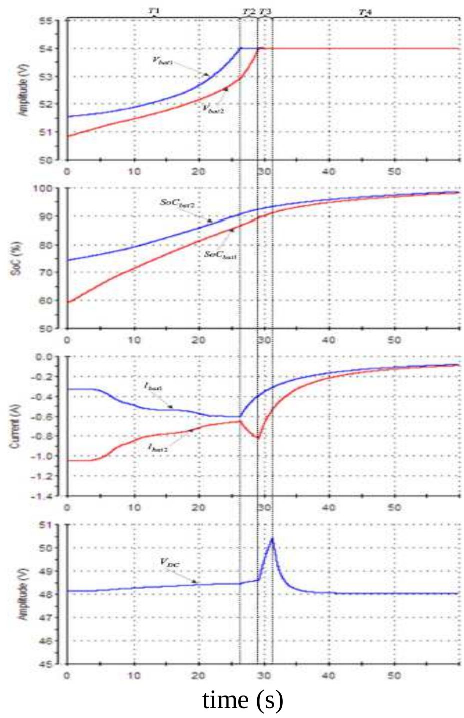

Fig. 7: Simulation result when Microgird changes from Mode I to Mode II.

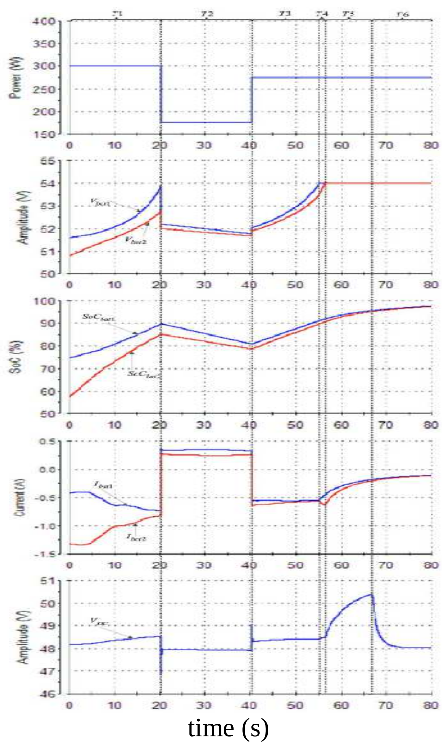

Fig. 8: Simulation results shows the charging and discharging of batteries under Mode I.

REFERENCES

Blaabjerg, F., Z. Chen and S. Kjaer, 2004. "Power electronics as efficient interface in dispersed power generation systems," *IEEE Trans. Power Electron.*, 19(5): 1184–1194.

Vandoorn, T., J. Vasquez, J. De Kooning, J. Guerrero and L. Vandevelde, 2013. "Microgrids: Hierarchical control and an overview of the control and reserve management strategies," *IEEE Ind. Electron. Mag.*, 7(4): 42–55.

Kakigano, H., Y. Miura and T. Ise, 2013. "Distribution voltage control for DC microgrids using fuzzy control and gain-scheduling technique," *IEEE Trans. Power Electron.*, 28(5): 2246–2258.

Salomonsson, D., L. Soder and A. Sannino, 2009. "Protection of low-voltage DC microgrids," *IEEE Trans. Power Del.*, 24(3): 1045–1053.

Kakigano, H., Y. Miura and T. Ise, 2010. "Low-voltage bipolar-type DC microgrid for super high quality distribution," *IEEE Trans. Power Electron.*, 25(12): 3066–3075.

Schonberger, J., R. Duke and S. Round, 2006. "Dc-bus signaling: A distributed control strategy for a hybrid renewable nanogrid," *IEEE Trans. Ind. Electron.*, 53(5): 1453–1460.

Sun, K., L. Zhang, Y. Xing and J.M. Guerrero, 2011. "A distributed control strategy based on DC bus signaling for modular photovoltaic generation systems with battery energy storage," *IEEE Trans. Power Electron.*, 26(10): 3032–3045.

Balog, R.S. and P.T. Krein, 2011. "Bus selection in multibusDC microgrids," *IEEE Trans. Power Electron.*, 26(3): 860–867.

Boroyevich, D., I. Cvetkovic, D. Dong, R. Burgos, F. Wang and F. Lee, 2010. "Future electronic power distribution systems a contemplative view," in *Proc. 12th Int. Conf. Opt. Electr. Electron. Equipment*, 1369–1380.

Dragiˇcevi´c, T., J. Guerrero, J. Vasquez and D. Skrlec, 2013. "Supervisory control of an adaptive-droop regulated DC microgrid with battery management capability," *IEEE Trans. Power Electron.*, 29(2): 695–706.

Lasseter, R., 2002."MicroGrids," in *Proc. IEEE Power Eng. Soc. Winter Meet. Conf.*, 1: 305–308.

Pogaku, N., M. Prodanovic and T.C. Green, 2007. "Modeling, analysis and testing of autonomous operation of an inverter-based microgrid," *IEEE Trans. Power Electron.*, 22(2): 613–625.

Katiraei, F., M. Iravani and P. Lehn, 2005. "Micro-grid autonomous operation during and subsequent to islanding process," *IEEE Trans. Power Del.*, 20(1): 248–257.

Guerrero, J., J. Vasquez, J. Matas, M. Castilla and L. de Vicuna, 2009. "Control strategy for flexible microgrid based on parallel line-interactive ups systems," *IEEE Trans. Ind. Electron.*, 56(3): 726–736.

Dimeas, A. and N. Hatziargyriou, 2005. "Operation of a multiagent system for microgrid control," *IEEE Trans. Power Syst.*, 20(3): 1447–1455.

Li, Y.W. and C.N. Kao, 2009. "An accurate power control strategy for powerelectronics-interfaced distributed generation units operating in a low voltage multibus microgrid," *IEEE Trans. Power Electron.*, 24(12): 2977–2988.

Schneider, K., C.C. Liu and B. Howe, 2005. "Topology error identification for the neptune power system," *IEEE Trans. Power Syst.*, 20(3): 1224–1232.

Ciezki, J. and R. Ashton, 2000. "Selection and stability issues associated with a navy shipboard DC zonal electric distribution system," *IEEE Trans. Power Del.*, 15(2): 665–669.

Cho, B. and F. Lee, 1988. "Modeling and analysis of spacecraft power systems," *IEEE Trans. Power Electron.*, 3(1): 44–54.

Valenciaga, F. and P. Puleston, 2005. "Supervisor control for a stand-alone hybrid generation system using wind and photovoltaic energy," *IEEE Trans. Energ. Convers.*, 20(2): 398–405.

Chen, Y.K., Y.C. Wu, C.C. Song and Y.S. Chen, 2013. "Design andimplementation of energy management system with fuzzy control forDC microgrid systems," *IEEE Trans. Power Electron.*, 28(4): 1563–1570.

Vasquez, J., J. Guerrero, M. Savaghebi, J. Eloy-Garcia and R. Teodorescu, 2013. "Modeling, analysis, and design of stationary-referenceframe droop-controlled parallel three-phase voltage source inverters," *IEEE Trans. Ind. Electron.*, 60(4): 1271–1280.

Karlsson, P. and J. Svensson, 2003. "DC bus voltage control for a distributed power system," *IEEE Trans. Power Electron.*, 18(6): 1405–1412.

Schonberger, J., R. Duke and S. Round, 2006. "DC-bus signaling: A distributed control strategy for a hybrid renewable nanogrid," *IEEE Trans. Ind. Electron.*, 53(5): 1453–1460.

Lu, X., 2012. "SoC-based droop method for distributed energy storage in DC microgrid applications," in *Proc. IEEE Int. Symp. Ind.Electron. (ISIE)*, Hangzhou, China, 1640–1645.

Li, W., X. Mou, Y. Zhou and C. Marnay, 2012. "On voltage standards forDC home microgrids energized by distributed sources," in *Proc. 7th Int. Power Electron. Motion Control Conf. (IPEMC)*, 3. Harbin, China, 2282–2286.

McMenamin, D., 1998. "Case studies supporting -48 VDC as the power input of choice for computer equipment deployed in the telecom network," in *Proc. 20th Int. Telecommun. Energy Conf. (INTELEC)*, San Francisco, CA, USA, 261–265.

White, R., 1988. "Computers in the central office-a primer on powering equipment from -48 v," in *Proc. 13th Annu. Conf. Appl. Power Electron. Conf. Expo. (APEC)*, 2: 902–908.

Sun, K., L. Zhang, Y. Xing and J. Guerrero, 2011. “A distributed controlstrategy based on DC bus signaling for modular photovoltaic generation systems with battery energy storage,” *IEEE Trans. Power Electron.*, 26(10): 3032–3045.

Diaz, N., A. Luna and O. Duarte, 2011. “Improved MPPT short-circuit current method by a fuzzy short-circuit current estimator,” in *Proc. IEEE Energy Convers. Congr.Expo. (ECCE)*, Phoenix, AZ, USA, 211–218.

Errami, Y., M. Maaroufi, M. Cherkaoui and M. Ouassaid, 2012. “Maximum power point tracking strategy and direct torque control of permanent magnet synchronous generator wind farm,” in *Proc. Int. Conf. Complex Syst. (ICCS)*, 1–6.

Zhang, Y., H.J. Jia and L. Guo, 2012. “Energy management strategy ofislanded microgrid based on power flow control,” in *Proc. IEEE PESInnov. Smart Grid Technol. (ISGT)*, Washington, DC, USA, 1–8.

Rahimi, A. and A. Emadi, 2009. “Active damping in DC/DC power electronic converters: A novel method to overcome the problems of constant power loads,” *IEEE Trans. Ind. Electron.*, 56(5): 1428–1439.

Guerrero, J., J. Vasquez, J. Matas, L. de Vicuña and M. Castilla, 2011. “Hierarchical control of droop-controlled AC and DC microgrids ageneral approach toward standardization,” *IEEE Trans. Ind. Electron.*, 58(1): 158–172.

Nelson, L., Diaz, TomislavDragi˘cevi´c, Juan C. Vasquez and Josep M. Guerrero, 2014. “Intelligent Distributed Generation and Storage Unitsfor DC Microgrids—A New Concept onCooperative Control Without CommunicationsBeyond Droop Control”, *IEEE Trans. Smart grid., Electron.*, 5(5): 2476-2485.