A. Goikoetxea, J. M. Canales, R. Sanchez and P. Zumeta, "DC versus AC in residential buildings: Efficiency comparison," Eurocon 2013, 2013, pp. 1-5.

DOI: https://doi.org/10.1109/EUROCON.2013.6625162

DC versus AC in residential buildings: efficiency comparison

Ander Goikoetxea[#1], José María Canales [#2] Roberto Sanchez [*3], Pablo Zumeta [#4]

[#] *Electronics and Computing Department, Mondragon Unibertsitatea*
Loramendi 5, Arrasate-Mondragón, 20500, Spain
[1] agoikoetxeaa@mondragon.edu
[2] jmcanales@mondragon.edu
[4] pablo.zumeta@alumni.mondragon.edu
* *Orona EIC*
Polígono Epele, 20120 Hernani (Gipuzkoa), Spain
[3] rsanchezmo@orona-group.com

Abstract—**DC energy solutions are gaining interest in recent years, due to improvements in power electronics. Some companies have developed solutions for the domestic implementation of DC power systems. This article analyzes the state of the art about domestic DC applications and compares the efficiency of these systems in comparison to conventional AC systems. Different loads of a building as lighting, elevator or heating and renewable energies as PV panels or small wind generator are modeled for both AC and DC connections. With these models the power consumption of the building is simulated to compare the performance of both systems.**

Keywords: AC, DC, nanogrid, comparison, efficiency, residential building

I. INTRODUCTION

The increasing interest about renewable energies promoted during the last decade the installation of large amounts of renewable energies. In this context new policies that promote the integration of these technologies in residential buildings lead to the installation of Distributed Generation (DG) units at any new building. The view of PV panels or small wind generators has become common on the roof of residential buildings.

Most of these DG technologies pass through a DC voltage step to be connected to the grid. Furthermore most of the domestic loads use electronic components to transform the AC grid voltage to DC. In this context the use of domestic DC grids that integrate the DG and domestic loads in DC seems reasonable.

Nowadays most of the domestic loads are designed to work on AC grids, therefore new proposals of DC nanogrids appeared in the literature in recent years [1]–[5]. In recent years the research about the implementation of domestic DC nanogrids is getting importance as the creation of Emerge Alliance shows. This association of companies related to construction, illumination, power converters and other fields is leading the research and development on this field.

A DC nanogrid is a system with a DC bus in which different loads and generators are connected. This DC bus is linked to the AC electrical grid using a power inverter. One of the main advantages of this topology consists on the reduction of the THD since only the inverter would inject harmonics to the grid [6]. The most important aspects on the development of DC nanogrids are their control, protections and efficiency.

The control of DC nanogrids is simpler than AC nanogrids. The control is normally done using a DC bus Scheduling in which the converter of each element connected to the main DC bus contributes to the regulation of the bus voltage [7]–[10]. Works to adapt the control of DC nanogrids to actual standards have been also developed [11].

The protections are normally an important concern related to DC systems since it is more difficult (therefore more expensive) to extinguish a direct current [12]–[15]. However several authors point out that DC nanogrids are able to disconnect all the elements in the face of a fault, since they have a converter for the connection of each element [14], [16]. A well designed protection scheme is necessary for this protection method [17].

In terms of efficiency it is quite clear that the efficiency of actual DC loads (lamps, computers, household appliances...) is very low and connecting them to a common DC bus the efficiency will increase. The generation units connected to a DC bus are also more efficient if this energy is supplied in the same DC nanogrid, while the efficiency is worse if the power is injected to the grid.

In this article the DC nanogrid concept developed by the research group of CPES Virginia Tech [1], [2], [18], [19] is compared to an AC distribution. This concept proposes a main DC bus to connect the generation units and main loads and another DC bus to connect small electronic devices. In this article the loads and generation of the communal areas of a residential building are compared for AC and DC distributions. Regarding the upcoming renewables legislation (Net Metering) and the actual Building Technical Code (CTE-2006) this application of DC nanogrid is interesting in Spain and also for the rest of Europe.

II. SCENARIO FOR THE STUDY

In order to compare the efficiency of a DC distribution with an AC distribution in residential buildings it is necessary to define a comparative scenario. The communal areas of a residential building compound the scenario for this study.

The Spanish law of residential buildings CTE-2006 promotes the energy efficiency and the installation of Photovoltaic (PV) panels on the rooftop. In this context all the residents of the building are normally the owners of the PV panels and all the electric loads of the communal areas. The most important loads are the lights of the communal areas and the elevators, as well as the TV amplifier and other constant loads.

Furthermore the suppression of all the primes for renewable energy promotes the self consumption of the power generated by PV panels.

In this context the proposed scenario of a residential building with PV panels seems interesting to compare AC and DC distribution for near future applications. A building with 5 floors, 100 apartments and 4 elevators will be considered for the simulation.

The proposed system will be simulated for both AC and DC distribution. Therefore the different components of this system are modeled for both cases. These systems will be simulated as temporal variations of power. Each power converter will be modeled as performance curves, the inputs of the system (PV generation and load consumption) will be modeled as power profiles. With these models possible AC and DC distributions will be compared in terms of energy efficiency. The system is modeled as a grid node with different load flows. Different efficiency profiles are considered for each component of the grid.

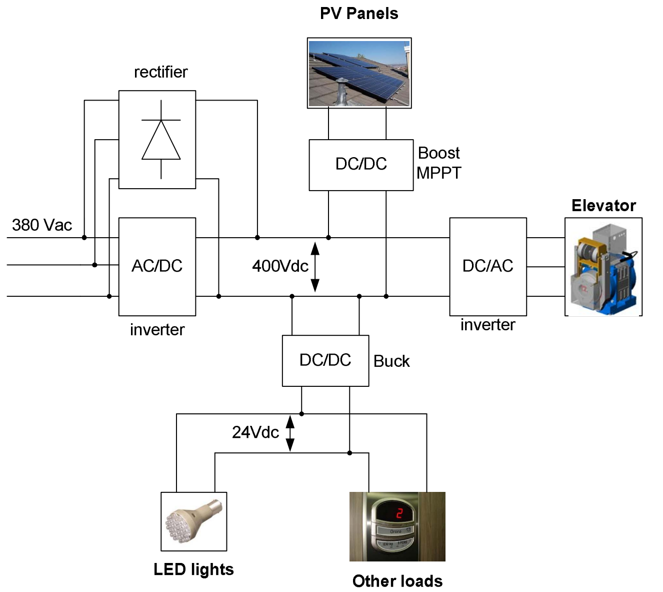

Fig. 1. DC distribution of the communal areas in a residential building

The DC distribution is defined as a system with two different voltage levels of 400V and 24V. Passive loads as LED lamps and others are directly connected to 24V while the elevator and PV panels are connected to 400V using different converters. The PV panels are connected using a boost converter with Maximum Power Point Tracking. The elevator is connected to the DC bus using an inverter. The 400V bus is connected to the LV grid using a rectifier to consume power and a smaller inverter to supply power to the grid.

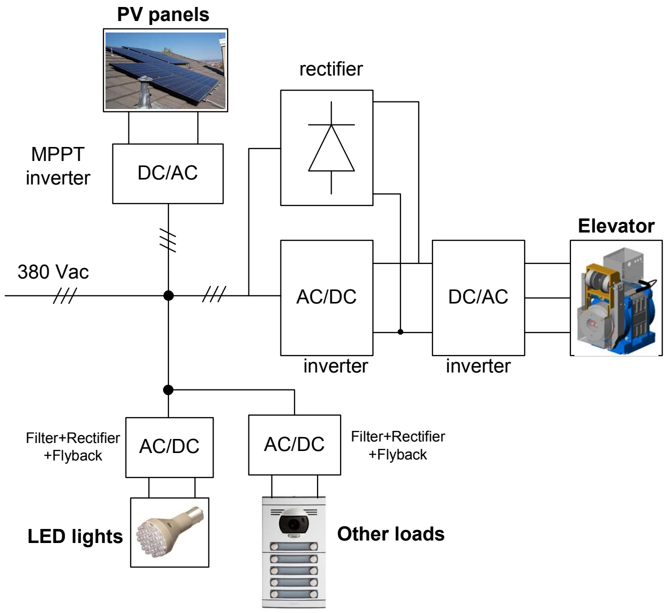

Fig. 2. AC distribution of the communal areas in a residential building

The AC distribution consists on the same elements directly connected to the grid with their own converters. All the passive loads have a rectifier and a flyback. The PV panels are connected using a MPPT inverter. The elevator is connected using an inverter connected to its DC bus which is connected to the grid with a rectifier and it has an inverter for the regenerative brake.

A. *PV panels:*

Four different (summer, autumn, winter and spring) solar profiles will be considered in two different placements: Zambrana (red line) and Arrasate (blue line) in the Basque Autonomous Community, in Spain. The first one is sunnier than the second.

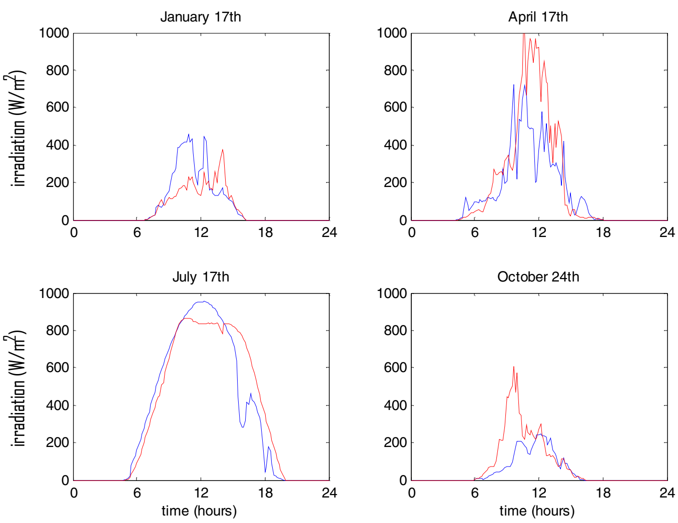

Fig. 3: Four different solar profiles used for the comparative simulation.

Different peak powers (Wp) are considered in order to compare the efficiency of the system. Considering the Wp factor as the power that PV panels will supply for a solar irradiation of 1000W/m^2. The effect of the temperature is not considered.

B. Elevator

Elevators are modeled using data recorded from one elevator in Mondragon Unibertsitatea, this elevator uses a regenerative brake that supplies power when the elevator is braking. A power profile for one hour was collected using the elevator every two minutes for different trips. For the simulation this profile is used as a peak power demand for the elevator. Different periods are defined during the day. The total energy consumption of the four elevators is 5,369kWh per day.

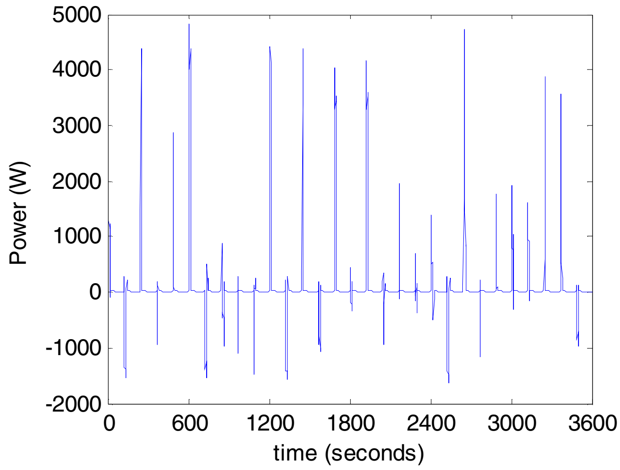

Fig. 4: Maximum consumption of the elevators during 1 hour.

C. Loads

The passive loads of the building are the LED lamps of the communal areas and other constant loads. The constant load consumes 150W and it is considered as a DC load. The power of the LED lamps in the entrances of the building is 200W and 80W at each floor.

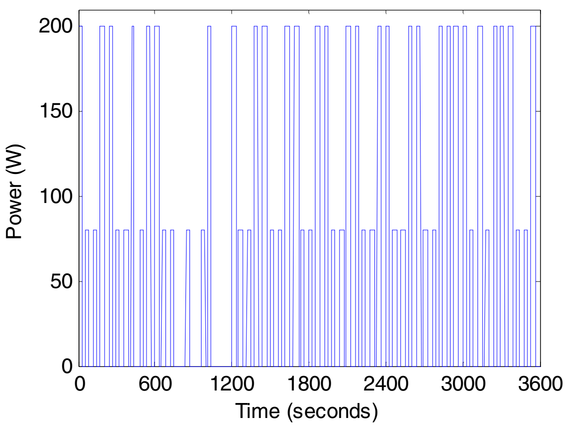

Fig. 5: Maximum illumination consumption during 1 hour.

Considering intelligent illumination the lamps are switched on 10 seconds before the elevator is used and they are switched off 30 seconds later. The load profile of the elevator and the load profile of the LED illumination are therefore related. The total energy consumption by all the illumination loads and the constant load is 5,7kWh per day.

D. Converters

The different power converters of both AC and DC systems are modeled as performance curves. All the converters and inverters shown in figures 1 and 2 are modeled with the following curves.

Fig. 6 shows the performance of an inverter. This model is used as a grid-tie in the DC distribution and it is also the curve for the grid-inverter of the elevator. This performance is based on the measurement of an elevator inverter used in the Power Electronics Laboratory of Mondragon Unibertsitatea. For the rectifiers for grid-tie and elevator a constant performance of 99% is considered.

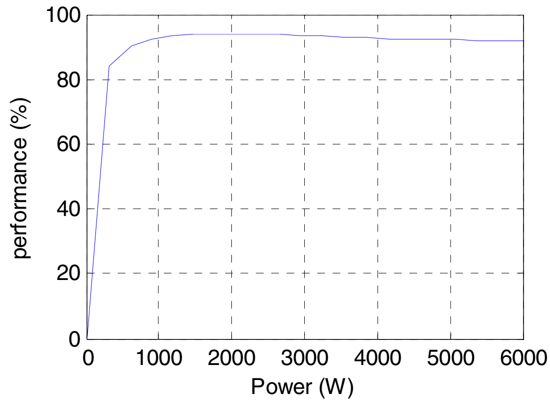

Fig. 6: Performance curve of the grid inverter.

Fig. 7 shows the performance of a MPPT inverter based on a PV installation of Mondragon Unibertsitatea. The DC MPPT is approximated considering a 2% better performance compared to common MPPT inverters.

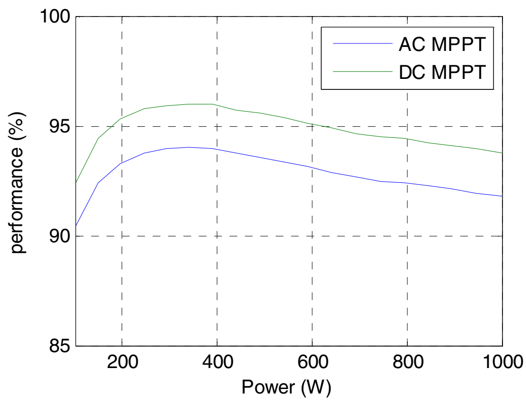

Fig. 7: Performance of AC and DC MPPT inverters

Fig. 8 shows on one hand the performance of a Buck converter to connect the main 400V Dc bus with the 24V bus to supply power to the passive DC loads. On the other hand it shows the performance of a commercial Rectifier+DC Flyback+Filter for LED lamps, this performance is considered for all the passive loads in the AC distribution.

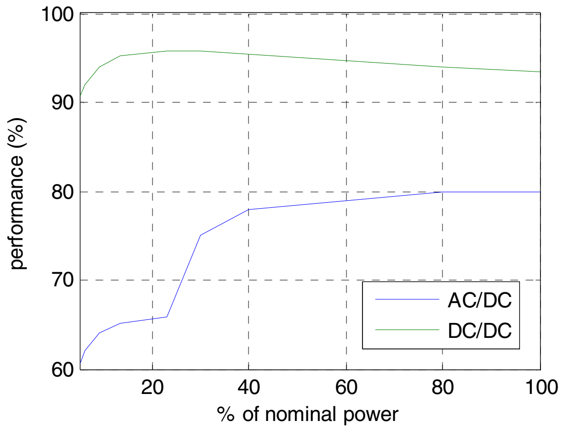

Fig. 8: Performance of the DC/DC Buck converter and AC/DC Rectifier+Flyback

III. Simulation Results

Both systems are simulated following the previously defined models. The efficiency of both systems is compared taking into account the energy consumed from the electrical grid and the energy regenerated to the grid.

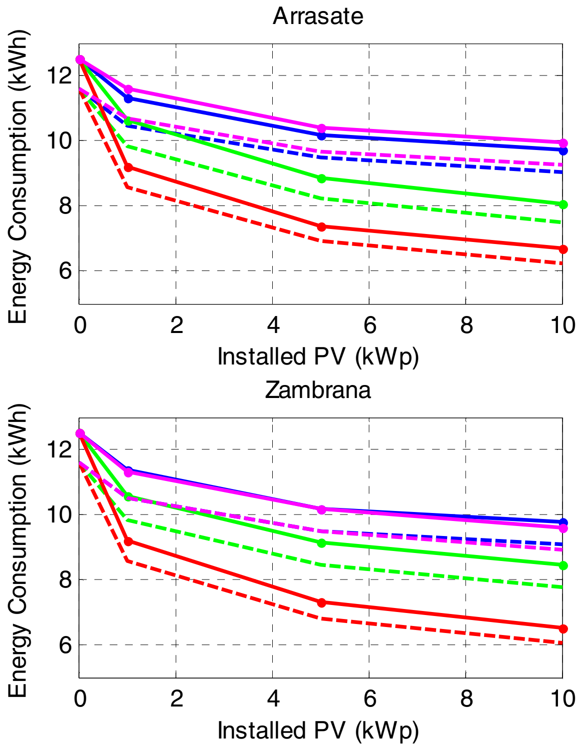

Fig. 9: Energy Consumption depending on the installed PV power, for DC (continuous line) and AC (dashed line) distributions, in different seasons.

The two different placements of Zambrana and Arrasate are compared for the four different irradiation profiles in Fig. 9, Fig. 10 and Fig. 11. The system is simulated for different installed PV power with the same load consumption in the building. In these graphs it is shown the energy consumption and the net metering of the building for AC and DC distributions depending on the installed PV power, placement and season of the year. The graphs with continuous lines are for DC distribution and the graphs with dashed lines are for AC distribution.

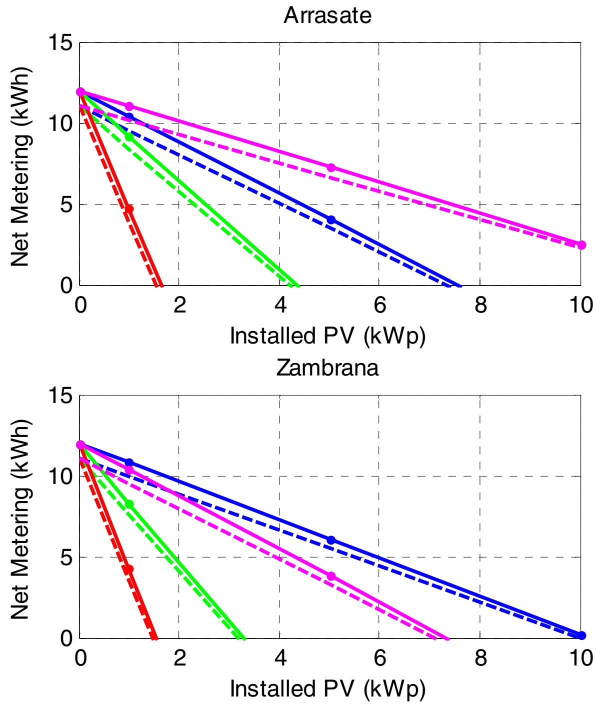

Fig. 10: Net Metering depending on installed PV power, for DC (continuous line) and AC (dashed line) distributions, in different seasons.

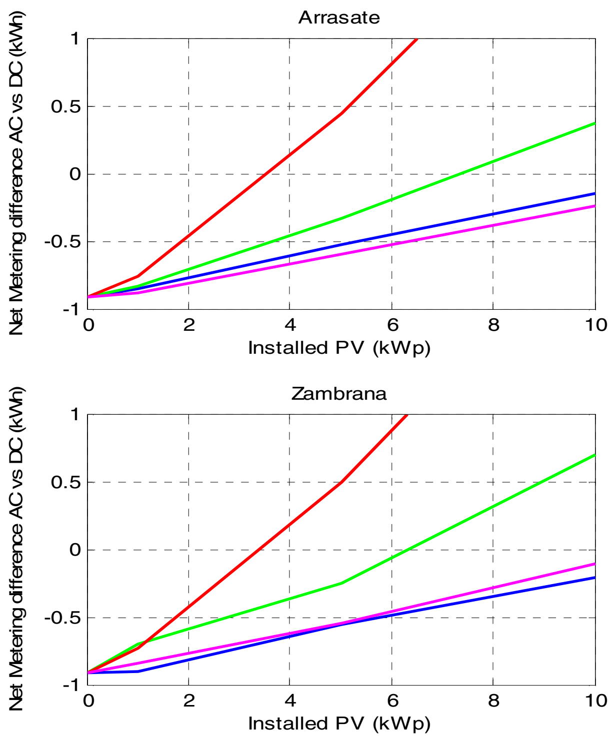

Fig. 11: Net Metering balance AC vs DC.

A positive Net Metering means that the building consumes more energy from the grid than supply, and negative means that the building is supplying more power to the grid than demanding. Net Metering is shown until 0 because the aim of new legislations promoting this issue is to generate the power that is consumed not to become a power generator.

Fig. 11 shows the difference of the Net Metering for AC and DC distributions. The negative difference means that the DC distribution has a better performance and vice-versa.

IV. Conclusion

The connection of LED lamps to a common DC bus is more efficient than their connection to actual AC plugs by means of rectifiers. This point seems to be the most important to improve the efficiency of a DC systems.

The connection of PV panels and the regenerative elevator to the DC bus is efficient while this power is consumed by the loads connected to this bus. In a scenario in which the power supplied to the grid is not paid the DC distribution is better since the power has lower impedance in the way to loads. However if this power is paid with the same price of the consumed power (Net Metering) the efficiency of the system is dependent on the installed power.

The simulations showed that during different periods of the year the efficiency of the DC distribution is better while the Net Metering is above 0.

From these considerations it can be concluded that for a Net Metering scenario in which the electrical company returns the price of the generated power if this has been consumed the DC distribution for the proposed scenario of the communal areas of a residential building is better.

References

[1] [1] D. Boroyevich, I. Cvetkovic, Dong Dong, R. Burgos, Fei Wang, and F. Lee, “Future electronic power distribution systems a contemplative view,” in Optimization of Electrical and Electronic Equipment (OPTIM), 2010 12th International Conference on, 2010, pp. 1369–1380.

[2] [2] I. Cvetkovic, T. Thacker, Dong Dong, G. Francis, V. Podosinov, D. Boroyevich, F. Wang, R. Burgos, G. Skutt, and J. Lesko, “Future home uninterruptible renewable energy system with vehicle-to-grid technology,” in Energy Conversion Congress and Exposition, 2009. ECCE 2009. IEEE, 2009, pp. 2675–2681.

[3] [3] J. Lee, B. Han, and N. Choi, “DC micro-grid operational analysis with detailed simulation model for distributed generation,” in Energy Conversion Congress and Exposition (ECCE), 2010 IEEE, 2010, pp. 3153–3160.

[4] [4] D. Salomonsson, “Modeling, Control and Protection of Low-Voltage DC Microgrids,” Doctoral Thesis, Royal Institute of Technology School of Electrical Engineering Electric Power Systems, Estocolmo, Suedia, 2008.

[5] [5] A. Sannino, G. Postiglione, and M. H. J. Bollen, “Feasibility of a DC network for commercial facilities,” Industry Applications, IEEE Transactions on, vol. 39, no. 5, pp. 1499– 1507, 2003.

[6] [6] A. Tofighi and M. Kalantar, “Power management of PV/battery hybrid power source via passivity-based control,” Renewable Energy, vol. 36, no. 9, pp. 2440–2450, Sep. 2011.

[7] [7] M. M. Amin, M. A. Elshaer, and O. A. Mohammed, “DC bus voltage control for PV sources in a DC distribution system infrastructure,” in Power and Energy Society General Meeting, 2010 IEEE, 2010, pp. 1–5.

[8] [8] J. Bryan, R. Duke, and S. Round, “Decentralized generator scheduling in a nanogrid using DC bus signaling,” in Power Engineering Society General Meeting, 2004. IEEE, 2004, pp. 977– 982 Vol.1.

[9] [9] P. Karlsson and J. Svensson, “DC bus voltage control for a distributed power system,” Power Electronics, IEEE Transactions on, vol. 18, no. 6, pp. 1405– 1412, 2003.

[10] [10] K. Kurohane, A. Uehara, T. Senjyu, A. Yona, N. Urasaki, T. Funabashi, and C.-H. Kim, “Control strategy for a distributed DC power system with renewable energy,” Renewable Energy, vol. 36, no. 1, pp. 42–49, Enero 2011.

[11] [11] J. M. Guerrero, J. C. Vasquez, J. Matas, L. G. de Vicuna, and M. Castilla, “Hierarchical Control of Droop-Controlled AC and DC Microgrids—A General Approach Toward Standardization,” Industrial Electronics, IEEE Transactions on, vol. 58, no. 1, pp. 158–172, 2011.

[12] [12] H. C. Cline, “Fuse Protection of DC Systems,” presented at the Annual Meeting of the American Power Conference, 1995.

[13] [13] W. A. Elmore, Protective Relaying Theory and Applications. New York: Marcel Dekker Inc., 2004.

[14] [14] D. Salomonsson, L. Soder, and A. Sannino, “Protection of Low-Voltage DC Microgrids,” Power Delivery, IEEE Transactions on, vol. 24, no. 3, pp. 1045–1053, 2009.

[15] [15] “ABB circuit-breakers for direct current applications,” Technical Application Papers.

[16] [16] R. M. Cuzner and G. Venkataramanan, “The Status of DC Micro-Grid Protection,” in Industry Applications Society Annual Meeting, 2008. IAS ’08. IEEE, 2008, pp. 1–8.

[17] [17] P. Cairoli, I. Kondratiev, and R. A. Dougal, “Controlled power sequencing for fault protection in DC nanogrids,” in Clean Electrical Power (ICCEP), 2011 International Conference on, 2011, pp. 730–737.

[18] [18] I. Cvetkovic, D. Boroyevich, P. Mattavelli, F. C. Lee, and D. Dong, “Non-linear, hybrid terminal behavioral modeling of a dc-based nanogrid system,” in Applied Power Electronics Conference and Exposition (APEC), 2011 Twenty-Sixth Annual IEEE, 2011, pp. 1251–1258.

[19] [19] Wei Zhang, Dong Dong, I. Cvetkovic, F. C. Lee, and D. Boroyevich, “Lithium-based energy storage management for DC distributed renewable energy system,” in Energy Conversion Congress and Exposition (ECCE), 2011 IEEE, 2011, pp. 3270–3277.