DC Nanogrid using IEC 61850

GoWoon Kang*, JooWon Park*, SooHyun Shin*, HyoSik Yang*

*Department of Computer Engineering, Sejong University, Republic of Korea

kkw0098@naver.com, joooooa0740@naver.com, schz307@naver.com, hsyang@sejogn.edu

Abstract— **Small-scale power grids are considered as a ways to improve energy efficiency and reduce greenhouse gas emissions. The DC nanogrid is a low-voltage and low-power digital power grid with a kW-level of a small distributed autonomous grid module that can bundle power and communication among small-scale power grids. In this paper, we propose a USB-based DC nanogrid and implement a hardware testbed using IEC 61850 communication profile, an international standard for power automation, to verify the validity and grid connection of the DC nanogrid system.**

Keywords— **DC nanogrid, IEC61850, USB Type-C, RESTful, EMS**

I. INTRODUCTION

While the world is facing a climate crisis due to global warming, efforts are being made to solve environmental destruction through technological development. As a result, the first climate agreement, the Paris Climate Agreement, was signed in 2016 as the need to reduce greenhouse gas emissions emerged, and carbon neutrality was declared to make greenhouse gas emissions. Energy generation and consumption, the main cause of greenhouse gas emissions, accounted for about 86.9% of greenhouse gas emissions as of 2021, and the World Green Building Council reported that about 40% of them are emitted by energy used in buildings. Therefore, when energy is supplied to buildings by producing eco-friendly energy, a large amount of greenhouse gas is reduced [1], and renewable energy facilities are installed to create a Net-Zero building that replaces the existing energy.

Such efforts are also being made in the power system field. Currently, centralized power generation on large-scale fossil fuel power generation facilities is the main focus, and 30.8 billion tons of carbon dioxide are emitted in the air every year [2]. Centralized power generation mainly uses a one-way AC power grid that facilitates voltage boosting and lowering. However, the unidirectional AC power grid has a problem of surplus power processing, an increase in power conversion equipment due to an increase in DC load, and an energy loss due to long-distance transmission, which degrades energy efficiency, so a new power grid is required to solve this problem. Therefore, it is necessary to switch to a distributed power generation system centered on small-scale power generation facilities that can actively accommodate renewable energy [3].

As the demand for distributed power generation systems and ESS (Energy Storage Systems) increases in islands and mountains areas that require such a power system, research on small-scale power grids has been actively conducted. Typically, a smart grid and a microgrid that uses multiple renewable energy as a small-scale independent power grid are used as a solution. However, because microgrids cannot replace traditional power grids due to difficulties in maintaining power quality, DC nanogrids, which can bundle power and communication among small-scale power grids, have recently emerged as a solution to increase energy efficiency [4-6].

DC Nano Grid is a low-voltage, low-power digital power grid with a kW level of a small distributed and autonomous small-scale grid module. Unlike AC power grids, DC-based systems such as solar energy and ESS can be connected to the grid without multiple power conversion devices such as converters and inverters. In addition, it is superior in terms of voltage and frequency stability, can be linked to other systems, and can overcome the shortcomings of existing power grids in terms of cost and energy efficiency [7-8].

DC nanogrids have the potential to be linked to other grids in the future. However, the equipment constituting the existing power grid has a proprietary communication protocol optimized for the manufacturer. As the use of each proprietary communication protocol increases, complexity increases and interoperability is hindered, requiring common data models and standardized services [9-13]. IEC 61850, an international standard for power automation, is essential for future integration with existing power grids, ensuring interoperability by using standardized data and service model [14].

We propose a building-level DC nanogrid system capable of providing power and high-speed data based on USB Type-C PD (Power Delivery) using IEC 61850 data and service model that can guarantee interoperability and implements a testbed.

Chapter 2 proposes a building-level DC nanogrid, Chapter 3 designs an experimental environment to develop a testbed, Chapter 4 deals with testbed communication results, and Chapter 5 draws conclusions.

II. DC NANOGRID SYSTEM

The DC nanogrid is a small kW-level distributed and autonomous small-scale grid that modulates connections rather than nodes, and is a low-voltage, low-power digital power grid that exchanges tens of V and hundreds of W of DC power in a similar way to packet switching. It also refers to a microgrid in a customer that connects a low-voltage distribution network and various digital devices in the customer in series through a gateway based on a building or DC-based local distribution technology. DC Nanogrid is a powerful and smart connection module that connects low-voltage distribution networks to buildings or distributed power generation and various digital devices in a Plug & Play way, converting voltage and current between many nodes, and relaying power transactions [15-19]. DC nanogrid is a smart link, and there is a difference in approach from existing smart grids or microgrids that deal with nodes. The following Table 1 shows the differences between the existing smart grids, microgrids, and nanogrids. In addition, the DC nanogrid, which is the core of simple modularity, is a power grid that can be modularized so that it can be developed at a lower cost than microgrids, and because of its simple modularity, it can reduce the burden of installation and maintenance costs.

TABLE 1. DIFFERENCES BETWEEN GRIDS

	Microgrid, Smartgrid	**DC nanogrid (Digital Power Grid)**
Origin	Smart power node (Electrical devices)	Smart Link (Smart electrical wires, electrical to communication convergence connection)
Basic Unit	From hundreds of kW to MW and GW	From hundreds of W to tens of kW
Electrical Type	Mainly AC, some current type DC	DC especially volt type DC
Communication Type	Communication using power line	Power and communication bundling
Technical Function	Nodes(devices) with unique function is responsible for only a fixed function	Connection itself has no intrinsic function, Function so granted by the connected node (device), and the function also changes when the node changes
Application	Commercial power grid, Standalone power grid with renewable energy	Power for smart office, distribution network for home)

In the case of small-scale power grids such as buildings and houses, there is a high possibility of switching to DC power grids [20]. DC nanogrid can reduce power conversion devices, such as converters and inverters, due to a surge in DC-based digital devices, and to this end, research on converters for DC nanogrid is being conducted in various ways [21-24]. In addition, AC frequency stabilization and reactive power problem can be solved. Due to AC characteristics, all voltage and frequency must be controlled, but DC controls only voltage and system control is convenient.

DC Nanogrid is a smart link or smart connectome for electrical services that connects various electrical devices within small buildings, offices, and housing generations. A smart link does not have a function by itself, but the function of a DC nanogrid is given by the function required by the connected node. Therefore, it must be very simple and not complicated, and it has a single domain grid configuration with the same quality and control. DC nanogrid can be connected to LVDC (Low Voltage Direct Current) distribution network through DC/DC converter, and digital load can be connected from various customers using USB standard interface for DC power use.

The PD of the USB Type-C can provide 100W and ultra-fast data on a single line according to the standards defined in the USB-IF (Implementers Forum). The latest revision of the USB Type-C standard, recently announced by USB-IF, said 240W of power can be supplied [25], which will enable future charging of electric vehicles, large screen monitors, TVs, and high-performance computer power supply without loss. In addition, the EU has agreed to unify the charging terminals of all new portable devices in Europe into USB Type-C by the fall of 2025. Thus, DC nanogrid using USB Type-C PD, which is expected to increase demand in the future, can provide integrated power network and data communication services into a single channel through a PD gateway, and can control load data in more detail than existing power grids [26].

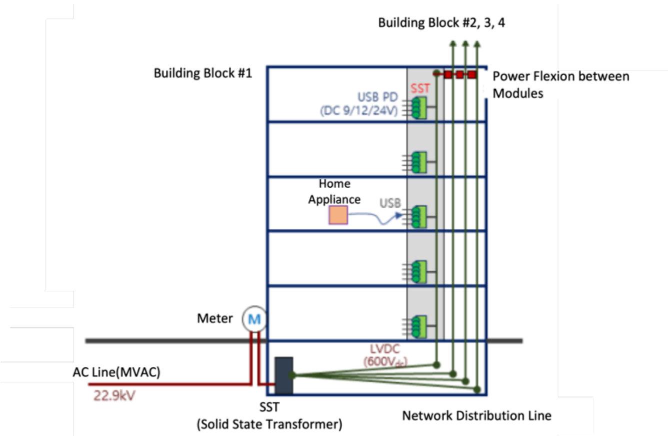


Figure 1. DC nanogrid configuration

As shown in Figure 1, the DC nanogrid converts AC power that enters MVAC (Middle Voltage Alternating Current) into LVDC using Solid State Transformer (SST) to supply power to each layer, and each layer uses USB Type-C PD to simultaneously communicate power consumption and data. It also increases energy efficiency by adding solar energy. It also increases energy efficiency by adding solar energy. When the amount of PV generation, which is the main energy source, is insufficient, a relay is added on each floor to facilitate AC-DC conversion and AC power can be used. By accurately and quickly providing power supply information in the building to each node, it is possible to replace the existing AC infrastructure with DC technology and convert it into a Plug & Play form that can provide power and communication together using USB Type-C PD. Using data models and services standardized in IEC 61850, nanogrids are collected to form microgrids in the future, and microgrids are collected to enable commercial power distribution network configuration, enabling more efficient energy management systems. Universal power services that significantly reduce costs and maximize utilization can be realized with technologies applicable regardless of geographical environment, building type, and income level.

III. Testbed Environment

A. Hardware configuration

The following Figure 2 and Figure 3 show the DC nanogrid testbed hardware configuration and the DC nanogrid control module configuration.

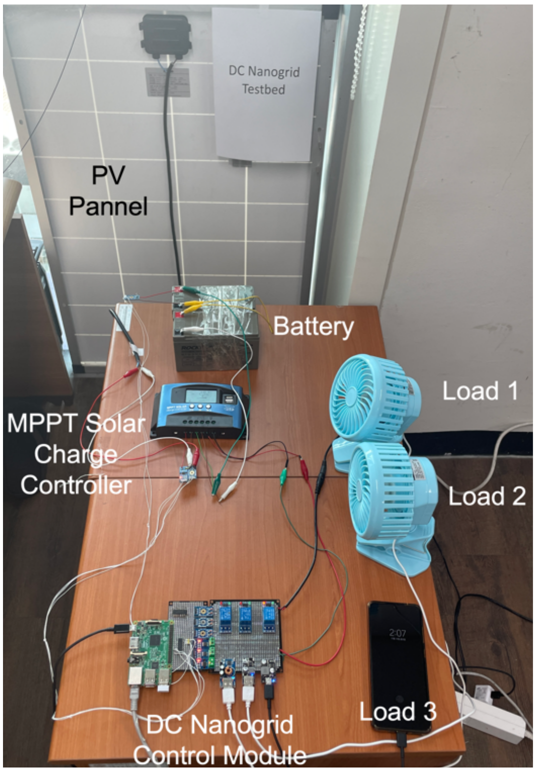


Figure 2. DC Nanogrid hardware configuration

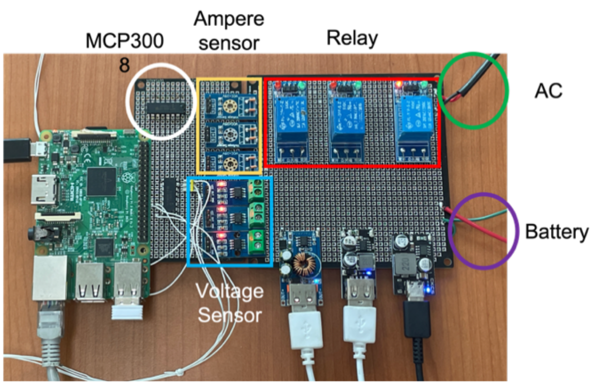


Figure 3. DC Nanogrid control module

Figure 3 shows DC nanogrid control module consisting of PV panel, battery (purple circle), control module, DC load, AC barrel jack (green circle), voltage sensor (blue square), current sensor (yellow square), MCP 3008, i.e., analog-digital converter (ADC) (white circle), and relay (red square).

Power generated in a PV panel is stored in a battery, and a voltage sensor and a current sensor are installed between the PV panel or battery and the MPPT solar charging system to measure the power generation and charging amount, respectively. Three voltage sensors and three current sensors are installed to measure the load amount of each load. The value measured through the voltage and current sensors is input to each channel of the MCP 3008, and is transmitted through SPI communication. The PV power generation measures the current voltage between the PV panel and the MPPT controller and transmits it in the same manner. The relay connected to the board switches DC power and AC power. If the battery charge falls below a certain range, Relay disconnects from the DC and switches the relay to use AC power. DC power produced by PV panel is the initial default power source.

B. Testbed Communication

The data model are mapped to Logical Node defined in IEC 61850-7-4, the international standard for power automation [27]. Raspberry Pi is used to build a server using the MMSlite API and maps values measured through SPI communication to the corresponding logical node. The client requests the measured value to the server, and the server that receives the request sends the mapped measured value using mms. The RESTful API Server was implemented using the Spring boot framework in the EMS located in the external server room, and Mysql was installed as a database. The client sends a request message to the EMS for storing measured values from the server, and the EMS stores the received measured values in the Mysql DB. In EMS, the measured values are displayed on the web to control the power and buttons for AC and DC power control are configured. Figure 4 shows the communication structure. The hardware specifications used in the testbed are summarized in Table 3.

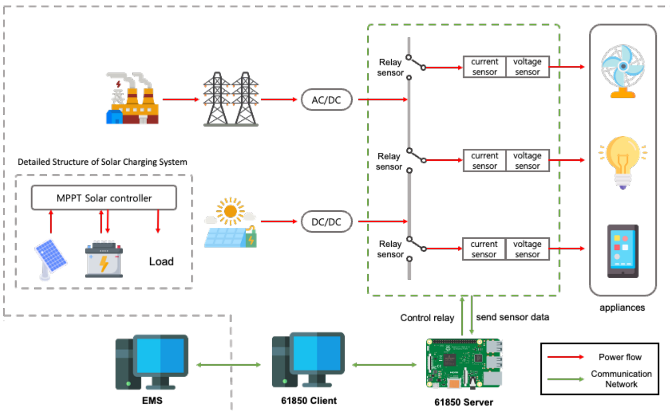


Figure 4. Testbed data communication configuration

TABLE 2. TESTBED HARDWARE SPECIFICATION

Application	Specification
IEC 61850 Server	Raspberry Pi 3B+
IEC 61850 Client	CPU : 3.4 GHz Intel Quad Core i7-2600 RAM : DDR3 SDRAM 4GB
EMS (HTTP Server & Mysql)	CPU : Intel Xeon E5-2640 2.6GHz RAM : DDR4 SDRAN 32GB

IV. TESTBED COMMUNICATION RESULTS

Figure 5 shows the WWW based EMS screenshot of the test bed using IEC 61850 standard. Figure 5 shows the current and voltage measurement values of three DC loads from No. 1 to No. 3. AC-DC Relay indicates what kind of power is currently being used, and AC-DC can be switched by controlling the relay through a button. In addition, the amount of power generation can be checked through the voltage and current measurement values of the power generated by the PV panel, and the battery condition can be viewed. The EMS system can centrally control the power of the entire building in the future, and it is expected that the power quality problem of the existing microgrid can be solved by grid-connecting with automatic AC-DC conversion, enabling efficient energy management.

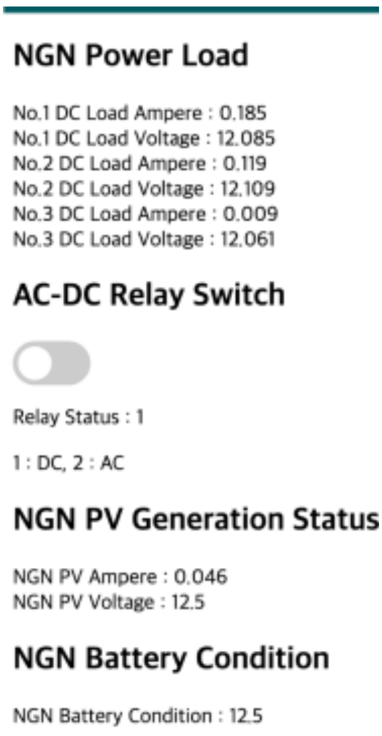


Figure 5. EMS WWW screenshot

V. CONCLUSIONS

This paper demonstrates a DC nanogrid testbed by configuring hardware and implementing communication to show that DC nanogrid, a small-scale power grid that can improve energy efficiency, can be implemented in units of generations. The IEC 61850 data model used in the test bed showed the possibility of integration with the existing power system, and it seems that it is possible to research to increase energy efficiency by scheduling the EMS system based on the power generation and load prediction model using artificial intelligence technology.

ACKNOWLEDGMENT

This research was supported by Technology Development Program to Solve Climate Changes through the National Research Foundation of Korea(NRF) funded by the Ministry or Science, ICT (2021M1A2A206544711).

REFERENCES

[1] M. H. Shwehdi and S. R. Mohamed, *Proposed smart DC nano-grid for green buildings—A reflective view*, Proc. Int. Conf. Renew. Energy Res. Appl. (ICRERA), pp. 765-769, 2014.

[2] P. Friedlingstein, R. Houghton, *Update on CO2 emissions*, Nat Geosci 2010.

[3] S. Kalambe, G. Agnihotri, *Loss minimization techniques used in distribution network: bibliographical survey*, Renew Sustain Energy, pp. 184-200, Rev, 29, 2013.

[4] P. Basak, S. Chowdhury, S. Halder nee Dey, S.P. Chowdhury, *A literature review on integration of distributed energy resources in the perspective of control, protection and stability of microgrid*, Renew Sustain Energy, pp. 5545-5556, Rev, 16, 2012.

[5] 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.

[6] Burmester, D.; Rayudu, R.; Seah, W.; Akinyele, D., *A review of nanogrid topologies and technologies*, Renew. Sustain. Energy Rev., 67, 760–775, 2017.

[7] K. Kim, K. Park, G. Roh, and K. Chun, *DC-grid system for ships: A study of benefits and technical considerations*, J. Int. Maritime Saf.,Environ. Affairs, Shipping, vol. 2, no. 1, Nov. 2018.

[8] Nasr S, Iordache M, Petit M., *Smart micro-grid integration in DC railway systems*, In: PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), Istanbul, Turkey, 2014.

[9] M. I. Ridwan, N. S. Miswan, M. S. M. Shokri, M. N. Noran, R. M. Lajim, and H. N. Awang, *Interoperability in smart grid using IEC 61850standard: A power utility prospect*, in Proc. IEEE Innovat. Smart GridTechnol.—Asia, pp. 261–266 , 2014.

[10] Tianqi Xu, Hui Hou and Hongwei Yu, *Analyses on IEC 61850 Interoperability Support*, IEEE Power Engineering Society General Meeting, pp. 1-6. 2007.

[11] Chan Hong, Ru Feng, and Xue Junyi, *Interoperability Analyses and System Implement to IEC61850 Semantic Information Model*, Advanced Technology of Electrical Engineering and Energy, vol. 24, pp. 58-62, Jul.2005.

[12] F. Ayadi, I. Colak, and R. Bayindir, *Interoperability in Smart Grid*, 7th International Conference on Smart Grid (icSmartGrid), Newcastle, Australia, 9-11 Dec, 2019.

[13] M. Flechl and L. Field, *Grid interoperability: joining grid information systems*, Journal of Physics: Conference Series, vol. 119, no. 6, 2008.

[14] F. Cleveland, F. Small, T. Brunetto, *Smart Grid: Interoperability and Standards An Introductory Review*, Sept 2008.

[15] Cvetkovic I, Dong D, Zhang W, Jiang L, Boroyevich D, Lee FC., et al, "*A testbed for experimental validation of a low-voltage DC nanogrid for buildings*, In: 2012 15th International Power Electronics and Motion Control Conference, IEEE 2012.

[16] G. Liu, A. Khodamoradi, P. Mattavelli, T. Caldognetto and P. Magnone, *Plug and play DC-DC converters for smart DC nanogrids with*

advanced control ancillary services, Proc. IEEE 23rd Int. Workshop on Comput. Aided Modeling Des. Commun. Links and Netw. (CAMAD), pp. 1-6, 2018.

[17] Qu D, Wang M, Sun Z, Chen G., *An improved DC-bus signaling control method in a distributed nanogrid interfacing modular converters*", In: 2015 IEEE 11th International conference on Power Electronics, Drives and Energy Systems, IEEE 2015.

[18] Lee, Sangkeum, et al, *Reinforcement Learning Based Cooperative P2P Energy Trading between DC Nanogrid Clusters with Wind and PV Energy Resources*, arXiv preprint arXiv:2209.07744, 2022.

[19] S. Lee, D. Har, H. Jin, and S. Nengroo, *P2P Power Trading between Nanogrid Clusters Exploiting Electric Vehicles and Renewable Energy Sources*, International Conference on Computational Science and Computational Intelligence, CSCI 2021, 2021: American council on science and education. 2021.

[20] D. J. Becker and B. J. Sonnenberg, *DC microgrids in buildings and data centers*, in Proc. IEEE Int. Telecomm. Energy Conf., 2011.

[21] S. I. Ganesan, D. Pattabiraman, R. K. Govindarajan, M. Rajan, and C. Nagamani, *Control scheme for a bidirectional converter in a self sustaining low-voltage DC nanogrid*, IEEE Trans. Ind. Electron., vol. 62,no. 10, pp. 6317–6326, Oct. 2015.

[22] I. Askarian, M. Pahlevani, and A. Knight, *A three-port bidirectional DC/DC converter for DC nano-grids*, IEEE Trans. Power Electron., vol. 36, no. 7, pp. 8000–8011, Jul. 2020.

[23] R. W. De Doncker, *Dynamic and Balanced Control of Three-Phase High-Power Dual-Active Bridge DC–DC Converters in DC-Grid Applications*, in IEEE Transactions on Power Electronics, vol. 28, no. 4, pp. 1880-1889, April 2013.

[24] S. Ansari, A. Chandel and M. Tariq, *A Comprehensive Review on Power Converters Control and Control Strategies of AC/DC Microgrid*, in IEEE Access, vol. 9, pp. 17998-18015, 2021.

[25] USB 3.0 Promoter Group, *Universal Serial Bus Type-C Cable and Connector Specification*, vol. Release 2.1, 2021.

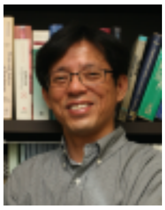
[26] L. Mackay, T. Hailu, L. Ramirez-Elizondo and P. Bauer, *Towards a DC distribution system - opportunities and challenges*, 2015 IEEE First International Conference on DC Microgrids (ICDCM), 2015.

[27] IEC TC-57, *Communication networks and systems in substations –Part 7-4: Basic communication structure for substation and feeder equipment – Compatible Logical Node Classes and Data Classes.* International Electrotechnical Commission, Geneva, Switzerland, Draft Standard 61850-7-4, IEC 2001.

GoWoon Kang received the B.E. degrees in computer engineering from Sejong University, Seoul, South Korea, in 2022, where she is currently working toward the M.S. degree in computer engineering.

JooWon Park received the B.E. degrees in computer engineering from Sejong University, Seoul, South Korea, in 2022, where she is currently working toward the M.S. degree in computer engineering.

SooHyun Shim received the B.E. and M.S. degrees in computer engineering from Sejong University, Seoul, South Korea, in 2019 and 2021, where he is currently working toward the Ph.D. degree in computer engineering.



Hyo-Sik Yang received the B.E. degree in information and communication engineering from Myongji University, Yongin, South Korea, in 1998, and the M.S. and Ph.D. degrees in electrical engineering from Arizona State University, Tempe, AZ, USA, in 2000 and 2005, respectively. He joined Sejong University, Seoul, Korea, in 2006, where he is currently an Associate Professor with the Department of Computer Science and Engineering. Before joining Sejong University, he was an Assistant Professor with Kyungnam University, Masan, Korea. He served as a Faculty Research Associate with Arizona State University until 2005. His research interests include wavelength-division multiplexing (WDM) all-optical networks, mobile ad hoc networks, and smart grid, in particular, on IEC 61850 and communication architecture.