City University of New York (CUNY)

CUNY Academic Works

Publications and Research

City College of New York

2018

Effect of Wireless Communication Delay on DC Microgrids Performance

Mahmoud Saleh
CUNY City College

Yusef Esa
CUNY City College

Ahmed Mohamed
CUNY City College

[How does access to this work benefit you? Let us know!](#)

More information about this work at: https://academicworks.cuny.edu/cc_pubs/633

Discover additional works at: <https://academicworks.cuny.edu>

This work is made publicly available by the City University of New York (CUNY).
Contact: AcademicWorks@cuny.edu

Effect of Wireless Communication Delay on DC Microgrids Performance

Mahmoud Saleh, Yusef Esa, *Student Member, IEEE* and Ahmed Mohamed, *Senior Member, IEEE*

Abstract—This paper investigates the effect of wireless communication technologies latency on the converters and the bus voltage of centrally communication based controlled DC microgrids (MGs) during islanding. A DC microgrid with its communication based control scheme was modeled to show the impact of latency. Simulation results show that the impact may be severe depending on the design, and the operational condition of the microgrid before latency occurs.

Index Terms— Communication based control, microgrid, green energy, renewable energy, smart grid, wireless latency.

I. INTRODUCTION

POWER grid transition to a smarter one mandates increased dependence on information and communication technologies (ICT) [1], [2]. This dependence is continuously growing with the introduction and evolution of emerging technologies, such as advanced metering infrastructure (AMI), MGs, phasor measurement units and electric vehicles. Therefore, it is crucial to analyze the impact of ICT networks performance degradation, such as communication latency and/or packet loss, on the operation of the power grid.

While there are a few papers in the literature that study the interdependence between the power grid and ICT network on a large scale [3], [4], e.g. the power system of a whole country, there are no studies on the impact of ICT on the performance of distributed energy resources (DERs) and DC MGs. Some papers focused on the AC MG [5], [6]. To the best of our knowledge, this paper is the first attempt to investigate and analyze the impact of communication latency on DC MGs performance.

An MG is a group of interconnected loads and distributed energy resources controlled by a supervisory controller. It acts as a single controllable entity with respect to the grid and can function in either a grid-connected or an islanded mode [7], [8]. In order to optimize the operation of an MG, i.e. maintain generation/demand balance, maximize energy harvesting from renewables, minimize dependence on the main grid, etc., an efficient control technique is required. DC MG control could be realized using one of two methods: (1) Voltage based droop control; or (2) Communication based control [9].

Voltage droop control is analogous to frequency droop in AC networks, and is achieved by means of cooperative operation among parallel converters. It is based on using the voltage of

the physical link between the converters, namely the DC bus, to signal deviations in the generation/demand ratio [10], [11]. For instance, a decrease in the DC bus voltage indicates generation deficiency; therefore, all converters start to increase their output power set points until the balance is achieved, i.e. the DC bus voltage is restored to its rated value. This control technique has several pros, e.g. it allows power sharing while providing active damping to the system, it offers a plug and play feature since new converters can be seamlessly integrated to the DC bus, and above all, it does not require communication [11]. However, it has some drawbacks as well, such as the deterioration of current sharing caused by load dependent voltage deviations, having circulating currents [12], and its failure to achieve an optimal coordinated performance of the MG.

In communication based control, individual DERs and controllable loads, if any, are controlled via local control agents. The data from local DER and load agents are aggregated in the MG central controller (MGCC), processed through a predefined control algorithm, then feedback commands are sent back to the local agents through wired or wireless communication. This allows the design of energy management algorithms that have the potential to achieve an optimal, or at least near-optimal, MG performance. However, the main concern about communication based control is the hypothesis that the reliability of the MG may be affected by the intrinsic drawbacks to ICT networks, e.g. delays and/or packet loss. Even though this hypothesis is decisive while designing MGCCs, it received minor attention in the literature.

II. MG COMMUNICATION NETWORKS

In MGs, and in smart grids generally, the communication network functional requirements, e.g. data rate and coverage range, significantly vary depending on the control layer.

Fig. 1. Communication hierarchical architecture of a smart grid.

Therefore, the communication networks of a smart grid are typically designed in a hierarchical multilayered architecture [13], as shown in Fig. 1. This architecture includes:

Home Area Network (HAN): it provides low bandwidth, two-way communications between home appliances and equipment (e.g. smart meters), or among MG resources and loads. Data being exchanged might be voltage, current and frequency measurements, which could be utilized in MGCC, demand side management, demand response, home/building automation, etc. The communication technologies that are usually deployed within these networks could be wired or wireless, such as Zigbee, Bluetooth, and WiFi [14].

Neighborhood Area Network (NAN): it acts as a gateway between HANs and the upper layer, transmitting information from the consumer premises to the utility data center for processing and feedback action [15], [16]. NANs involve LTE, WiMax, WiFi, etc. This layer is needed when aggregating geographically dispersed DERs and distributed generators in a community MG or a virtual power plant.

Wide Area Network (WAN): its main task is to transfer the overall aggregated data to grid operators, and command signals to the consumers; therefore, it has to be highly reliable, and be able to carry large data on a wide range [16].

Wireless technologies can be used for information exchange between controllers in a MG. They eliminate the need for physical connections. Moreover, they can be used as a redundant system even if a wired connection exists for increased reliability or improved performance. For instance, data traffic could be routed to the wireless network, mitigating congestion on wired links, to increase data transfer speed. Table I shows a comparison of some common wireless communication technologies, including Zigbee, Long Term Evolution Machine to Machine (LTE M2M), High Speed Packet Access M2Machine (HSPA M2M) and WiFi [17]-[19].

III. DC MICROGRID MODEL TOPOLOGY

The topology of the DC MG example under study in this paper is depicted in Fig. 2. It comprises the followings: a 6 kW photovoltaic (PV) system that is integrated to the DC bus through a step up DC-DC converter, a 1.5 kWh battery system integrated to the DC bus through a bidirectional DC-DC charger, a bidirectional AC-DC smart inverter tying the DC MG. The working voltage of the DC MG is 300 V, and it includes a total load of 8 kW. A coil was added to the output of the bidirectional converter to smooth the output current during islanding mode when the bidirectional converter regulates the DC bus voltage. The values used for the converters inductances and capacitances can be found in Table II.

The various individual converters are controlled locally, and a central MGCC is used to coordinate the operation of the local control agents and optimize the MG performance. The complete details about the example MG, including the circuits design, the components values, the monitoring system and the complete control algorithm can be found in [20] – [29].

In order to analyze the impact of ICT dependence, we will intentionally introduce communication latency to the control

TABLE I
WIRELESS COMMUNICATION TECHNOLOGIES

Technology name	Zigbee	LTE M2M	HSPA M2M	WiFi
Average Delay (msec)	50 ~ 140 [17]	30 ~ 40 [18]	10 ~ 26 [18]	Up to 300 [19]
Coverage range	Short	Wide range	Wide range	Short
Advantages	Low cost, Power & scalable	Reliable	Low latency	Ease of use

Fig. 2. DC MG model circuit.

messages communicated between the MGCC and local controllers, and inspect the impact on the MG operation. Even though this study can be expanded to many scenarios, in this paper, we will focus on analyzing a critical case when the delay occurs while the MG is within the process of islanding itself from the main grid.

In order to completely understand this impact, we will highlight the control actions, to be taken by the MGCC, pertaining to the transition from grid-connected mode to islanding mode. Prior to islanding, the inverter regulates the voltage of the DC bus, and the MGCC determines the power set points of the battery, which indirectly determines the amount of power exchanged with the main grid, while the boost converter is set to track the maximum power point of the PV system. The inverter is operated in a constant-voltage mode, while the PV and battery are operated in a constant-power mode. Once a problem is detected on the main grid (e.g. under frequency, under voltage, or any other violation), the MGCC disconnects the Solid-State Relay (the main breaker between the MG and the main grid), and sends a command to the battery system to

TABLE II
INDUCTANCES AND CAPACITANCE OF THE CONVERTERS OF THE DC MG

Converter	Component	Value
Bidirectional converter	L_{BD}	4.5 mH, 0.25 Ohm
	C_{BD}	890 μ F
	Smoothing coil	8mH, 1 Ohm
Boost converter	L_B	4.5 mH, 0.25 Ohm
	C_{pv}	1200 μ F
	L_{DC}	19m H, 1.4 Ohm
Inverter	C_{DC}	1488 μ F
	L_{AC}	3-phase each (19 mH, 1 Ohm)

Fig. 3. Control scheme for the DC microgrid during grid-tie and islanded mode. In normal operation, the inverter is fixing the DC bus voltage to 300 V, the boost converter is MPPT controlled and the bidirectional converter is current controlled. Once the MG is islanded the MGCC receive a signal from the protection system. Accordingly, the MGCC sends a three-bit signal to the local controllers ($S^{MGCC} = 111$). Each bit in this signal corresponds to a control type for a specific local controller. For example, the least significant bit changes in S^{MGCC} reflects only on the bidirectional converter control type. The logic impeded in the bidirectional converter local controller, shown in Fig. 3, is set up to read only the least significant bit. If the bit is zero that means that the bidirectional converter is current controlled, when it changes to one, the bidirectional converter regulates the DC bus voltage of the MG. Similarly, the inverter local controller reads the most significant bit of S^{MGCC} , if it is zero, the inverter regulates the DC bus voltage, when it changes to one, the inverter is disconnected. The values of K_p and K_i for all controllers are shown in Table III.

IV. CONTROL SCHEME FOR THE DC MICROGRID

The control hierarchy for the DC MG shown in Fig. 2, is a communication based scheme. In the primary layer, the local controllers are continuously monitoring input and/or output voltages and/or currents of their converters, based on the desired control type (i.e. current, voltage or maximum power point tracking control). In the secondary layer, the modes and set points are being assigned to each LC by the MGCC, to maintain the required voltage level within the DC MG and reliable operation.

To maintain reliable operation in a centralized communication based controlled DC microgrid, a predefined control can be applied. The control logic could be designed based on the expected events that may encounter the DC microgrid (e.g. microgrid islanding) and set up control schemes accordingly.

The control scheme for the DC MG model shown in Fig. 2 is depicted in Fig. 3. During grid-tie mode the MGCC maintain

TABLE III

K_p AND K_i OF VARIOUS CONTROL TECHNIQUE USED IN THE DC MG

Converter	Control technique	Outer Loop		Inner Loop			
		K_p	K_i	Charge		Discharge	
				K_p	K_i	K_p	K_i
Bidirectional converter	Current control	N/A	N/A	0.02	110	0.02	3
	Voltage control	3	1	0.002	10	0.02	3
		Outer Loop		I_d		I_q	
Inverter	Voltage control	0.1	10	192.1	97671	192.1	97671

normal operation, where the inverter is fixing the DC bus voltage to 300 V, the boost converter is MPPT controlled and the bidirectional converter is current controlled. Once the MG is islanded the MGCC receive a signal from the protection system. Accordingly, the MGCC sends a three-bit signal to the local controllers ($S^{MGCC} = 111$). Each bit in this signal corresponds to a control type for a specific local controller. For example, the least significant bit changes in S^{MGCC} reflects only on the bidirectional converter control type. The logic impeded in the bidirectional converter local controller, shown in Fig. 3, is set up to read only the least significant bit. If the bit is zero that means that the bidirectional converter is current controlled, when it changes to one, the bidirectional converter regulates the DC bus voltage of the MG. Similarly, the inverter local controller reads the most significant bit of S^{MGCC} , if it is zero, the inverter regulates the DC bus voltage, when it changes to one, the inverter is disconnected. The values of K_p and K_i for all controllers are shown in Table III.

In the following section, a delay (α) will be introduced to the S^{MGCC} once the microgrid is islanded to show the impact on the DC bus voltage of the microgrid.

V. RESULTS, ANALYSIS AND DISCUSSION

In this section, the impact of communication delay on the voltage of the DC bus (V_{DC}) and converters switches (V_{bo}^{sw} and V_{bi}^{sw}) of the MG have been shown and discussed using results obtained from the Simulink model for the MG shown in Fig. 2. To simulate the impact of delay on the DC bus voltage of the MG, a delay (α) has been imposed on the S^{MGCC} signal once the protection system islands the MG. In this scenario, the islanding of the MG occurs at 0.5 sec. In case of delay, none of the converters is maintaining the DC bus voltage.

Fig. 4 shows the effect of different delays, i.e. different values of α , which represents the delays that might be associated with the various communication technologies shown in Table 1, on V_{DC} with constant total capacitance ($C_T = C_{bo} + C_{bi} = 4800 \mu F$), and mismatch current ($I_m = 7.1 A$). The mismatch current is the current that was supplied from the grid through the

inverter. It can be noticed that as the delay lasts longer, the voltage deviation increases, which leads to an increased error in the PI controller of the bidirectional converter, that is supposed to regulate the bus voltage in case of islanding, causing higher spikes. With HSPA M2M, LTE M2M and Zigbee average delays shown in Table 1, at these values of C_T and I_m , the voltage deviation might reach up to approximately 8.3%, 15%, and 17.3%, respectively. Furthermore, the voltage deviation is a function of the mismatch current I_m and total capacitance C_T as well, i.e. worst-case scenario could take place if the generated power from the DERs at the instant of islanding is zero, e.g. a cloud was passing by the solar panels, the batteries are depleted, and C_T was critically small to hold the voltage. This scenario might lead to swift changes in the voltage level, triggering protection relays of the DC MG, which are occasionally based on the (d/dt) values of voltage and current, and/or voltage limits of $\pm(5\sim10)\%$ of its nominal value [30].

Figs. 5(a), 5(b), and 5(c) demonstrate the voltage across the boost converter switch S_{bo} during zero (i.e. normal operation), 15, and 150 ms delay, respectively. It can be noticed that the voltage across the switch V_{bo}^{sw} is almost the same as the DC bus voltage in Fig. 4, if the voltage across the diode is neglected. It can be seen that V_{bo}^{sw} during delays can reach up to more than 1.5 the nominal value of the DC bus voltage. This effect should be taken into consideration while designing the boost switches.

Figs. 6(a), 6(b), and 6(c) depict the voltage across the bidirectional converter switch S_{bi} during zero (i.e. normal operation), 15, and 150 ms delay, respectively. It can be seen that before the islanding (i.e. 0.5 sec) the bidirectional converter was not boosting any current (i.e. current reference to the PI controller is zero) and V_{bi}^{sw} was almost equal to the battery system voltage 210 V. L_{BD} was almost short-circuited since the bidirectional was not operational. In Figs. 6(b) and 6(c), it can be noticed that once the delay ends, V_{bi}^{sw} can reach to more than double the nominal DC bus voltage. In case the delay last longer and there was a mismatch current supplying a considerable portion of the DC bus loads, V_{bi}^{sw} might be more than 2.5 the nominal DC bus voltage. The voltage across S_{bi} is equal to the DC bus voltage plus the voltage drop across the smoothing coil and the diode as shown in (1):

$$V_{bi}^{sw} = V_{DC} + V_{bi}^{diode} + V_{Smoothing\ coil} \quad (1)$$

Where V_{bi}^{diode} is the voltage across the series diode in the bidirectional converter and the voltage across the smoothing coil is:

$$V_{Smoothing\ coil} = L \frac{di_{bi}}{dt} \quad (2)$$

Where i_{bi} is the output current of the bidirectional converter.

Figs 7(a), 7(b), 7(c) and 7(d) present the impact of different delays on the load current, output boost and bidirectional converters currents and the DC bus voltage, respectively. It can be seen that once the delay α ends and the bidirectional converter gets the S^{MGCC} signal to regulate the DC bus voltage, it's PI controller overshoot. This overshoot reflects on the boost output current and the load current. It can be noticed from Figs. 7(a), 7(b), and 7(c) that an overshoot of ~ 75 A is injected from the bidirectional converter once the 15 ms delay ends. This causes a momentary ~ 25 A overshoot in the load current and

the rest is absorbed by the boost capacitor. Also, Oscillations start to show up in the DC bus voltage and converters current due to the presence of the RLC circuit. As the delay increases, the V_{DC} deviation increases and the error $e(t)$ to the PI controller of the bidirectional converter increases as shown in (3):

$$K_p * e(\alpha) + K_i * \int_0^\alpha e(t) dt \quad (3)$$

As the error increases, the bidirectional converter needs to inject more current to maintain the DC bus voltage and the integral controller causes more overshoot. This leads to higher di_{bi}/dt , which increases V_{bi}^{sw} and might damage the switch if the switch was not properly designed.

VI. CONCLUSION

This paper analyzes the impact of latency of various wireless communication technologies, within HAN, on the DC MG voltage and the converters switches during islanding. Simulink model was developed to show the behavior of microgrids during latency. It was found that the severity varies with the mismatch current, which is unpredictable, MG converters

Fig. 4. DC bus voltage variation with different α , $C_T = 4800 \mu F$ and $I_m = 7.1$ A.

Fig. 5. Impact of delay on the boost converter switch S_{bo} , $C_T = 4800 \mu F$ and $I_m = 7.1$ A: a) during grid-tie, b) for a delay of 15 ms, c) for a delay of 150 ms.

Fig. 6. Impact of delay on the bidirectional converter switch S_{bi} , $C_T = 4800 \mu F$ and $I_m = 7.1$ A: a) during grid-tie, b) for a 15 ms delay, c) for a 150 ms delay.

Fig. 7. Shows the impact of different delays with $C_T = 4800 \mu\text{F}$ and $I_m = 7.1 \text{ A}$ on a) load current, b) boost converter output current, c) bidirectional output current, and d) DC bus voltage.

design (i.e. capacitors, inductors switches of the converters), and the duration of the delay. This study suggests that the design of an MG should be coordinated along with the selection of the communication technology. If cost effective communication technology with long delays is to be deployed, more investment has to be done on the MG design, e.g. if Zigbee were to be used, a high capacitance should be implemented to mitigate the effect of the long delay. If HSPA M2M were to be implemented, less capacitance is required. However, the use of large capacitance to compensate for the mechanical inertia as in the AC systems leads to high fault currents. Moreover, long latencies at high mismatch current and low capacitance will cause a swift change in DC bus voltage and current, which might cause the protection relays to be triggered. Also, using an inductor for a converter to smooth its output current, increases the impact of the delays on the load current and the voltage stress on the converter switch. Therefore, MGs should be designed, while considering communication technology latency, capacitance, inductors, and switches of the DER's converters, and protection relay settings.

REFERENCES

- [1] Yih-Fang Huang; Werner, S.; Jing Huang; Kashyap, N.; Gupta, V., "State Estimation in Electric Power Grids: Meeting New Challenges Presented by the Requirements of the Future Grid," *Signal Processing Magazine, IEEE*, vol.29, no.5, pp.33,43, Sept. 2012.
- [2] "Smart Grid." *Department of Energy*. N.p., n.d. Web. June-July 2016.
- [3] M. Parandehgheibi and E. Modiano, "Robustness of interdependent networks: The case of communication networks and the power grid," in *Proc. IEEE GLOBECOM'13*, Dec. 2013.
- [4] M. Rahnamay-Naeini, and M. M. Hayat, "On the role of power-grid and communication-system interdependencies on cascading failures," *Global Conference on Signal and Information Processing*, Austin, TX, pp. 527-530, December, 2013.
- [5] S. C. Liu, X. Y. Wang, and P. X. Liu, "Impact of communication delays on secondary frequency control in an islanded microgrid," *IEEE Trans. Ind. Electron.*, vol. 62, no. 4, pp. 2021-2031, Apr. 2015.
- [6] C. A. Macana, E. Mojica-Nava, and N. Quijano, "Time-delay effect on load frequency control for microgrids," in *Proc. 10th IEEE Int. Conf. Networking, Sensing and Control (ICNSC)*, Apr. 10-12, 2013.
- [7] "Microgrid Activities." *Microgrid Activities*. Department of Energy, n.d. Web. 28 Mar. 2016.
- [8] A. Ali, A. Farooq, Z. Muhammad, F. Habib, S. Malik, "A Review: DC Microgrid Control and Energy Management System," *energy sources (RES)*, 7, p.10.
- [9] P. Karlsson and J. Svensson, "DC bus voltage control for a distributed power system," *IEEE Trans. Power Electron.*, vol. 18, no. 6, pp. 1405-1412, Nov. 2003.
- [10] R. S. Balog, "Autonomous local control in distributed DC power systems," Ph.D. dissertation, Univ. Illinois UC, Champaign, IL, USA, 2006.

- [11] T. Dragicevic, X. Lu, J. C. Vasquez, and J. M. Guerrero, "DC microgrids—Part I: A review of control strategies and stabilization techniques," *IEEE Trans. Power Electron.*, vol. 31, no. 7, pp. 4876-4891, Jul. 2016.
- [12] Y. Ito, Y. Zhongqing, and H. Akagi, "DC micro-grid based distribution power generation system," *IEEE IPEMC*, 2004, vol. 3, pp. 1740-1745.
- [13] M. Kuzlu, M. Pipattanasomporn, and S. Rahman, "Communication network requirements for major smart grid applications in HAN, NAN and WAN," *Comput. Netw.*, vol. 67, pp. 74-88, Jul. 2014.
- [14] S. Safdar, B. Hamdaoui, E. Cotilla-Sanchez, M. Guizani, "A Survey on Communication Infrastructure for Micro-grids," *2013 9th International Wireless Communications and Mobile Computing Conference (IWCMC)*, IEEE, July 2013, pp. 545-550.
- [15] A. Llarra, G. Terrasson, O. Curea, and J. Jimenez "Application of Wireless Sensor and Actuator Networks to Achieve Intelligent Microgrids: A Promising Approach towards a Global Smart Grid Deployment," *Ecole Supérieure des Technologies Industrielles Avancées (ESTIA), Technopole Izarbel, 64210 Bidart, France*, February 2016.
- [16] M. Kuzlu "Assessment of Communication Technologies and Network Requirements for Major Smart Grid Applications," *Innovative Smart Grid Technologies (ISGT)*, IEEE PES, 2013.
- [17] H. Sherazi, R. Iqbal, S. Hassan, M. Chaudary, and S. Gilani "ZigBee's Received Signal Strength and Latency Evaluation under Varying Environments," *Journal of Computer Networks and Communications*, Volume 2016.
- [18] M. Laner, P. Svoboda, P. Romirer, N. Nikaein, F. Ricciato, A comparison between one-way delays in operating HSPA and LTE networks, in: *Proc. WINMEE*, 2012.
- [19] "Swappa :: Reti Wireless - Zigbee." *Swappa :: Reti Wireless - Zigbee*. N.p., n.d. Web. Oct.-Nov. 2016.
- [20] M. Saleh, Y. Esa, and A. Moahmed "Communication Based Control for DC Microgrids," *IEEE Smart Grid Transactions*, Nov. 2017.
- [21] M. Saleh, Y. Esa and A. Moahmed, "Hardware Based Testing of Communication Based Control for DC Microgrid," *International Conference on Renewable Energy Research and Applications (ICRERA)*, San Diego, 2017.
- [22] M. Saleh, Y. Esa, A. Moahmed "Design and Implementation of CCNY DC Microgrid Testbed," *IAS, IEEE*, October 2016, Portland, OR.
- [23] M. Saleh, Y. Esa, and A. Moahmed "Centralized Control for DC Microgrid Using Finite State Machine" *IEEE Innovative Smart Grid Technologies Conference (ISGT)*, Washington D.C. Metro Area, USA, 23-26 April 2017.
- [24] M. Saleh, Y. Esa and A. Mohamed, "Application of Complex Network Analysis in Electric Power Systems," *Energies, Smart Grids issue*, March 2018.
- [25] M. Saleh, Y. Esa, and A. Moahmed, "Energy Management Algorithm for Resilient Controlled Delivery Grids," *Industry and Application Society (IAS) conference*, Cincinnati, OH, 1-5 October 2017.
- [26] M. Saleh, O. Dutta, Y. Esa, and A. Moahmed, "Quantitative Analysis of Regenerative Energy in Electric Rail Traction Systems," presented at *Industry and Application Society (IAS) conference*, Cincinnati, OH, 1-5 October 2017.
- [27] M. Saleh, A. Althaibani, Y. Esa, Y. Mhandi and A. Mohamed, "Impact of clustering microgrids on their stability and resilience during blackouts," *International Conference on Smart Grid and Clean Energy Technologies (ICSGCE)*, Offenbourg, 2015, pp. 195-200.
- [28] M. Saleh, Y. esa, A. Mohamed, "Optimal Microgrids Placement in Electric Distribution Systems Using Complex Network Framework," *International Conference on Renewable Energy Research and Applications (ICRERA)*, San Diego, CA, 2017.
- [29] M. Saleh, Y. Esa, and A. Moahmed, "Impact of Communication Latency on the Bus Voltage of Centrally Controlled DC Microgrid," accepted at *IEEE Transactions on Sustainable Energy*.
- [30] J. Choi, H. Jeong, J. Choi, D. Won, S. Ahn and S. Moon, "Voltage control scheme with distributed generation and grid connected converter in a DC microgrid," *Energies*, 2014, 7, 6477-6491.

Mahmoud S. Saleh is a PhD student at the Smart Grid Laboratory, Department of Electrical Engineering, City college of New York. He received his M.S. in Electrical Engineering from CCNY in 2013. His research interest includes microgrid design and control.

Yusef Esa is a M.S. student at the Smart Grid Laboratory, City College of New York. He received the B.S. degree in electrical engineering from CCNY in 2015. His research interest includes microgrids design.

Ahmed A. Mohamed (El-Tallawy) (GS'2009, M'2013) is an Assistant Professor of Electrical Engineering, City College of New York. He is the director of the Smart Grid Laboratory at CCNY. His research interests include microgrids, and smart grids.