A Local Voting Protocol Based Cooperative DC Community Microgrids

Sahoo, Subham; Chih-Hsien Peng, Jimmy ; Mishra, Sukumar ; Dragicevic, Tomislav

Published in:
Proceedings of the 3rd International Conference on DC Microgrids 2019

Publication date:
2020

Document Version
Accepted author manuscript, peer reviewed version

A Local Voting Protocol Based Cooperative DC Community Microgrids

Subham Sahoo, Jimmy Chih-Hsien Peng
Department of Electrical and Computer Engineering
National University of Singapore
Email: elesubh@nus.edu.sg; jpeng@nus.edu.sg

Sukumar Mishra
Department of Electrical Engineering
Indian Institute of Technology Delhi
New Delhi, India
Email: sukumar@ee.iitd.ac.in

Tomislav Dragičević
Department of Energy Technology
Aalborg University
Denmark 9000
Email: tdr@et.aau.dk

***Abstract*—Under the conventional schemes, the battery management systems are usually designed from the system operator's perspective aligning them with common modes of operation to either ensure the longevity of each battery or an economically viable option. However, in DC microgrids with the batteries reinforced by local investments of each customer, their operation is primarily governed by the consumers' preferences. To support this feature, this paper introduced a local voting scheme using a binary distributed protocol based power management strategy for an autonomous network of PV-battery based cooperative DC community microgrid, allowing each customer to *vote* to undergo either energy balancing or load sharing between the batteries in a distributed manner based on their respective future usage. Moreover, it manifests these objectives using a voting index based on majority & emergency events which is used to resolve the system operation. The proposed control strategy is simulated to demonstrate its effectiveness for various voting scenarios under physical disturbances such as communication delay, link failure, converter failure & data packet loss and experimentally validated on a 600 W FPGA based experimental prototype.**

I. INTRODUCTION

The increased use of renewable energy sources (RESs) has bolstered harvesting these sources locally thereby increasing the transmission capacity of the system [1]-[2]. Moreover, availing these sources locally can increase efficiency by reduction in the number of AC/DC conversion stages [3]-[4]. As a result, local management between these sources in autonomous DC microgrids enhances the system efficiency. To maintain system reliability owing to the intermittent nature of renewable sources, battery energy storage systems (BESSs) are often employed to maintain DC voltage via mitigation of power mismatch [5]. In case of grid-connected systems [6], the power balancing is easily managed by the utility grid. However in autonomous mode [7], it is a sumptuous task to coordinate between the available BESSs. Failure to mitigate the power mismatch can either create voltage dips or lead to oscillations depending on the nature of the active loads. Such conditions usually arise when BESSs run out of their capacity. Accounting these issues, a proper battery management system is obviated thereby ensuring its longevity. However, these objectives are primarily based on achieving common goals such as ensuring battery longevity and maintaining system performance accounting heavy investments on purchase and installment of all the sources in a microgrid by a single entity/shareholder [8], [9], [10]. This philosophy can be usually categorized as a generic case considering the techno-economical benefits which are usually retained by the distribution system operators (DSOs) [14]. However, the same concept can't be extended in a DC community microgrid with energy storage devices acquired and invested by each individual consumer, in particular, where the objectives are governed by usage pattern of each individual. In such cases, the system performance index isn't crucial since there's no accountable investment for the system which determines the control philosophy. On the other hand, the susceptibility to communication adversities increases as the abovementioned philosophies are reliant upon a centralized infrastructure, which is costly and goes ineffective with a single point of link-failure [13]. Considering this view point, an insight on DC community microgrids which facilitates each user to vote for the mode of operation for their respective BESS based on their future usage has not gained significant attention yet. On the other hand, this idea allows flexibility for the customers' load consumption profile in an autonomous microgrid and encourage community participation as a whole. Since such measures require intensive communication, many secondary controllers for battery management systems have already been devised in [11], [12]. However, these papers are only based on techno-economic system perspective, which establishes common goals for each unit in the community. As a result, these conventions can't be extended with the aim to solely provide consumer usage flexibility.

To address these points, this paper proposes a cooperative model for community based DC microgrid which operates using distributed communication. Since every home user has invested for local BESS supply to ensure reliability in the absence of grid, this paper investigates consumer voting options as per their future usage determined using local voting concept using a binary distributed protocol to either operate in proportionate load sharing or energy balancing mode as per their future usage. Since it facilitates a variant of sets for the voting options, a compromised operation is determined in this paper using a voting index to accommodate the system objectives without any conflict among the consumers.

This paper is organized as follows. The cyber-physical architecture is illustrated in Section II with a brief overview on

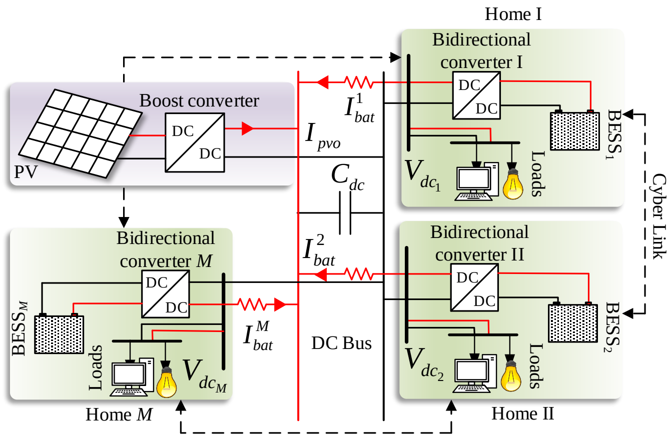

Fig. 1. Generic cyber-physical model of a DC community microgrid.

the conventional control philosophy. Section III discusses the proposed norm for PV-BESSs based cooperative DC community microgrids with detailed explanation on the control objectives and the role of consumers in the local voting protocol concept. The control strategies have been simulated for various disturbances to test the performance of the controller along with experimental validation in Section IV & V respectively. Finally, Section VI concludes the paper.

II. Cyber-Physical Architecture

The architecture of the considered system is shown in Fig. 1. It consists of a PV farm connected via DC/DC boost converter supplying power to M homes each consisting of BESS via DC/DC bidirectional converters of equal capacities with few DC loads, both resistive and dynamic loads, where i^{th} home is connected to the DC bus via resistive lines r_i. Each BESS operate to maintain output voltage which regards them as *agents* in the cyber graph since PV always acts as a current source since it runs to achieve maximum point power tracking (MPPT). Modeling each home as an agent, the communication graph in Fig. 1 is represented as an undirected graph via edges and links using an adjacency matrix $\mathbf{A} = [a_{ij}] \ \epsilon \ R^{NXN}$ with communication weights given by

$$a_{ij} = \begin{cases} > 0, & \text{if } (x_i, x_j) \ \epsilon \ \mathbf{E} \\ 0, & \text{else} \end{cases} \tag{1}$$

where $\mathbf{E}$ is an edge connecting two homes, x_i & x_j being the local and neighboring node respectively. Using (1) to formulate a cyber graph for the entire system, a Laplacian matrix $\mathbf{L}$ is formed, where $\mathbf{L} = \mathbf{Z}_{in} - \mathbf{A}$ with $\mathbf{Z}_{in}$ being the matrix representing incoming information from the neighbors. More details on consensus theory in a distributed cyber topology can be referred from [15].

Usually in DC microgrids, the voltage at each bus is maintained to regulate the power imbalance in the network. Moreover, the entire load in the network is usually shared between each source proportionately to minimize the flow of circulating current between the converters [16]. This can be achieved in many ways with or without communication with a trade-off in the system performance. The voltage at i^{th} bus is regulated alongwith ensuring proportionate load sharing by generating a voltage reference $V^*_{dc_i}$ for the primary controller using

$$V^*_{dc_i} = V_{dc_{ref}} - I_{b_i} R_{vir_i} + \underbrace{V_{com}}_{\text{Secondary controller}} \tag{2}$$

where $V_{dc_{ref}}$ is the global reference voltage, I_{b_i} is the battery output current and R_{vir_i} is the virtual resistance based droop, which is given by $R_{vir_i} = \Delta V_{dc}/I^{max}_{b_i}$, where ΔV_{dc} & $I^{max}_{b_i}$ denote the allowable voltage deviation and maximum current rating of i^{th} converter. In case of decentralized system in (2), $V_{com} = 0$ which introduces a steady state error in the voltages; leading to inefficacy in operation of the loads. Moreover, it operates in the absence of global information leading to further vulnerabilities. To ensure voltage restoration, secondary controllers are usually employed to provide a control input V_{com} using the global information obtained from communication among controllers & sensors. Since centralized cyber topologies are very costly involving heavy infrastructure with single point of failure vulnerability, distributed communication is preferred owing to high reliability and efficiency. Acknowledging these features, many papers [13], [15] have proposed average voltage regulation & proportionate load sharing, which is carried using the following control updates:

- Average voltage regulation:

$$\dot{\bar{V}}_{dc_i}(t) = \dot{V}_{dc_i}(t) + \sum_{j \epsilon N_i} (\bar{V}_{dc_j}(t) - \bar{V}_{dc_i}(t)) \tag{3}$$

where $\bar{V}_{dc_i}$ is the average voltage estimate of i^{th} agent with the neighboring estimate given by V_{dc_j} in the set of neighboring agents N_i. Since the line resistances in a DC network creates an irregular voltage profile, a voltage observer is designed in (3) to estimate the average voltage such that the voltages at each bus always lie within a specific bound. To ensure proper power management between the sources, the system load is usually shared proportionately among the available sources. On the other hand, proper resource allocation in the community is ensured by carrying out energy balancing between the BESSs such that their charge/discharge cycles are kept uniform. It should be noted that once energy is balanced between BESSs, it will eventually result into power management, which associates the abovementioned strategies using

- Proportionate load sharing:

$$\dot{I}_{b_i}(t) = -b_i \sum_{j \epsilon N_i} [I_{b_i}(t)/I^{max}_{b_i} - I_{b_j}(t)/I^{max}_{b_j}] \tag{4}$$

where b_i is the coupling gain. Moreover, if the available energy of each BESS, expressed as state of charge (SoC), in p.u., need to be balanced, it is carried out using

- Energy balancing:

$$\dot{\chi}_i(t) = -d_i \sum_{j \epsilon N_i} [SoC_i - SoC_j] \tag{5}$$

where SoC_i is the available SoC of the BESS in i^{th} home. It should be noted that (4) & (5) are the objectives which is consistent for every BESS, which doesn't provide much flexibility to the convenience of end customers. This extends for a fair possibility where a DC community microgrid is made up of BESSs invested by each consumer in their homes. As a result, the objectives would become individual-centric which gives them an option to regard with a set of objectives based on their future usage. Since it becomes a cumbersome task to accommodate all the options voted by each home, this paper covers this aspect using a local voting protocol using a binary consensus concept. As a consequence, every end user in a home gets to vote for either of the objectives from (4) & (5) to be operated based on their usage pattern in the future.

III. Cooperative DC Community Microgrid

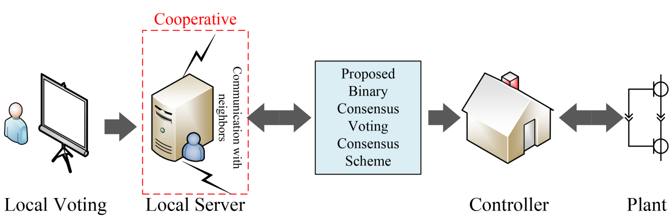

Fig. 2. Cooperative community microgrid: Operation schema.

This section details out on the cooperative norm for DC community microgrids where each user in a home votes for either proportionate load sharing or energy balancing based on their future usage requirements. It can be intuitively extended to the fact of human behavior that a user in i^{th} home foreseeing a high amount of loading locally will chose to vote for energy balancing if SoC_i is considerably low. However, this voting scenario may vary based on the system loading level & energy content of other homes which doesn't convey a significant advantage for a particular home to operate in either modes. It should be noted that the consumer behavior based on different system conditions in accounted as future scope as this paper primarily focuses on the control adversities to achieve a compromise between these objectives using a local voting concept in a cooperative manner. This is achieved by local binary voting v_i for i^{th} home using

$$v_i = \begin{cases} 1, \text{Proportionate load sharing} \\ 0, \text{Energy balancing} \end{cases} \tag{6}$$

Using (6), a voting term accounting the measurements from the neighboring homes is calculated using a voting index for i^{th} home, given by c_i, which is determined using a dynamic binary consensus concept in

$$c_i(t) = v_i(t) + \int_0^\tau \sum_{j\epsilon N_i} (c_j(\tau) - c_i(\tau))d\tau \tag{7}$$

It can be seen that (7) delineates dynamic averaging of all the votes in a cooperative manner for the entire physical network. As shown in Fig. 2, the binary voting input from each user

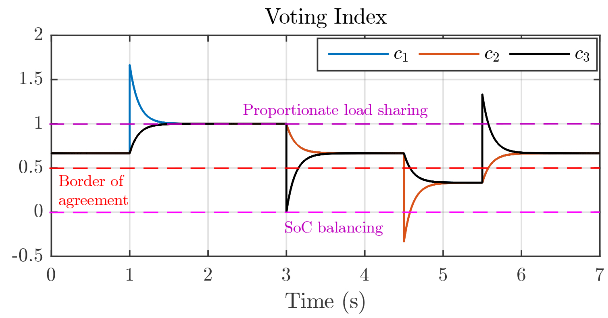

Fig. 3. Variation of voting index in a DC community microgrid comprising M = 3 agents.

considering measurements from their neighbors is used in (7) to re-define the conventional sharing objectives in (4) & (5). Moreover as the dynamic consensus updates the voting index, it can be seen in Fig. 2 that the flow of information is bidirectional.

Remark I: Modeling a system with M agents, each contributing to one vote, will have M votes in total. A *majority* to operate for either proportional load sharing or energy balancing is achieved when a minimum of $M/2$ votes is acquired in the network. An indicative property of (7) is that it determines the majority easily in a distributed manner as an attribute of dynamic averaging using the condition

$$c_i = \begin{cases} > 0.5, \text{Operate with: Proportionate load sharing} \\ \leq 0.5, \text{Operate with: Energy balancing} \end{cases} \tag{8}$$

where 0.5 is the border of agreement.

Remark II: If all the agents respond in a manner such that a common goal can be achieved in the community having received the same vote from each agent without disparity, the voting in the community is said to achieve *voting agreement*, if $c_i = 0$ or $c_i = 1$. Otherwise, the voting condition is usually referred to as a *voting conflict*. Using Remark I & II, a general case of voting scenario is considered for a system comprising M = 3 agents in Fig. 3. It can be seen that during various instances of voting change from different agents, the voting index of each agent varies accordingly owing to the averaging policy. Using Remark I, a *voting agreement* is achieved for proportionate load sharing by every agent as c_i = 1 at t = 1 s. However, the following voting changes depict instances of *voting conflict* where a *majority* of votes is obtained for proportionate load sharing at t = 3 & 5.5 s and energy balancing at t = 4.5 s using Remark I. On a longer time-scale, it can be easily directed that when the energy of each BESS is balanced, it will lead to proportional load sharing. Keeping this aspect in view, a settlement based load sharing operation is proposed for the minority voters as it may usually correspond to a state of emergency. To carry this operation, a majority-based proportionate load sharing for the set of minority voters **F** is carried out using

$$\dot{I}_{b_y} = -b_y \sum_{m\epsilon N_y} [(c_y \dot{\chi}_y I_{b_y}(t))/M I_{b_y}^{max} - I_{b_m}(t)/I_{b_m}^{max}] \tag{9}$$

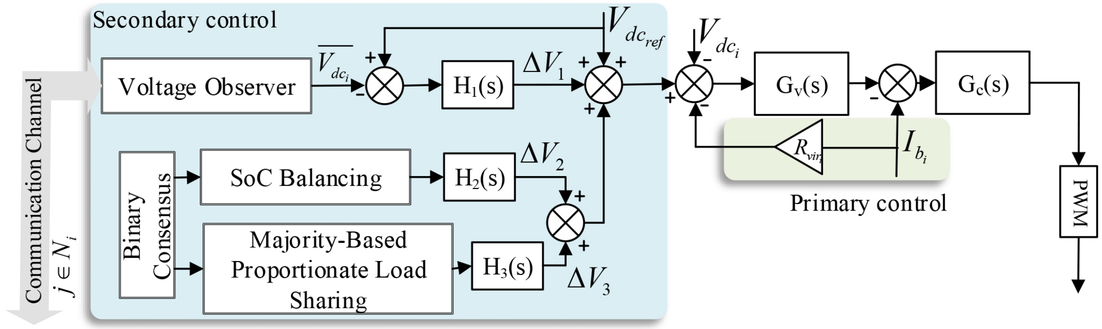

Fig. 4. Proposed controller for i^{th} agent.

where I_{b_y} and I_{b_m} denote the battery current of the minority voting agents and its neighbors respectively. The significance behind using weights in the minority voters' output current term in (9) is to minimize/maximize equal load sharing proportion in such a manner so that the minority voting group gets more/less current for energy balancing based on the value of difference between SoC of the neighboring BESSs respectively, ascribed using the term χ. As shown in Fig. 4, the sharing objectives, SoC balancing and proportionate sharing are alternatively used which is administered using the binary consensus theory for each home. It should be further noted that for cases involving *voting agreement* for c_i = 1, the system operates with the conventional proportionate load sharing in (4) without going through energy balancing. As shown in Fig. 4, these objectives are usually carried out by respective voltage correction terms added to the global reference voltage which are obtained using

$$\Delta V_1 = H_1(s)(V_{dc_{ref}} - \bar{V}_{dc}) \tag{10}$$

$$\Delta V_2 = H_2(s)\dot{\chi} \tag{11}$$

$$\Delta V_3 = H_3(s) \underbrace{\dot{I}_b}_{\text{Eq. (9)}} \tag{12}$$

where $H_1(s)$, $H_2(s)$ and $H_3(s)$ denote PI controllers. Using (10)-(12), the final voltage reference for each agent is given by

$$V^*_{dc_{ref}} = V_{dc_{ref}} + \Delta V_1 + \Delta V_2 + \Delta V_3 \tag{13}$$

Finally using a voltage adjustment policy established in (13), the local voting protocol based cooperative power management scheme is carried out in the DC community microgrid.

IV. Simulation Results

The proposed secondary control strategy is tested on a DC community microgrid of 315 V as shown in Fig. 1 with M = 3 homes comprising BESSs of equal capacity of 3 kW alongwith a PV farm of 10 kW are interconnected to each other via a resistive lines. Each source acts as an agent in the cooperative network such that the local information is only shared among the neighbors. The proposed controller is tested with load change in each home under various scenarios such as communication delay, link failure, converter outage and data packet loss. Furthermore, the performance of the proposed local voting protocol scheme followed by votes from each home is realized using the MATLAB/SIMULINK environment. It should be further noted that the system parameters, SoC values for Scenario I & II are detailed in Appendix A.

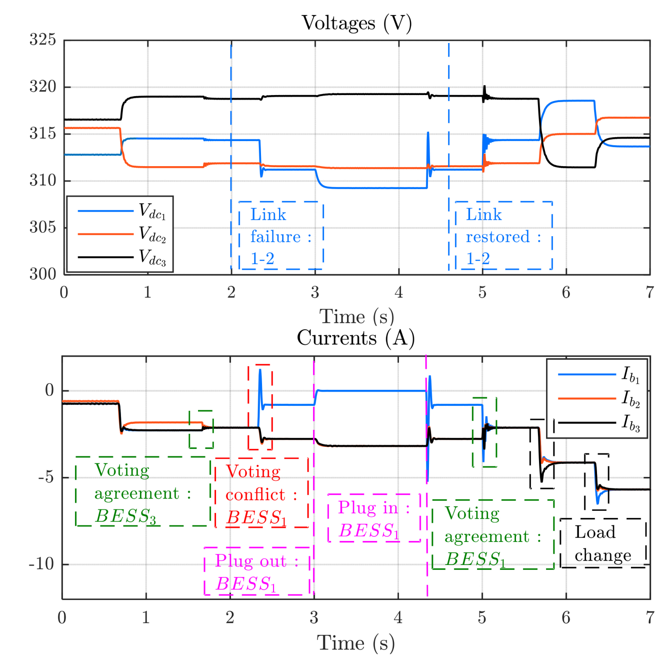

Fig. 5. Scenario I: Performance of local voting scheme in the presence of link failure & converter outage(plug-and-play) in cooperative DC community microgrid.

A. Scenario I

In this scenario, link failure and converter outage(plug-and-play) is simulated in presence of the proposed local voting protocol concept. Initially, it can be seen in Fig. 5 that there's a *voting conflict* where $BESS_2$ is operating in energy balancing mode. However since the majority of votes are with proportionate load sharing, the rest of the BESSs are sharing the load. At t = 1.6 s, a *voting agreement* is achieved for c_i = 1 as $BESS_2$ resorts back to operate in the proportionate load sharing mode. As per the distributed cyber topology with a ring structure, it can be further seen that despite link

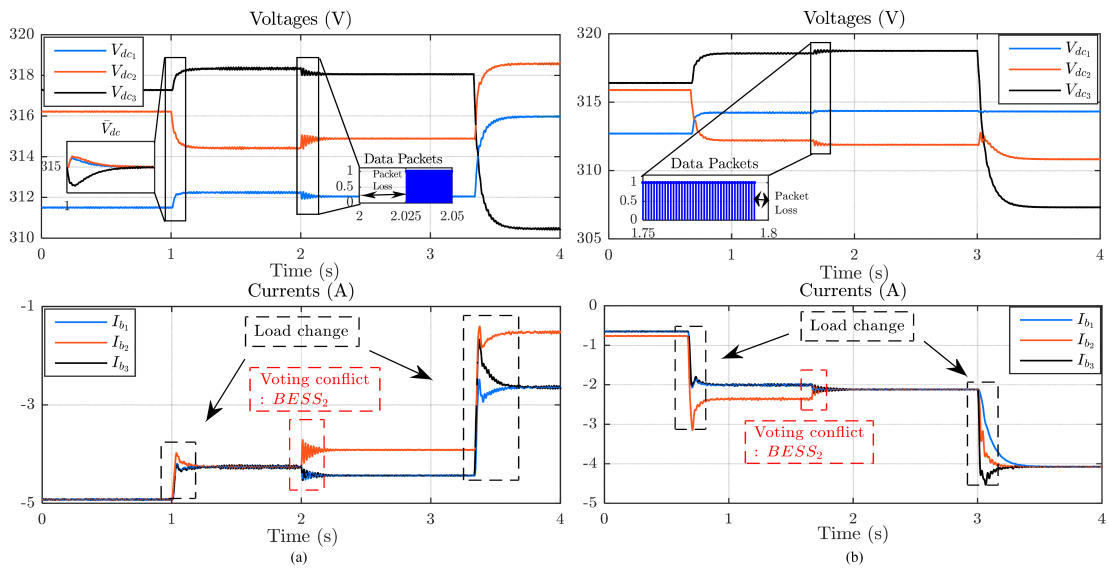

Fig. 6. Scenario II: Performance of local voting protocol in a cooperative DC community microgrid with a (a) communication delay of 100 ms with 50% data packet loss & (b) communication delay of 225 ms with 10% data packet loss.

failure between home 1 & 2, the objectives are successfully met. Further, a conflict follows as $BESS_1$ votes for energy balancing mode at t = 2.25 s. Considering a practical scenario, it may happen that homes may opt out to participate in any of the objectives which relates to converter outage considering a contingency. Under such cases, it can be seen that the rest of the BESSs respond satisfactorily to meet the demand when $BESS_1$ is plugged out at t = 3 s. Similarly when $BESS_1$ is plugged in at t = 4.5 s, the load sharing profile is restored. This property can be ascribed to a well-spanning distributed cyber graph which ensures convergence. Following another instance of voting agreement for c_i = 1 at t = 5 s, it can be clearly seen in Fig. 5 that each BESSs are sharing the system load equally.

B. Scenario II

In this scenario, the local voting consensus theory is tested under delay in the cyber network and drop-out of data packets in Fig. 6. In Fig. 6(a), a maximum communication delay of 100 ms with 50% data packet loss per sample for a communication sampling rate of 200 Hz is introduced in the cyber network. This is done using a "FIFO Queue" in MATLAB/SIMULINK environment by limiting the channels for simultaneous transmission of packets. Similarly, in Fig. 6(b), a maximum communication delay of 225 ms with 10% data packet loss per sample is introduced in the cyber network. However, the distributed cyber topology in lieu of the local voting protocol ascertains zero convergence under all scenarios owing to the dynamic averaging policy.

V. Experimental Results

An experimental prototype of DC voltage 48 V consisting of three units, two BESSs, and one PV via DC/DC bidirectional converters and a DC/DC boost converter respectively are inter-connected via tie-lines with load at unit 1 & 2 as shown in Fig.

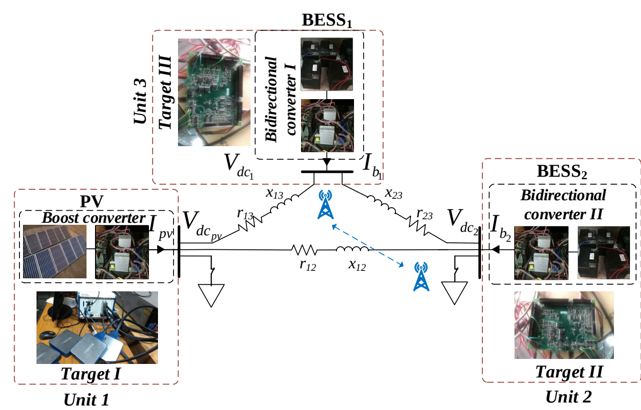

Fig. 7. Experimental setup of cyber-physical DC community microgrid.

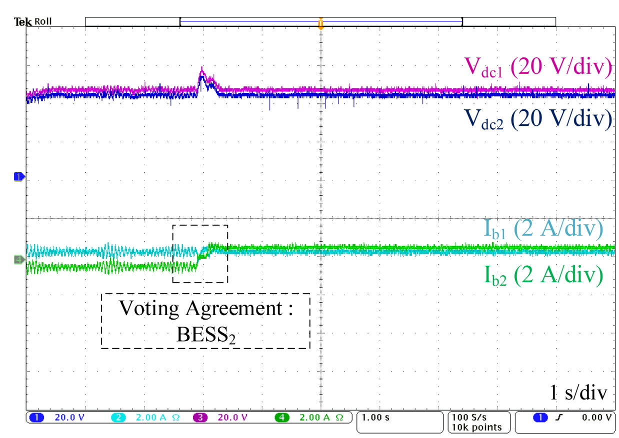

Fig. 8. Experimental result: Performance of local voting protocol for *voting agreement* in DC community microgrid.

7. All the sources are controlled using independent controllers, highlighted as targets. The MPPT mode of operation for

PV is programmed a using NI PXIe 7853R series (Target I) with NI PXIe 7853R series acquisition boxes. Similarly, the analog measurements from both the BESS(represented as homes) are acquired using two individual chassis of NI sbRIO 9606, namely Target II & III respectively for real-time implementation. All the control algorithms are implemented in LabVIEW which ultimately processes each controller to produce respective gating signals for the converters. Category-5 Ethernet conforming to IEEE 802.3 specifications is used for communication between Unit 2 & 3. The proposed control algorithm is implemented in a PC (host) using LabVIEW which provides a GUI to produce respective gating signals for both the converters. The testbed plant and controller parameters are provided in Appendix B.

It can be seen in Fig. 8 that the controllable agents, i.e., unit 2 & 3 in the cyber graph are operating to maintain an average voltage of 48 V in the network. Moreover, it can be seen that initially, $BESS_1$ & $BESS_2$ is discharging and charging respectively due to a voting conflict by $BESS_2$ to operate with energy balancing mode prior to low SoC since c_i = 0.5. However, as highlighted in Fig. 8, during an event which involves a load change and voting agreement by all the BESSs to operate in proportionate load sharing mode, the BESS currents are equally sharing the load. This validates the proposed philosophy which can be extended to any network with M agents.

VI. Conclusion

This paper proposes a local voting protocol based cooperative norm for DC community microgrid which allows each home-user to vote for any objective based on their future load usage. This concept is independent of managing the objectives from a system operator's point of view as it stresses on individual flexibility with local investments on purchase & installation of energy storage systems. Based on the voting index for various levels, a system-level decision for the mode of operation is taken in a distributed manner. Moreover, a compromised mode of operation is determined which allows the minority voters to undergo energy balancing. This can be readily applied to the apartment based societies in India with BESSs as the back-up supply. To extrapolate the future scope of this work, the human behavior and their role can be studied.

Appendix A
Simulation Parameters

It is to be noted that the line parameter r_i is connected to i^{th} BESS.

Plant: r_1 = 1.2 Ω, r_2 = 1.5 Ω, r_3 = 1.8 Ω

Converter: L_i= 3 mH, C_{dc_i}= 250 μF

Controller: $V_{dc_{ref}}$= 315 V, R_{vir_1} = R_{vir_2} = R_{vir_3} = 0.75, b_i = 1.2, d_i = 1.5

SoC of BESSs:

Scenario I: SoC_1 = 56.7%, SoC_2 = 68.2%, SoC_3 = 75.8%

Scenario II(a): SoC_1 = 52.6%, SoC_2 = 80.4%, SoC_3 = 71.3%

Scenario II(b): SoC_1 = 54.1%, SoC_2 = 43.1%, SoC_3 = 51.8%

Appendix B
Testbed Parameters

Plant: r_{12} = 1.3 Ω, x_{12} = 65 μH, r_{13} = 1.55 Ω, x_{13} = 60 μH, r_{23} = 2.0 Ω, x_{23} = 50 μH

Converter: L_i= 3 mH, C_{dc_i}= 100 μF

Controller: $V_{dc_{ref}}$= 48 V, R_{vir_1} = R_{vir_2} = 0.75, b_i = 1.05, d_i = 1.25

SoC of BESSs: SoC_1 = 66.8 %, SoC_2 = 34.5 %

References

[1] N. Hatziargyriou and H. Asano, R. Iravani and C. Marnay, “Microgrids,” *IEEE Power and Energy Magazine*, vol. 5, no. 4, pp. 54–65, 2007.

[2] A. Khodaei and M. Shahidehpour, "Microgrid-based co-optimization of generation and transmission planning in power systems." *IEEE Trans. Power Systems*, vol. 28, no.2, pp. 1582-1590, 2013.

[3] T. Dragicevic, et al. "Advanced LVDC Electrical Power Architectures and Microgrids: A step toward a new generation of power distribution networks." *IEEE Electrification Magazine*, vol. 2, no. 1, pp. 54-65, 2014.

[4] ER Diaz, JC Vasquez and JM Guerrero. "Potential energy savings by using direct current for residential applications: A Danish household study case." *DC Microgrids (ICDCM), 2017 IEEE Second International Conference on*, 2017.

[5] T Dragicevic, X Lu, JC Vasquez, JM Guerrero,"DC microgrids–Part II: A review of power architectures, applications, and standardization issues", *IEEE Trans. on Power Elect.*, vol. 31, no. 5, pp. 3528–3349, 2016.

[6] S. Mishra, S. Sahoo and A. Dugar, “Hybrid MVMO based controller for energy management in a grid connected DC microgrid,” in *2015 IEEE Power, Communication and Information Technology Conference (PCITC)*, pp. 114–119, 2015.

[7] D Chen and L Xu, "Autonomous DC voltage control of a DC microgrid with multiple slack terminals," *IEEE Trans. on Power Systems*, vol. 27, no. 4, pp. 1897–1905, 2012.

[8] S Sahoo, Shatakshi, S Mishra, B Singh,"Fuzzy logic based control of power converter system in autonomous DC microgrid",*Power Electr. (IICPE), 2016 7th India Intl. Conf.*, pp. 1-5, 2017.

[9] X Lu, K Sun, JM Guerrero, JC Vasquez and L Huang, "State-of-charge balance using adaptive droop control for distributed energy storage systems in DC microgrid applications", *IEEE Trans. Ind. Elect.*, vol. 61, no. 6, pp. 2804–2815, 2014.

[10] T Dragičević, JM Guerrero, JC Vasquez and D Škrlec, "Supervisory control of an adaptive-droop regulated DC microgrid with battery management capability," *IEEE Trans. Power Elect.*, vol. 29, no. 2, pp. 695–706, 2014.

[11] T Morstyn, M Momayyezan, H Branislav and GV Agelidis, "Distributed control for state-of-charge balancing between the modules of a reconfigurable battery energy storage system", *IEEE Trans. Power Elect.*, vol. 31, no. 11, pp. 7986–7995, 2016.

[12] T Morstyn, H Branislav and GV Agelidis, "Cooperative multi-agent control of heterogeneous storage devices distributed in a dc microgrid", *IEEE Trans. Power Systems*, vol. 31, no. 4, pp. 2974–2986, 2016.

[13] S Sahoo, and S Mishra, "A Distributed Finite-Time Secondary Average Voltage Regulation and Current Sharing Controller for DC Microgrids", *IEEE Trans. Smart Grid*, 2017.

[14] K Kaur, R Rana, N Kumar, M Singh, S Mishra,"A colored petri net based frequency support scheme using fleet of electric vehicles in smart grid environment",*IEEE Trans. Power Systems*, vol. 31. no. 6, pp. 4638–4449, 2016.

[15] V. Nasirian, S. Moayedi, A Davoudi and F. L. Lewis, “Distributed Cooperative Control of DC Microgrids,” *IEEE Trans. Power Elect.*, vol. 30, no. 4, pp. 2288–2303, 2015.

[16] S Anand, BG Fernandes, and JM Guerrero, "Distributed control to ensure proportional load sharing and improve voltage regulation in low-voltage DC microgrids", *IEEE Trans. Power Electr.*, vol. 28, no. 4, pp. 1900–1913, 2013.