Multiagent-based Distributed Control for Operation Cost Minimization of Droop Controlled DC Microgrid Using Incremental Cost Consensus

Li, Chendan; Quintero, Juan Carlos Vasquez; Guerrero, Josep M.

Published in:
41th Annual Conference of IEEE Industrial Electronics Society, IECON 2015

DOI (link to publication from Publisher):
10.1109/IECON.2015.7392917

Publication date:
2015

Document Version
Accepted author manuscript, peer reviewed version

Multiagent-based Distributed Control for Operation Cost Minimization of Droop Controlled DC Microgrid Using Incremental Cost Consensus

Chendan Li, Juan C. Vasquez, and Josep M. Guerrero
Microgrid Research Programme www.microgrids.et.aau.dk
Department of Energy Technology, Aalborg University
Aalborg, Denmark
{che , juq , joz}@et.aau.dk

***Abstract*—In this paper, a multiagent based distributed control is proposed for DC microgrid to minimize the operation cost. The power of each distributed generator (DG) is dispatched in a distributed manner in a multiagent system by means of voltage scheduling. Every DG unit is taken as an agent, and they share the load corresponding to the operation cost of all the units in the system with only communication with direct neighbors through incremental cost consensus. The power regulation according to the power reference generated by consensus is implemented through voltage scheduling in local primary controllers. Simulation verification shows that total operation cost of the DC microgrid is successfully reduced though the proposed method.**

***Keywords*—multiagent; DC microgrid; operation cost minimization; droop control; incremental cost consensus**

I. Introduction

Microgrid, as is defined by U.S. Department of Energy, is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. The main feature of a microgrid is that, it cannot only work in grid-connected mode but also in islanded mode.

Recently, DC microgrids are gaining more interests due to its advantages to reduce energy conversion stages and improve power quality. Moreover, this reignited interest for DC system is also triggered by the outburst of various DC loads and generations (such as photovoltaic panels, batteries, fuel cells, LEDs, etc.). Actually, most of renewable energy resources (RESs) operate either inherently at DC or have a DC bus within the system.

Similar with bulk power system, reducing total generation cost through economic dispatch is essential for improving the efficiency of the system, especially when different types of DGs exist in the system. However, the major concern of the most previous works are focused on sharing the power among the DGs based on their respective power ratings [1], different SoC values of the battery[2][3], power loss[4], operation modes [5], through virtual impedance[1][6], adaptive droop[7]. There is also a work deal with the power flow in DC microgrid [8]. There is almost no previous works trying to take the operation cost into consideration for DC microgrid. For AC microgrid, authors in [9] firstly took the operation cost of different DG into consideration along with power ratings in a new droop scheme. In [10], incremental cost consensus is used in a smart grid context, but the details of power regulation realization are not given.

Typically, there are two ways of implementation to realize the optimization for the microgrid. Most of the applications are realized in centralized way with a single centralized controller to make the decision for optimization. In the decentralized way, without a single centralized controller, the local controllers through certain collaborative mechanism achieve the optimum.

In this paper, a multiagent based distributed control is proposed for DC microgrid to minimize the operation cost. The power of each DG is dispatched in a distributed manner through this multiagent system by means of voltage scheduling. Via only communicates with its direct neighbors, each unit can get the global information, make the decision locally and coorperate to achive the operation cost minimization of the whole system.

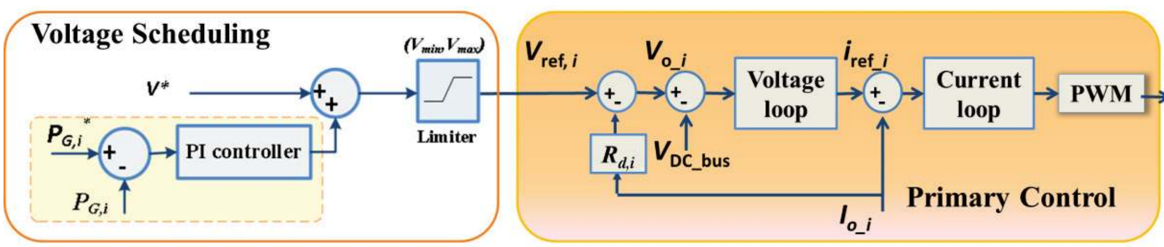


Fig. 1. Control scheme of frequency scheduling of each DG unit

II. VOLTAGE SCHEDULE FOR POWER RULATION OF DROOP CONTROLLED DC MICROGRID

The basic droop control for DC microgrid explained in literature is using a virtual impedance to regulate the output voltage so as to regulate output power of DG units, which can be expressed as

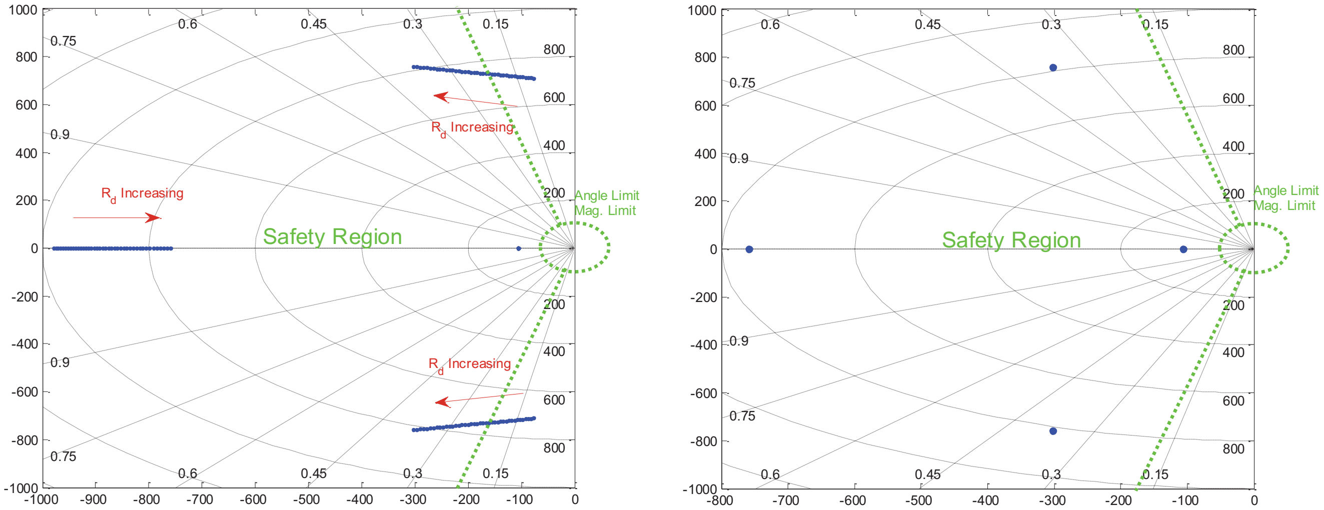
$$V_{o\_i} = V_{ref,i} - R_{d,i} i_{o,i} \tag{1}$$

where V_{o_i} is the voltage command given to the voltage loop of the converter i, $V_{ref,i}$ is the voltage reference for the droop controller and $R_{d,i}$ is the virtual impedance, and $i_{o,i}$ is the output current.

$$V_{ref,i} = V^* + Kp(P_{G,i}^* - P_{G,i}) + Ki\int(P_{G,i}^* - P_{G,i}) \tag{2}$$

Instead of changing $R_{d,i}$, in this work $V_{ref,i}$ is modified directly based on the power command. This control strategy actually not only maintains the benefit of traditional droop control to avoid power circulation, but also realizes accurate power sharing if power command is correctly given. The voltage reference is modified as (2), and the control diagram is given in Fig. 2.

Assume the converter as buck converter, the small signal analysis shows that, voltage regulation has higher stability margin [11]. The eigenvalue trace is shown as in Fig. 2 (b) than modifying droop gain as in Fig.2 (a).



(a) Impact of R_d on system stability (b) Impact of V_{ref} on system stability

Fig. 2. Comparison of impact of R_d and V_{ref} on system stability

III. MULTIAGENT SYSTEM FOR COST MINIMIZATION USING COST INCREMENTAL COST CONSENSUS

A. Problem Statement

The generation costs of different DGs (fuel cells, batteries, diesel generators, etc.) include many factors, which are surely not the same, but they might have a similar pattern which can be generalized as quadratic cost function [7] [9] [12].

$$C_i(P_{G,i}) = \alpha_i P_{G,i}^2 + \beta_i P_{G,i} + \gamma_i \tag{3}$$

where α_i, β_i and γ_i are the coefficient of cost function of DG unit i,

The total cost of operation of a microgrid with n generators can be expressed as,

$$C_{total} = \sum_{i=1}^{n} C_i(P_{G,i}) = \sum_{i=1}^{n} \alpha_i P_{G,i}^2 + \beta_i P_{G,i} + \gamma_i \tag{4}$$

Considering the constraints of power balance and power generation limitation, the objective to minimize the operation cost is to minimize the following function:

$$\begin{aligned} & Min \sum_{i=1}^{n} \alpha_i P_{G,i}^2 + \beta_i P_{G,i} + \gamma_i \\ & s.t. \ \sum_{i=1}^{n} P_{G,i} = P_D \\ & P_{G,i}^{\min} \le P_{G,i} \le P_{G,i}^{\max} \end{aligned} \tag{5}$$

where $P_{G,i}$ denotes the output power of unit i, and P_D denotes the total power demand of the system.

B. Incremental cost consensus

Same as conventional economic dispatch method, the incremental cost of each DG is defined as

$$r_i = \frac{\partial C_i(P_{G,i})}{\partial P_{G,i}} = 2\alpha_i P_{G,i} + \beta_i \tag{6}$$

Without generation capacity constraints, when the incremental cost reaches equality, it is the solution to (5) [9]. The common optimal r^* can be expressed as

$$r^* = [\sum_{i=1}^{n} \frac{\beta_i}{2\alpha_i} + P_D] / (\sum_{i=1}^{n} \frac{1}{2\alpha_i}) \tag{7}$$

Conventionally, this optimal incremental cost is calculated by a centralized controller. However, this method suffers from single point failure and relatively heavy communication overhead. In this distributed control strategy, the update rule of proposed incremental consensus algorithm is as follows.

$$r_i[t+1] = \sum_{i \in N_i} d_{ij} r_j + \varepsilon P_{D,i}[t] \quad (8)$$

$$P_{G,i}[t+1] = \frac{r_i[t+1] - \beta_i}{2\alpha_i} \quad (9)$$

$$P_{D,i}^{'}[t+1] = P_{D,i}[t] - (P_{G,i}[t+1] - P_{G,i}[t]) \quad (10)$$

$$P_{D,i}[t+1] = \sum_{i \in N_i} d_{ij} P_{D,i}^{'}[t+1] \quad (11)$$

where $r_i[t]$ is the incremental cost of agent i at iteration t, ε is the feedback coefficients which controls the convergence of the consensus, $P_{D,i}[t]$ is the estimation of the global supply-demand mismatch, and d_{ij} is defined as

$$d_{ij} = \begin{cases} 2/(n_i + n_j + 1) & j \in N_i \\ 1 - \sum_{j \in N_i} 2/(n_i + n_j + 1) & i = j \\ 0 & otherwise \end{cases} \quad (12)$$

The overall control algorithm is shown in Fig. 3.

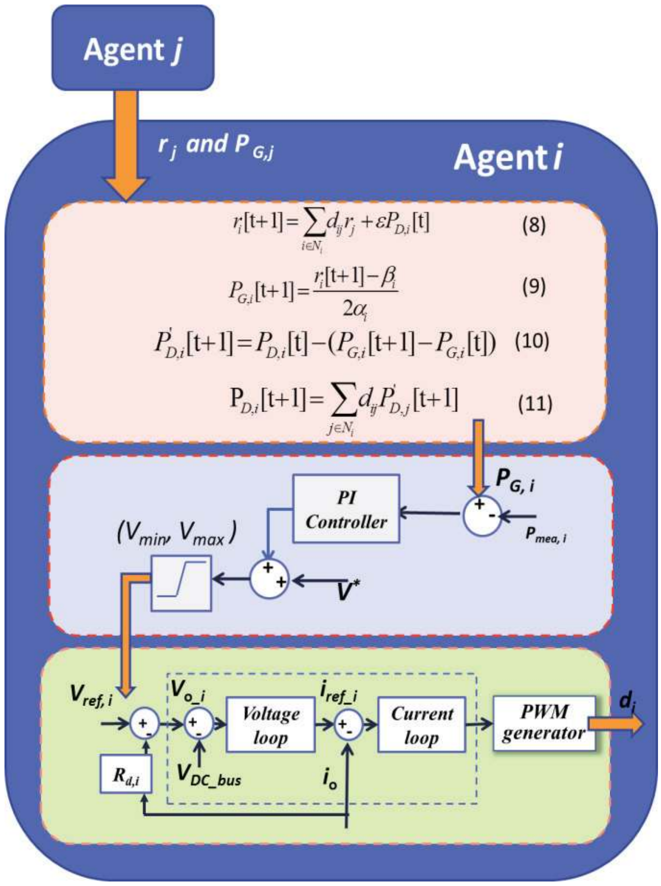


Fig. 3. Control algorithm for each agent.

IV. Simulation Results

In order to verify the proposed control strategy, simulation study is carried out to verify the proposed control strategy in a DC microgrid with four different DG units. Control parameters and operation cost coefficients for each unit are given in Table I and Table II, respectively.

During the simulation, only traditional droop is adopted at the beginning. At t = 5s, the proposed operation cost minimization method is activated. To the test the system during the load change, at t = 18s, the total load of the system is changed from 8.5kW to 13kW. Fig. 4 (a) to (d) show the total operation cost of the system, generation power of each DG unit, reference voltage of droop controller in each DG unit and DC bus voltage. It can be seen from Fig. 4 (a) that, the total operation cost is successfully reduced up to 3.4% using the parameter given in this paper. At the same time, the bus voltage is maintained in the acceptable level, as is shown in Fig. 4 (d). As is can be seen from Fig. 4 (b) and (c), the power is shared among differently according to the different voltage command.

TABLE I COEFFICIENTS OF THE OPERATION COST FUNCTION

Unit	α_i	β_i	γ_i
1	7.15e-3	0.77	0.002
2	4.75e-3	0.78	0.005
3	3.75e-3	0.55	0.001
4	3.45e-3	0.51	0.001

TABLE II CONTROL PARAMETER

Item	Symbol	Value
Nominal bus voltage	V^*	400V
Minimum bus voltage	V_{min}	420V
Maximum bus voltage	V_{max}	380V
Virtual impedance for DG1,3	$R_{d,1}$,$R_{d,3}$	0.2Ω
Virtual impedance for DG2,4	$R_{d,2}$,$R_{d,4}$	0.5Ω
Voltage scheduling proportional term	Kp	0.0009
Voltage scheduling integral term	Ki	0.001s-1
Consensus convergence coefficient	ε	0.001

V. Conclusion

This work proposes a multiagent based distributed control strategy to minimize the operation cost for DC microgrids. Every DG unit is taken as an agent, and they share the load corresponding to the operation cost of all the units in the system with only communication with direct neighbors. The power generation command is generated according to incremental cost consensus. Voltage scheduling is adopted for regulating the power. Simulation verification shows that total operation cost of the DC microgrid is successfully reduced though the proposed method while the DC bus voltage is maintained in the acceptable range.

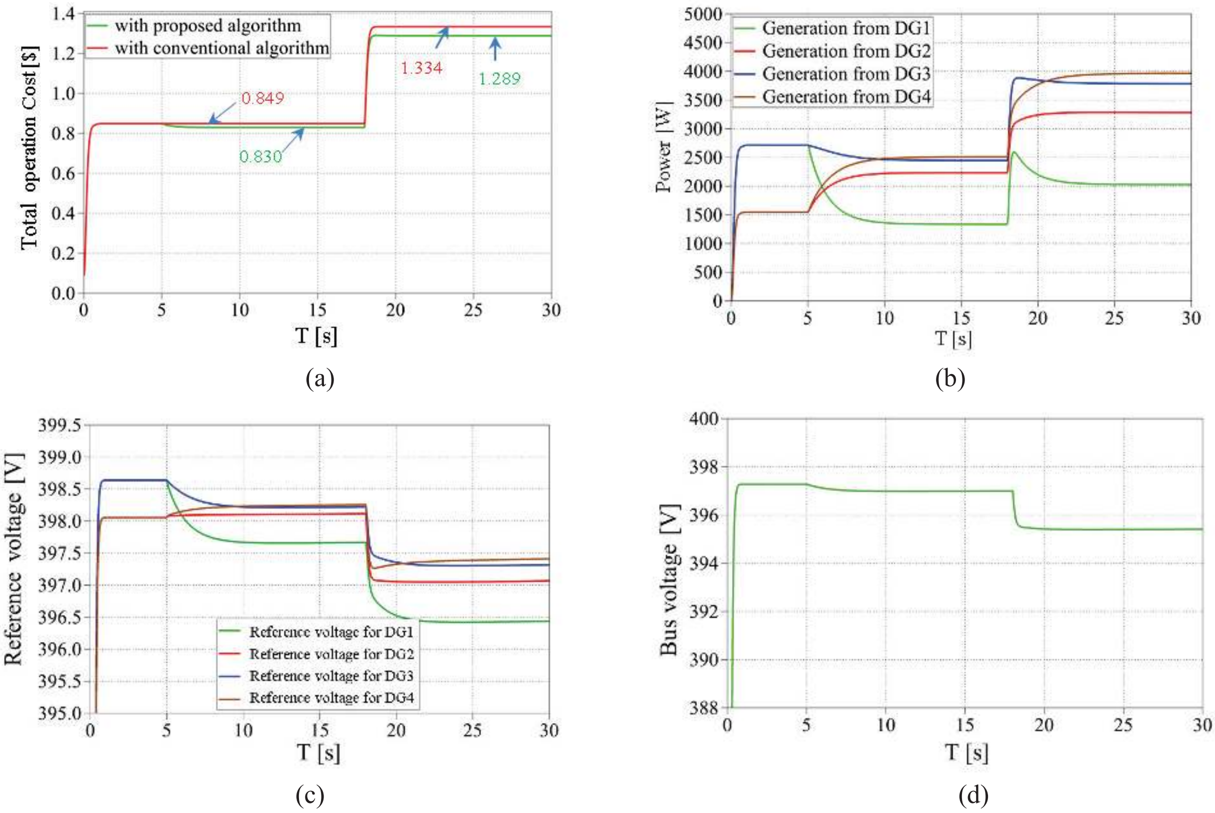


Fig. 4. Simulation results (a) Total operation cost. (b) Generation power of each DG unit. (c) Reference voltage of droop controller in each DG unit. (d) Bus voltage.

REFERENCES

[1] Guerrero, J.M.; Vasquez, J.C.; Matas, J.; de Vicuña, L.G.; Castilla, M., "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, Jan. 2011; doi: 10.1109/TIE.2010.2066534

[2] Xiaonan Lu; Kai Sun; Guerrero, J.M.; Vasquez, J.C.; Lipei Huang, "State-of-Charge Balance Using Adaptive Droop Control for Distributed Energy Storage Systems in DC Microgrid Applications," *Industrial Electronics, IEEE Transactions on* , vol.61, no.6, pp.2804,2815, June 2014;doi: 10.1109/TIE.2013.2279374;

[3] Chendan Li; Dragicevic, T.; Diaz, N.L.; Vasquez, J.C.; Guerrero, J.M., "Voltage scheduling droop control for State-of-Charge balance of distributed energy storage in DC microgrids," in *Energy Conference (ENERGYCON), 2014 IEEE International* , vol., no., pp.1310-1314, 13-16 May 2014

[4] Lexuan Meng; Dragicevic, T.; Guerrero, J.M.; Vasquez, J.C., "Dynamic consensus algorithm based distributed global efficiency optimization of a droop controlled DC microgrid," *Energy Conference (ENERGYCON), 2014 IEEE International* , vol., no., pp.1276,1283, 13-16 May 2014

[5] Yunjie Gu; Xin Xiang; Wuhua Li; Xiangning He, "Mode-Adaptive Decentralized Control for Renewable DC Microgrid With Enhanced Reliability and Flexibility," *Power Electronics, IEEE Transactions on* , vol.29, no.9, pp.5072,5080, Sept. 2014

[6] Dong Chen; Lie Xu; Liangzhong Yao, "DC network stability and dynamic analysis using virtual impedance method," *IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society* , vol., no., pp.5625,5630, 25-28 Oct. 2012

[7] Chaudhuri, N.R.; Chaudhuri, B., "Adaptive Droop Control for Effective Power Sharing in Multi-Terminal DC (MTDC) Grids," *Power Systems, IEEE Transactions on* , vol.28, no.1, pp.21,29, Feb. 2013

[8] Chendan Li; Dragicevic, T.; Diaz, N.L.; Vasquez, J.C.; Guerrero, J.M., "Voltage scheduling droop control for State-of-Charge balance of distributed energy storage in DC microgrids," in *Energy Conference (ENERGYCON), 2014 IEEE International* , vol., no., pp.1310-1314, 13-16 May 2014

[9] Nutkani, I.U.; Poh Chiang Loh; Blaabjerg, F., "Droop Scheme With Consideration of Operating Costs," *Power Electronics, IEEE Transactions on* , vol.29, no.3, pp.1047,1052, March 2014

[10] Ziang Zhang; Mo-Yuen Chow, "Convergence Analysis of the Incremental Cost Consensus Algorithm Under Different Communication Network Topologies in a Smart Grid," *Power Systems, IEEE Transactions on* , vol.27, no.4, pp.1761,1768, Nov. 2012

[11] Chendan Li; Dragicevic, T.; Garcia Plaza, M.; Andrade, F.; Vasquez, J.C.; Guerrero, J.M., "Multiagent based distributed control for state-of-charge balance of distributed energy storage in DC microgrids," in *Industrial Electronics Society, IECON 2014 - 40th Annual Conference of the IEEE* , vol., no., pp.2180-2184, Oct. 29 2014-Nov. 1 2014

[12] Shi, W.; Xie, X.; Chu, C.-C.; Gadh, R., "Distributed Optimal Energy Management in Microgrids," *Smart Grid, IEEE Transactions on* , vol.PP, no.99, pp.1,1