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## **Statistical Cooperative Power Dispatching in Interconnected Microgrids**

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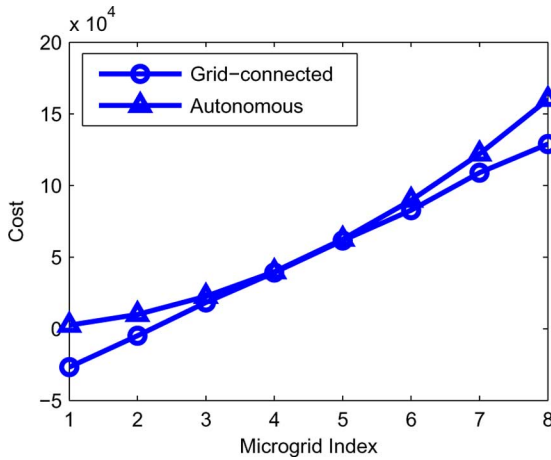


Fig. 7. Cost comparison between grid-connected SCPD and autonomous modes.

TABLE I  
OPTIMAL AVERAGE PRODUCED POWERS (KW)

MG <sub>1</sub>	MG <sub>2</sub>	MG <sub>3</sub>	MG <sub>4</sub>
223.0716	223.5716	224.0714	224.5709
MG <sub>5</sub>	MG <sub>6</sub>	MG <sub>7</sub>	MG <sub>8</sub>
225.0699	225.5689	226.0679	226.5672

In summary, as a numerical indicator, proposed SCPD in grid-connected mode achieves 20% cost reduce in comparison with stand-alone operation. In overall, this power sharing scheme transforms the parabolic cost curve to a linear one as shown in Fig. 7.

In order to evaluate SCPD algorithm in comparison with the optimal solution of (1) and (2), the problem at hand is also solved using IPM method to find the optimal solution, absolutely with given demands and maximum permitted supplies *a priori* at  $t = 1$ . The resulting average produced powers are shown in Table I. As seen, these values are mostly in accordance with those in Fig. 4 and average produced powers in Fig. 6. Moreover, the average operational cost of this solution is  $4.0646e5$  unit in comparison with  $4.0651e5$  and  $5.0933e5$  units in grid-connected and autonomous modes, respectively. The performance gap between the optimal cost and that of the grid connected mode is less than 0.1%. This reasonably verifies our results with the proposed cooperative power dispatching algorithm.

## VI. CONCLUSION

Load demand management with the aim of operational cost minimization in distributed smart grids have been investigated. It was shown that this objective could be achieved by a collaboration between MGs using a communication infrastructure and defining a set of parameters known as purchase prices. A natural consequence of this collaboration was to smooth the power generation within the grid. It was shown that power sharing in the grid-connected mode results in lower price than the stand-alone operation. This was due to the fact that low demand MGs revenue from purchasing power to the grid. On the other hand, high demand MGs reduces their production cost by purchasing power from the grid.

## APPENDIX

### CONVERGENCE OF THE STOCHASTIC ITERATION

As obtained in Section IV, the solution of dual problem (5) is obtained by stochastic iteration

$$x(t+1) = x(t) + \alpha(g(t))^+ \quad (11)$$

where  $x(t) \equiv \hat{\lambda}_n(t)$  and  $g(t) \equiv E_n - l_n^*(\gamma(t))$ . Let  $x^*$  be the optimal solution of  $x$ . Taking *norm-2* of  $(x(t+1) - x^*)$ , we get

$$\begin{aligned} \|x(t+1) - x^*\|^2 &\leq \|x(t) + \alpha g(t) - x^*\|^2 \\ &= \|x(t) - x^*\|^2 + 2\alpha g(t)(x(t) - x^*) + \alpha^2 \|g(t)\|^2. \end{aligned} \quad (12)$$

Considering the the concavity of  $D(\lambda)$ , we have  $D(x^*) \leq D(x(t) + \alpha g(t)(x^* - x(t)))$  [19]. This implies

$$\begin{aligned} \|x(t+1) - x^*\|^2 &\leq \|x(t) - x^*\|^2 - 2(D^* - D(t)) + \alpha^2 \|g(t)\|^2 \end{aligned} \quad (13)$$

where  $D(t) \equiv D(x(t))$  and  $D^* \equiv D(x^*)$ . Taking a similar recursive approach from  $x(t)$  to  $x(0)$  as an initial value, we derive

$$\begin{aligned} \|x(t+1) - x^*\|^2 &\leq \|x(0) - x^*\|^2 \\ &\quad - 2 \sum_{i=0}^t (D^* - D(t)) + \alpha^2 \sum_{i=0}^t \|g(i)\|^2. \end{aligned} \quad (14)$$

Since the left-hand side is always nonnegative, we derive

$$2 \sum_{i=0}^t (D^* - D(t)) \leq \|x(0) - x^*\|^2 + \alpha^2 \sum_{i=0}^t \|g(i)\|^2. \quad (15)$$

We take the following two assumptions:

- $\|g(i)\| \leq G$ , for all  $i$ .
- $\|x(0) - x^*\|^2 \leq R^2$ .

With reference to the system model in Section III, these assumptions are reasonable and can be provided in our case. Dividing both sides of (15) by  $2t$ , we derive

$$\frac{\sum_{i=0}^t (D^* - D(t))}{t} \leq \frac{R^2}{2t} + \frac{1}{2} \alpha^2 G^2. \quad (16)$$

If  $t \rightarrow \infty$ , by the law of large numbers we have

$$D^* - \bar{D} \leq \frac{1}{2} \alpha^2 G^2 \quad (17)$$

where  $\bar{D} = E[D(t)]$ . Since  $D$  is a concave function, by the Jensen's inequality [17] we have  $\bar{D} \leq D(\bar{x})$ , and accordingly

$$D^* - D(\bar{x}) \leq \frac{1}{2} \alpha^2 G^2. \quad (18)$$

Finally, choosing step size  $\alpha$  small enough, we conclude that the stochastic iteration (11) converges statistically.

## REFERENCES

- [1] W. El-Khattam and M. Salama, "Distributed generation technologies, definitions and benefits," *Elect. Power Syst. Res.*, vol. 71, no. 2, pp. 119–128, 2004.
- [2] H. Jiayi, J. Chuanwen, and X. Rong, "A review on distributed energy resources and microgrid," *Renew. Sustain. Energy Rev.*, vol. 12, no. 9, pp. 2472–2483, 2008.



- [3] I. Koutsooulos and L. Tassioulas, "Challenges in demand load control for the smart grid," *IEEE Netw.*, vol. 25, no. 5, pp. 16–21, Sep./Oct. 2011.
- [4] A. H. Mohsenian-Rad, V. Wong, J. Jatskevich, and R. Schober, "Optimal and autonomous incentive-based energy consumption scheduling algorithm for smart grid," in *Proc. Innovat. Smart Grid Technol. (ISGT)*, Jan. 2010, pp. 1–6.
- [5] M. Fathi and M. Gholami, "Localized demand-side management in electric power systems," in *Proc. Iranian Conf. Smart Grid (ICSG)*, Tehran, Iran, May 2012.
- [6] S. Caron and G. Kesidis, "Incentive-based energy consumption scheduling algorithms for the smart grid," in *Proc. IEEE Int. Conf. Smart Grid Commun. (SmartGridComm)*, 2010, pp. 391–396.
- [7] M. Pedrasa, T. Spooner, and I. MacGill, "Coordinated scheduling of residential distributed energy resources to optimize smart home energy services," *IEEE Trans. Smart Grid*, vol. 1, no. 2, pp. 134–143, Sep. 2010.
- [8] H. Allcott, "Real time pricing and electricity markets," *Group*, pp. 1–77, 2009.
- [9] C. Chowdhury, S. P. Chowdhury, and P. Crossley, *Microgrids and Active Distribution Networks*. London, U.K.: Inst. Eng. Technol., 2009.
- [10] R. H. Lasseter, J. H. Eto, B. Schenkman, J. Stevens, H. Vollkommer, D. Klapp, E. Linton, H. Hurtado, and J. Roy, "CERTS microgrid laboratory test bed," *IEEE Trans. Power Del.*, vol. 26, no. 1, pp. 325–332, Jan. 2011.
- [11] N. Hatziaargyriou, H. Asano, R. Iravani, and C. Marnay, "Microgrids," *IEEE Power Energy Mag.*, vol. 5, no. 4, pp. 78–94, Jul./Aug. 2011.
- [12] H. Bevrani, *Robust Power System Frequency Control*. New York, NJ, USA: Springer, 2009.
- [13] H. Bevrani and T. Hiyama, *Intelligent Automatic Generation Control*. Boca Raton, FL: CRC Press, 2011.
- [14] L. Robert, A. Akhil, C. Marnay, J. Stephens, J. Dagle, R. Guttromson, A. S. Meliopoulos, R. Yinger, and J. Eto, "Integration of distributed energy resources: The CERTS microgrid concept," in *Consort. Elect. Rel. Technol. Solutions*, Apr. 2002, California Energy Commission: P50003–089F.
- [15] Y. Fujioka, H. Maejima, S. Nakamura, Y. Kojima, M. Okudera, and S. Uesaka, "Regional power grid with renewable energy resources: A demonstrative project in Hachinohe," in *CIGRE Session*, Paris, France, 2006.
- [16] B. Awad, J. Wu, and N. Jenkins, "Control of distributed generation," *Elektrotech. Info.*, vol. 125, no. 12, pp. 409–414, 2008.
- [17] S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge, U.K.: Cambridge Univ. Press, 2004.
- [18] V. Solo and X. Kong, *Adaptive Signal Processing Algorithms: Stability and Performance*. Englewood Cliffs, NJ, USA: Prentice-Hall, 1995.
- [19] D. Bertsekas, *Nonlinear Programming*. Boston, MA, USA: Athena Scientific, 1999.



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