Cooperative Control of DC Microgrid Using Average Per-Unit Current Estimator

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Objective

- Proportional current sharing on the basis of source power ratings.
- Low voltage regulation of source buses.
- Reduced communication network.
- Lesser data congestion in the communication network [1].
- Link failure resiliency.
- Easily scalable.

Proposed Technique

Conventional droop controller:

$$v_j^{ref} = v_j^0 - d_j i_j^{p.u.} i_j^{rated}. \qquad (1)$$

Proposed droop controller:

$$v_j^{ref} = v_j^0 + \Delta v_j - d_j i_j^{p.u.} i_j^{rated} \qquad (2)$$

where,

$$\dot{d}_j = -g_j(\bar{i}_j^{p.u.} - i_j^{p.u.}) \qquad (3)$$

$$\Delta v_j = k_j \bar{i}_j^{p.u.} i_j^{rated} \quad [2]. \qquad (4)$$

Locally estimated average p.u. current:

$$\bar{i}_j^{p.u.} = \frac{i_j^{p.u.} + \sum_{i \in N_j} a_{ji} i_i^{p.u.}}{1 + \sum_{i \in N_j} a_{ji}}. \qquad (5)$$

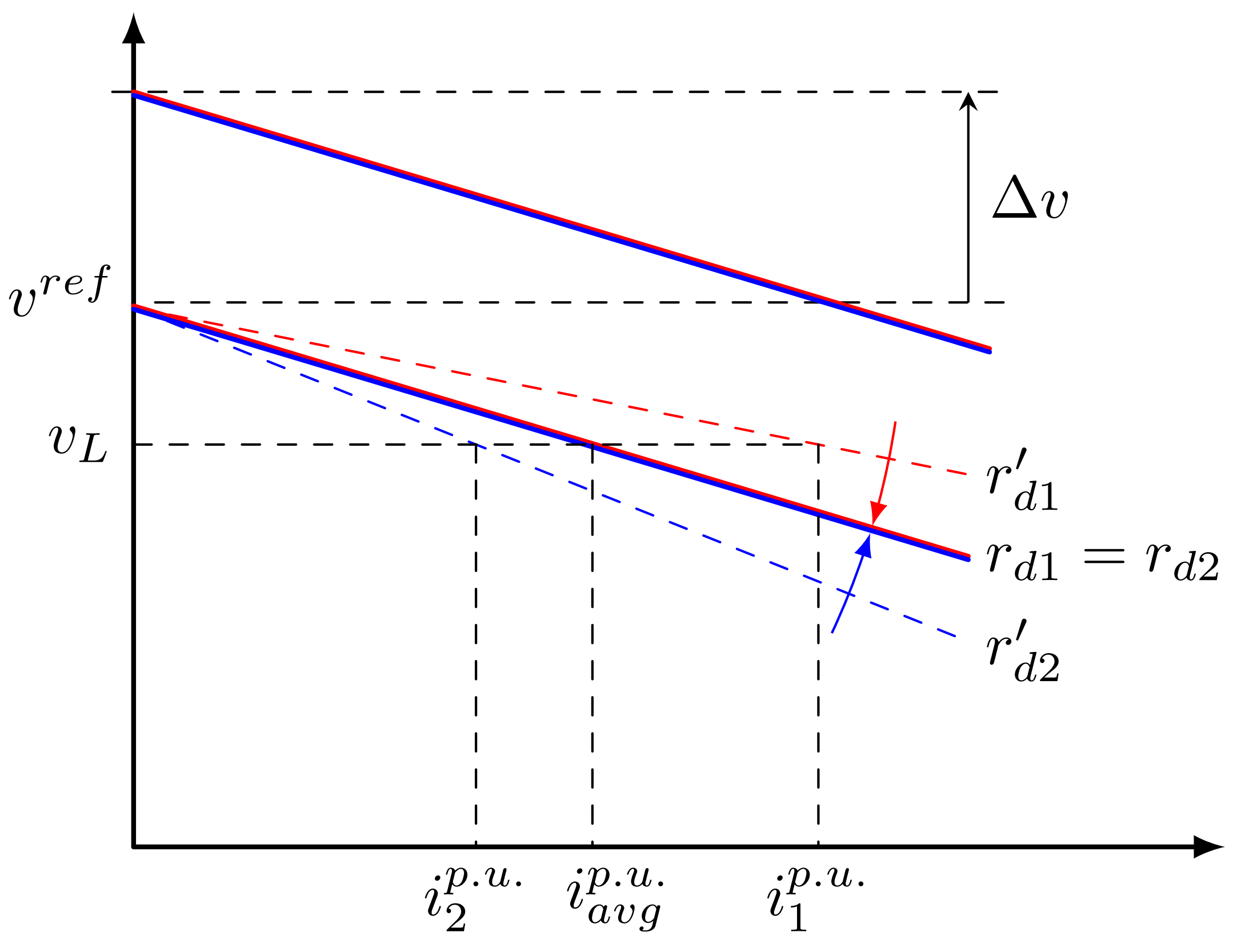


Fig. 1: Droop characteristics with proposed controller.

Block Diagram

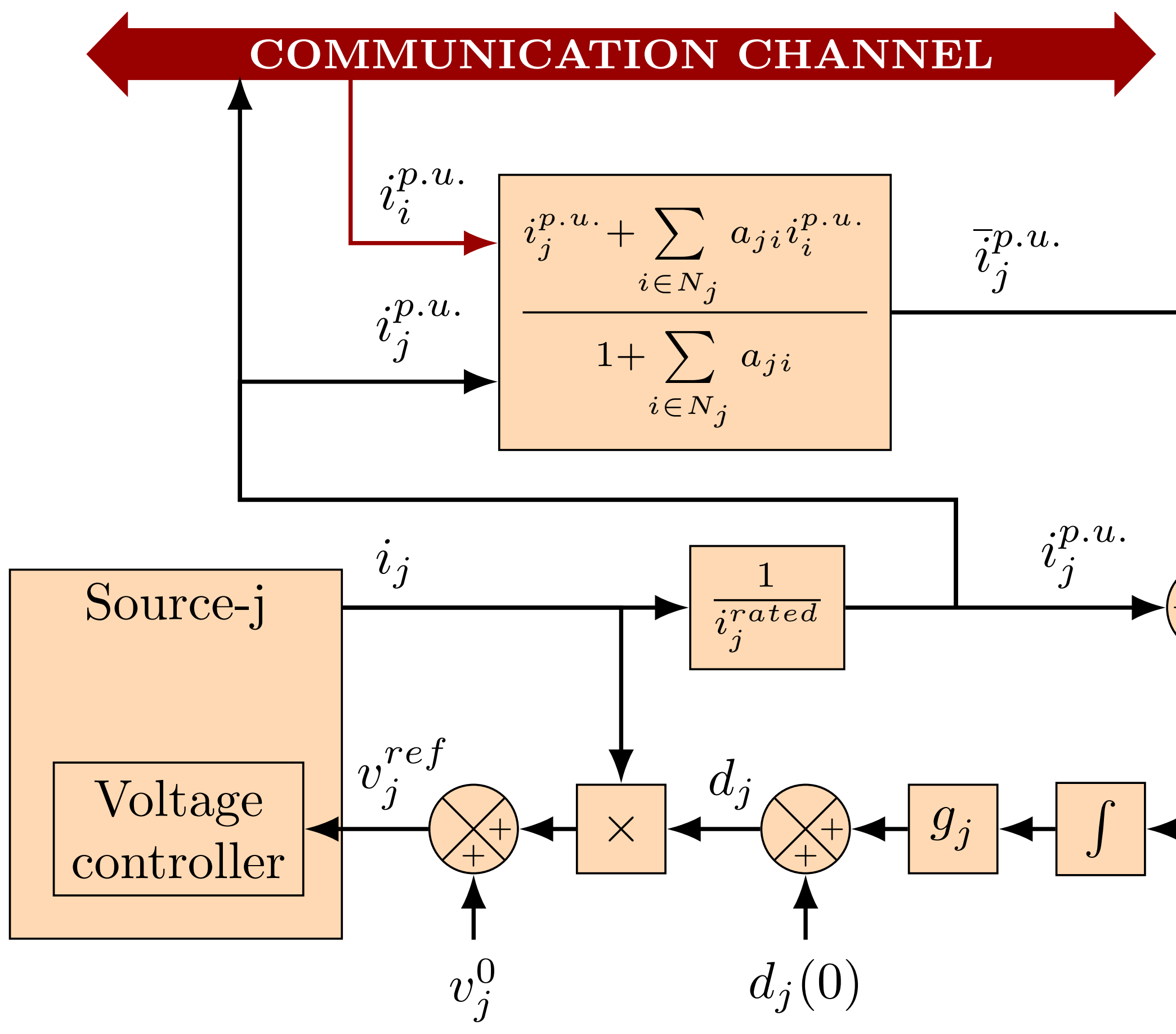


Fig. 2: Schematic of the proposed secondary controller.

Proof for Local Averaging leading to Global Average

(3) and (5) represented in vector form as below,

$$\dot{\mathbf{d}} = -\mathbf{G}(\bar{\mathbf{i}}^{p.u.} - \mathbf{i}^{p.u.}) \qquad (6)$$

$$\bar{\mathbf{i}}^{p.u.} = (\mathcal{D} + \mathbf{I})^{-1}(\mathcal{A} + \mathbf{I})\mathbf{i}^{p.u.} \qquad (7)$$

where $\mathcal{D}$ and $\mathcal{A}$ are the degree and adjacency matrices. At steady state, from (6), $\mathbf{i}^{p.u.} = \bar{\mathbf{i}}^{p.u.}$. Then (7) becomes,

$$\bar{\mathbf{i}}_{ss}^{p.u.} = (\mathcal{D} + \mathbf{I})^{-1}(\mathcal{A} + \mathbf{I})\bar{\mathbf{i}}_{ss}^{p.u.} \qquad (8)$$

which implies

$$[\mathbf{I} - (\mathcal{D} + \mathbf{I})^{-1}(\mathcal{A} + \mathbf{I})] = \mathbf{0} \qquad (9)$$

For j^{th} row, both $(\mathcal{D} + \mathbf{I})$ and $(\mathcal{A} + \mathbf{I})$ have row sum as $\sum_{i=1}^{N} a_{ji} + 1$. Thus, $[\mathbf{I} - (\mathcal{D} + \mathbf{I})^{-1}(\mathcal{A} + \mathbf{I})]$ has its row sum = 0, which implies **1** is a right eigen vector of $[\mathbf{I} - (\mathcal{D} + \mathbf{I})^{-1}(\mathcal{A} + \mathbf{I})]$. Hence at steady state p.u currents of all converters converge to the same value.

System used for Simulation

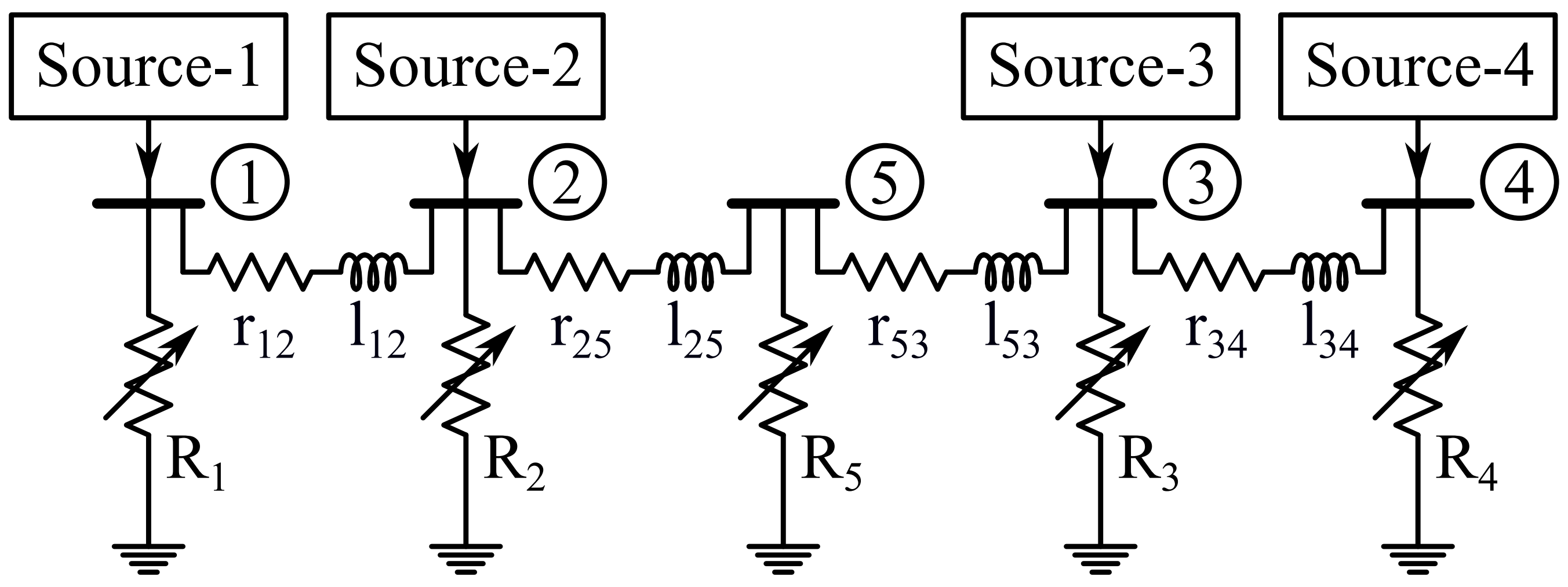


Fig. 3: DC microgrid system used for simulation.

Time (s)	R_1	R_2	R_3	R_4	R_5
0.6 < t < 1	6 Ω	6 Ω	6.5 Ω	6.25 Ω	6 Ω
t > 1	4.75 Ω	6 Ω	6.5 Ω	6.25 Ω	2.4 Ω

Table 1: Load distribution with time.

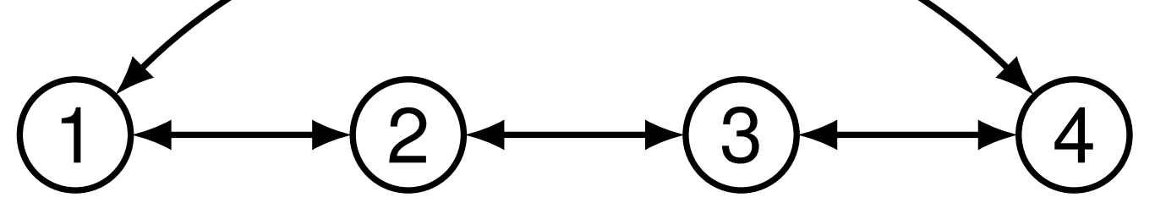
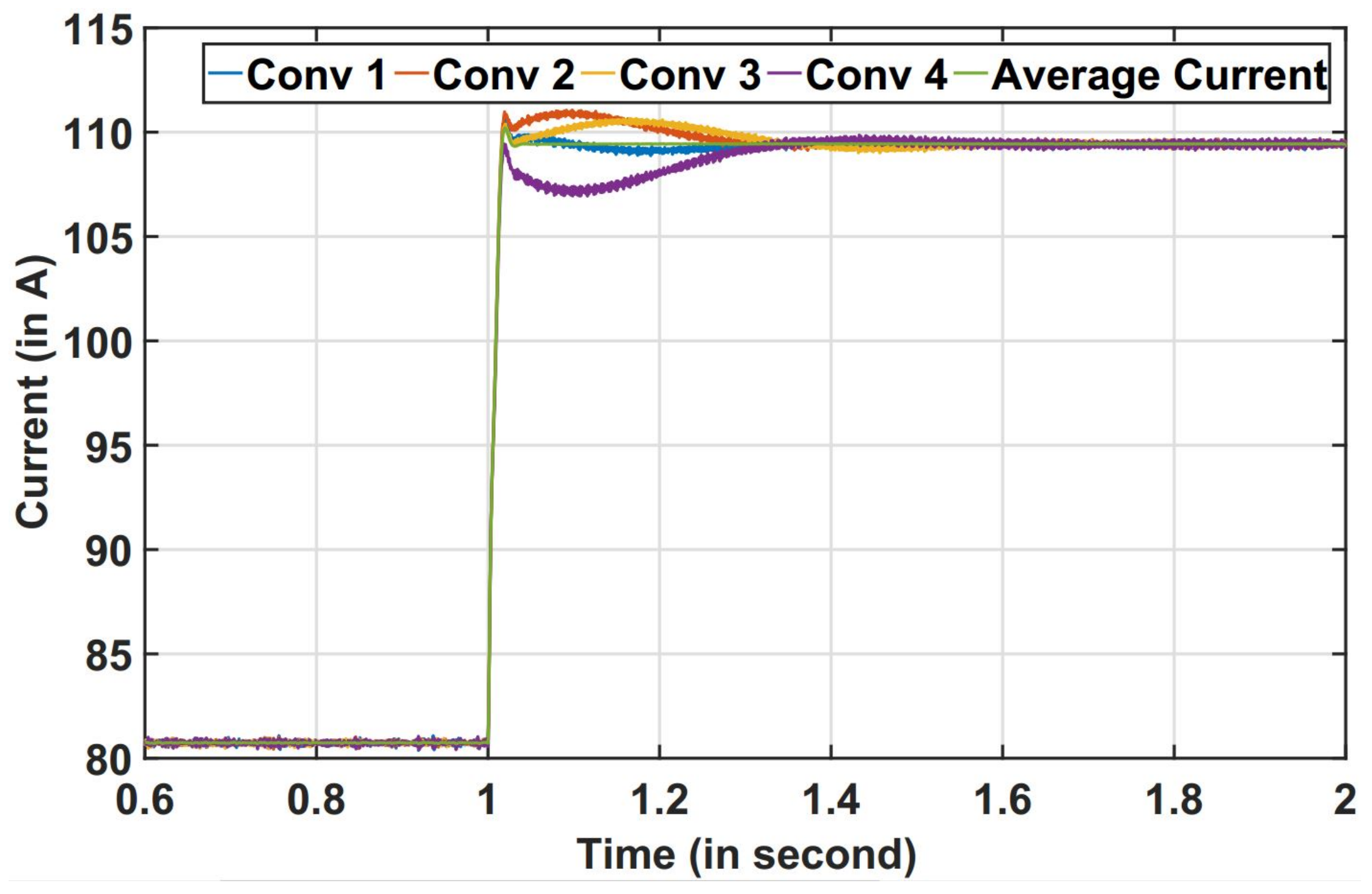


Fig. 4: Communication graph used for simulation.

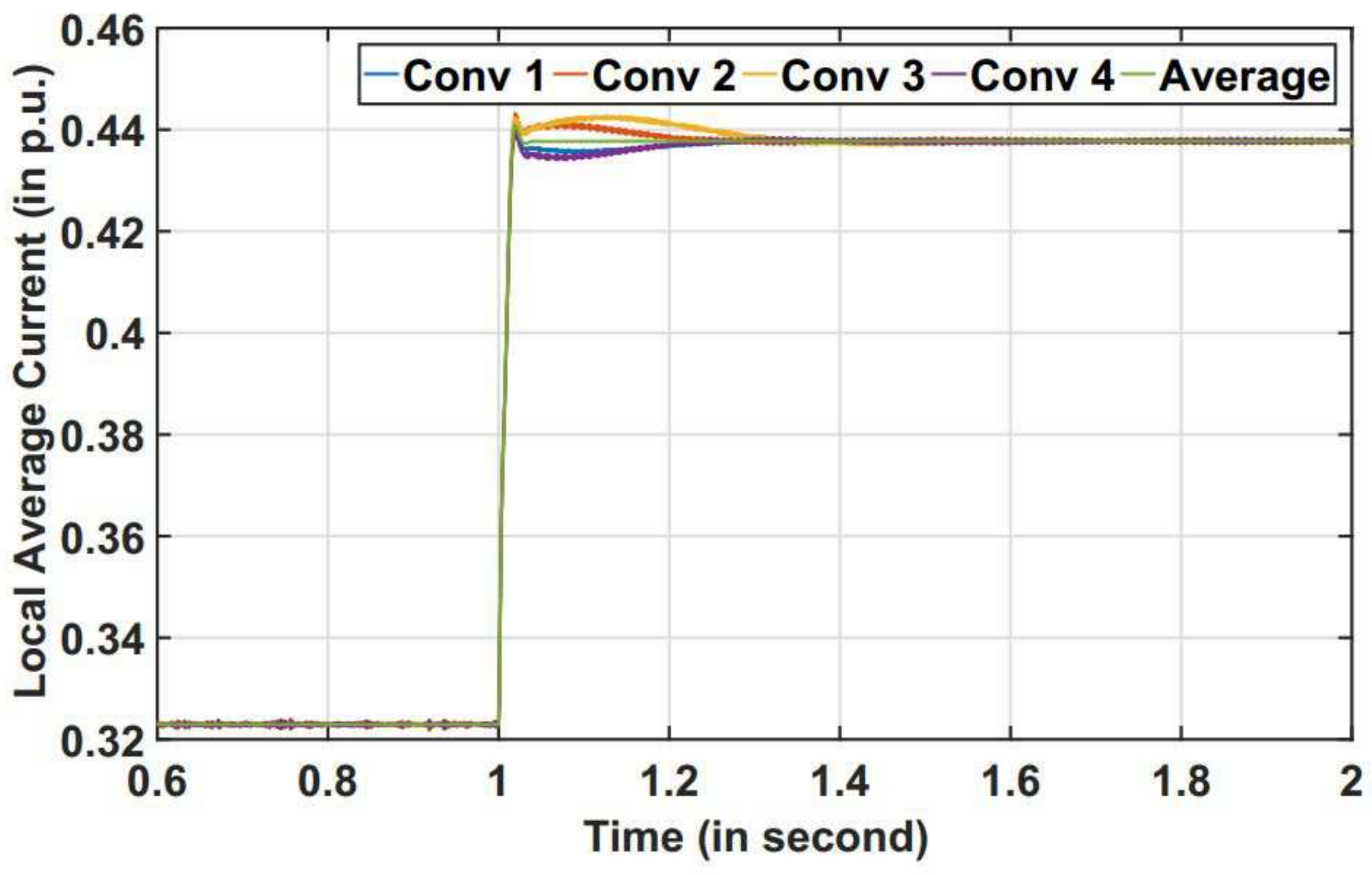
Parameter	Value
Source voltage rating	400 V
Source power rating	50 kW
Cable resistance	205 mΩ
Cable inductance	463 μH
Load capacitor	1000 μF
Initial droop value	1.9 Ω

Table 2: System parameters.

Current Waveforms



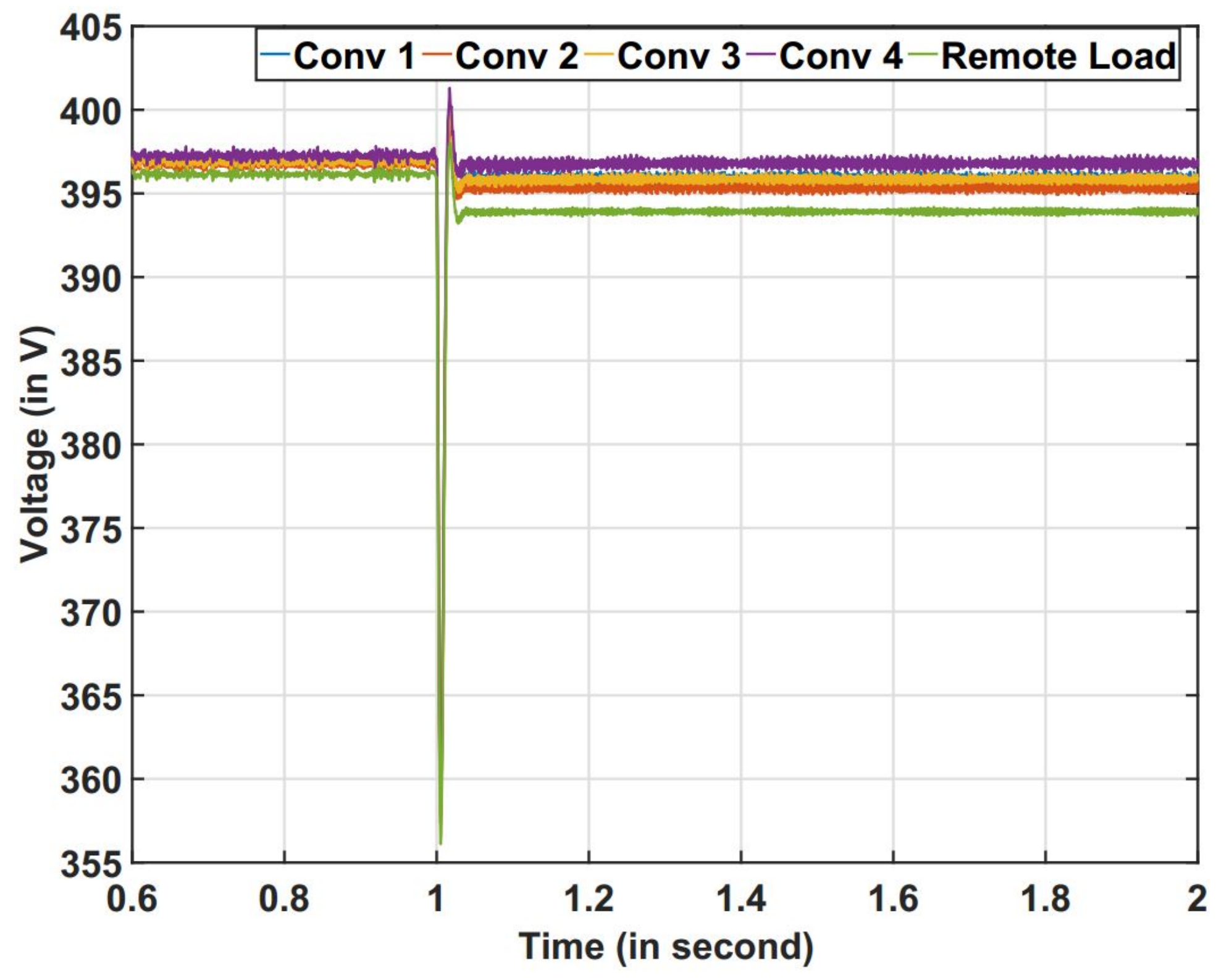
Local Average Currents



Result Comparison

	Full comm.		Proposed tech.	
Time (s)	V_{reg}	I_{sh}	V_{reg}	I_{sh}
0.6 < t < 1	0.97 %	0 %	0.97 %	0 %
t > 1	1.53 %	0 %	1.53 %	0 %

Voltage Waveforms



Conclusion

Proposed a cooperative control based secondary controller with reduced communication, having steady state responses identical to a secondary controller with full communication.

References

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[2] S. Anand, B. G. Fernandes, and J. M. Guerrero, "Distributed control to ensure proportional load sharing and improve voltage regulation in low-voltage dc microgrids," *IEEE Trans. Power Electron.*, vol. 28, no. 4, pp. 1900-1913, Apr. 2013.

[3] S. Thomas, S. Islam, S. R. Sahoo, and S. Anand, "Distributed secondary control with reduced communication in low-voltage dc microgrid," *2016 10th Int. Conf Compatibility, Power Electron. Power Eng. (CPE-POWERENG)*, Bydgoszcz, pp. 126–131, 2016.

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