Distributed Control for Bounded Time-Varying Power Sharing of Grid-Connected DDG Cluster

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Abstract

In this paper, the time-varying demand power sharing problem of a grid-connected AC microgrid is considered. An autonomous leader system is introduced to capture the time-varying demand. We first convert the power sharing problem into a tracking problem of a leader-follower multi-agent system by introducing a so-called canonical model. Then we show the exponential stability of the closed-loop system, hence reaching the desired bounded time-varying power sharing. The simulation results show that the theoretical part is supported by practice.

Problem Formulation

Consider a cluster of N interconnected DDGs which is shown in Fig. 1, the dynamics of the i-th DDG are given as follow:

$$\dot{y}_i = -\omega_c(y_i - z_i)$$
$$\dot{z}_i = A_i z_i + \Gamma_i(u_i - d_i), \quad i = 1, \ldots, N,$$

where $z_i \in \mathbb{R}^{2s}$ is the i-th system state, $y_i \in \mathbb{R}^{2s}$ is the i-th system output, $u_i \in \mathbb{R}^{2s}$ is the control input, and d_i is a constant disturbance. The following exosystem is captured a time-varying power demand y_d :

$$\dot{y}_d = A_1 y_d$$

where $A_1 \in \mathbb{R}^{2s}$ is a pre-defined matrix whose eigenvalues are simple and on the imaginary axis.

The command generator is employed as a leader system to estimate $m^{-1}y_d$ with the unknown total power capacity m:

$$\dot{y}_0 = A_1 y_0 + y_d - \sum_{i=1}^{N} y_i$$

Notice that the state of the command generator y_0 can only be obtained by some DDGs of its neighbor in the communication network.

For the above systems, we would like to design a distributed controller u_i using only local state measurement and neighboring information over the communication network such that for any initial condition, the following two properties can be fulfilled:

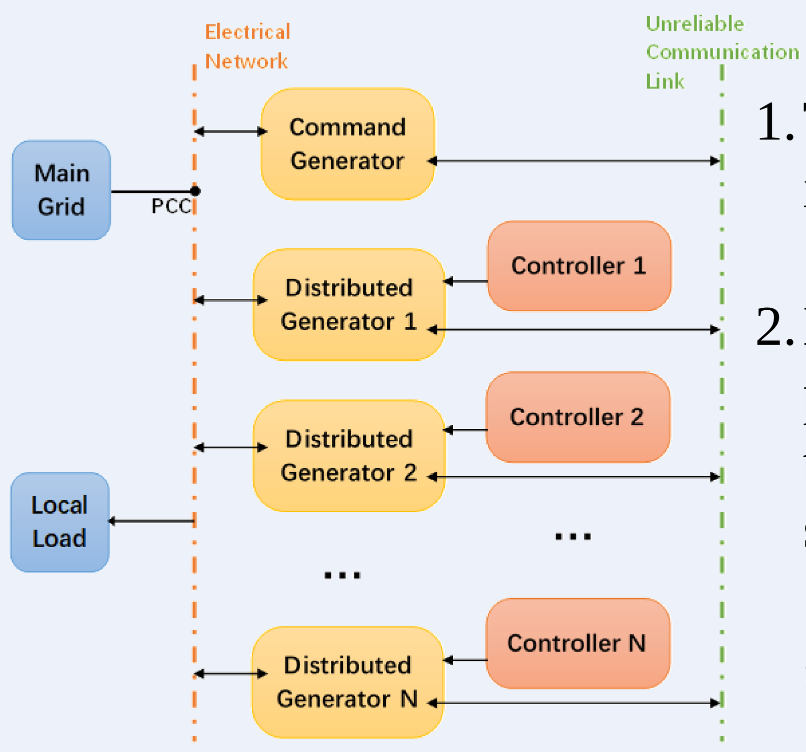

Fig. 1. Grid-connected Microgrid.

1. The state of the closed-loop system is bounded over $[0, +\infty)$.
2. Denote m_i and $m = \sum_{i=1}^{N} m_i$ be the power capacity of the i-th DDG and the whole DDG cluster, the power sharing error satisfies $\lim_{t\to\infty} e_i(t) = \lim_{t\to\infty}\left(y_i(t) - \frac{m_i}{m} y_d(t)\right) = 0, \ i = 1, \ldots, N.$

Main Result

The main control scheme can be synthesized by two parts: The secondary control and the primary control.

- The secondary control: Since the communication network is constrained, every DDG only receive the information of near DDGs or the command generator. A distributed compensator ζ_i as follow is introduced to estimate the command generator y_0 .

$$\dot{\zeta}_i = A_1\zeta_i + \mu\left(\sum_{j=1}^{N} a_{ij}\left(\zeta_j - \zeta_i\right) + a_{i0}(y_0 - \zeta_i)\right)$$

where $\zeta_i \in \mathbb{R}^{2s}$, $\mu > 0$ is the control gain.

- The primary control: Canonical internal model and controller make up the primary control. The canonical internal model is introduced to estimate the steady-state behavior of input u_i.

$$\dot{\eta}_i = M\eta_i + \mathrm{N}u_i = (I_{2s}\otimes\begin{bmatrix} 0 & I_{2s-1} \\ b_0 & b_1 \ldots b_{2s-1}\end{bmatrix})\eta_i + (I_{2s}\otimes\begin{bmatrix}0\\ \vdots \\ 0 \\ 1\end{bmatrix}_{2s\times 1}) u_i$$

$$u_i = \Psi T^{-1}\eta_i - K_i S_i(k_i y_i + z_i - k_i m_i \zeta_i - m_i\left(I_s \otimes \begin{bmatrix} 1 & \frac{1}{\omega_c} \\ -\frac{1}{\omega_c} & 1\end{bmatrix}\right)\zeta_i)$$

where $\eta_i \in \mathbb{R}^{2s}$, $K_i, k_i > 0$ are the control gain and the choice of $S_i \in \mathbb{R}^{2s\times 2s}$ is such that $\Gamma_i S_i$ is a positive definite constant matrix.

Under coordinate and input transformations, we can convert the augmented system into the form :

$$\dot{\bar{y}}_i = -\omega_c(1 + k_i)\bar{y}_i + \omega_c\tau_i + \Delta_{1i}(\varphi)$$
$$\dot{\tau}_i = -\Gamma_i K_i S_i \tau_i + \Delta_{2i}(k_i)\bar{y}_i + \Delta_{3i}(k_i)\tau_i + \Gamma_i \Psi T^{-1}\bar{\eta}_i + \Delta_{4i}(k_i, \varphi)$$
$$\dot{\bar{\eta}}_i = M\bar{\eta}_i + \Delta_{5i}(k_i)\bar{y}_i + \Delta_{6i}(k_i)\tau_i + \Delta_{7i}(k_i, \varphi)$$

At last, we use each subsystem in sequence and construct corresponding quadratic Lyapunov functions to analyze the exponentially stability of closed-loop system.

Simulation

In this paper, the DDG cluter considered in the simulation studies is shown in Fig. 2.

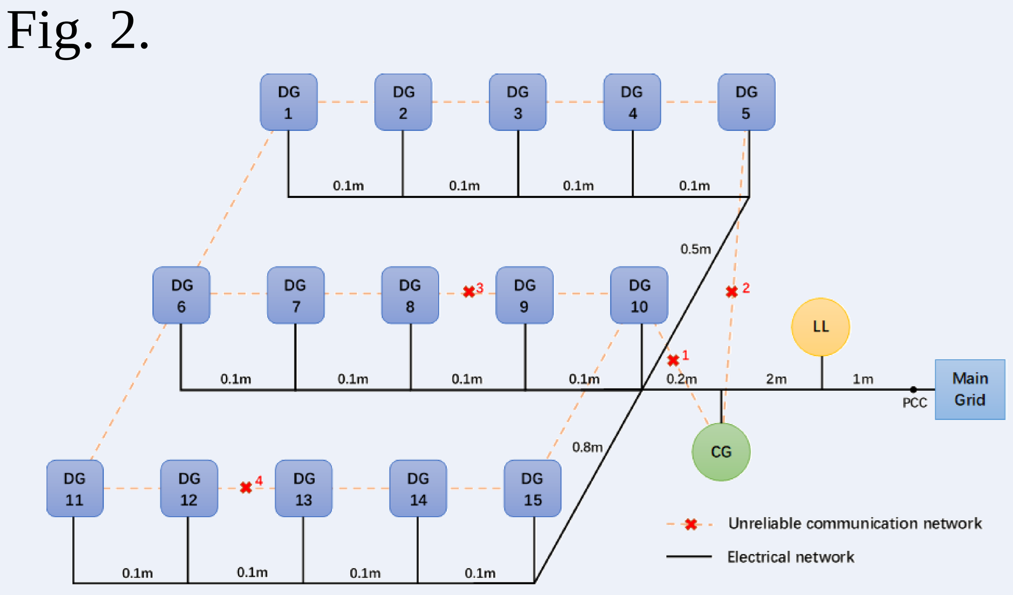

Fig. 2. Microgrid system considered in simulation.

By selecting the appropriate parameters, we get the following simulation diagram. It can be observed that our control ensures power demand is distributed to DGs successfully in different circumstances.

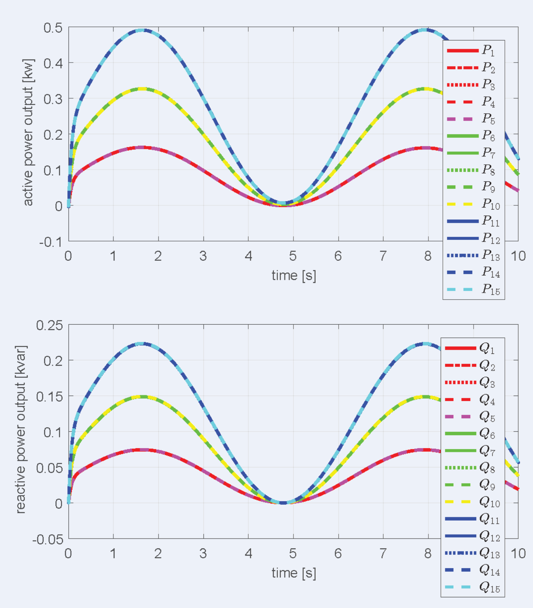

Fig. 3. Time varying active and reactive power outputs.

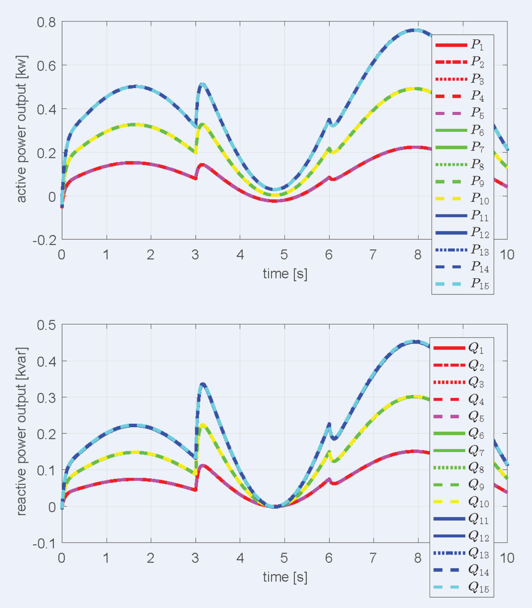

Fig. 4. Time varying active and reactive power outputs under demand change.

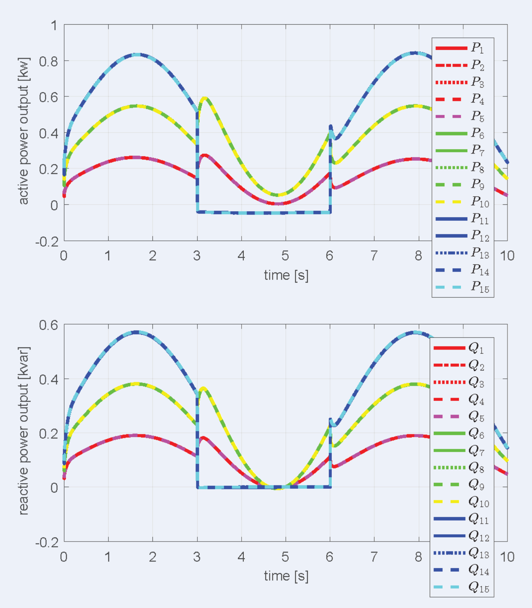

Fig. 5. Time varying active and reactive power outputs under plug-and-play test.

Conclusion

In this paper, a canonical internal model based distributed control scheme is designed to solve the time-varying power sharing problem within a grid-connected AC microgrid consisting of multiple dispatchable DGs. An autonomous linear leader system is employed to formulate the bounded time-varying desired power demand. It is shown that our novel control ensures the total power demand is allocated autonomously to each DG according to its power capacity. The future work will focus on using the nonlinear leader system to generate more general time-varying power demand.

References:
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