Distributed Cooperative Control for DC Microgrids

Current Sharing, Average Voltage Regulation, and State-of-Charge Balancing

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Introduction

- The goal of this thesis is to develop distributed control scheme for Direct-Current (DC) Microgrids. This latter will ensure several objectives as current sharing, Average Voltage Regulation, and State-of-Charge Balancing, with a proof of global stability.

Motivation

A MicroGrid (MG) is a cluster of several interconnected Distributed Generation Units (DGUs), loads, and energy storage system which coordinate between each-other to reliably provide energy, it can be connected to the main grid or operates independently. MGs have several advantages:

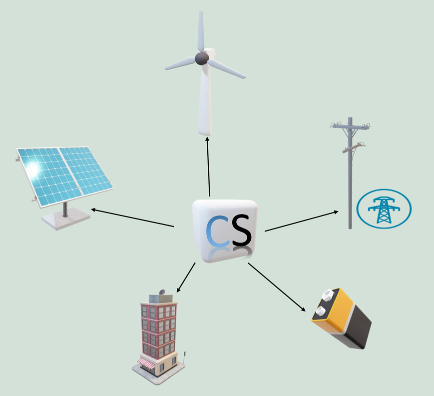
- Possibility to provide energy for isolated places.
- Simplify integration of renewable and eco-friendly power generation technologies with almost zero emissions.
- Distributed generation, reliability, etc.

Despite its advantages Microgrids still have several challenges to overcome as

- Current Sharing.
- Average Voltage Regulation.
- State of Charge Balancing.

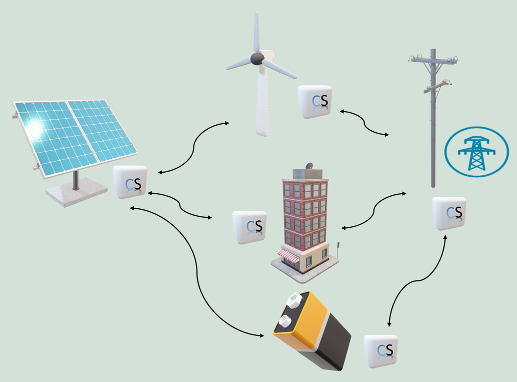
To overcome these challenges several control strategies are used, as

Centralized control



- ✓ Easy design and implementation
- ✗ Single point of failure.

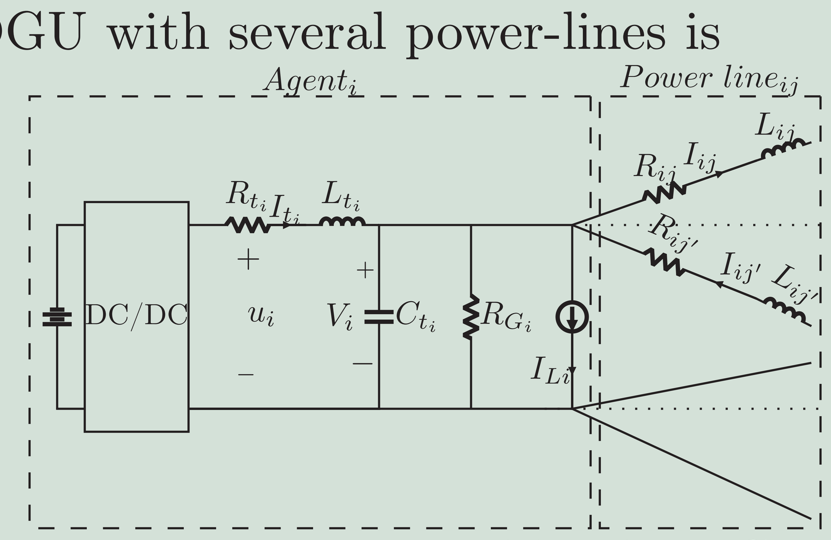
Distributed control



- ✓ Only local information are needed.
- ✓ More reliability and flexibility for the system.
- ✗ The design is not trivial.

Modelling

A DC-MG composed of N DGUs, m power-lines, and loads is considered; the electrical scheme of a DGU with several power-lines is



I_{ti} current generated by the DGU_i

V_i voltage near DGU_i

-The agent dynamic and the overall model are

$$Agent_i \begin{cases} L_{t_i}\dot{I}_{t_i} = -R_{t_i}I_{t_i} - V_i + u_i, \\ C_{t_i}\dot{V}_i = I_{t_i} - I_{Li} - \frac{V_i}{R_{G_i}} - \sum_{j\in\mathcal{N}_i^{pow}} \frac{1}{R_{ij}}(V_i - V_j). \end{cases}$$

$$MG \begin{cases} L_t\dot{I}_t = -R_tI_t - V + u, \\ C_t\dot{V} = I_t - R_G^{-1}V - \mathcal{L}^{pow}V - I_L. \end{cases}$$

Objectives and Problem formulation

Problem *Design a distributed control law u to achieve the considered objectives with a proof of global stability*

Objective 1. ***Current Sharing***

(Powerful/Powerless DGU $\overset{Consensus}{\Longrightarrow}$ *More/Less provided current)*

$$\lim_{t\to\infty} \omega_i I_{ti} = \omega_i \bar{I}_{ti} = \omega_j \bar{I}_{tj} \quad \forall i,j \in \mathcal{V},$$

where the weight ω_i, $i = 1, \cdots, N$ *are given parameters.*

Objective 2. ***Average Voltage Regulation***

$$\lim_{t\to\infty}\sum_{i=1}^{N}\frac{1}{\omega_i}V_i(t) = \sum_{i=1}^{N}\frac{1}{\omega_i}\bar{V}_i = \sum_{i=1}^{N}\frac{1}{\omega_i}V_i^{ref},$$

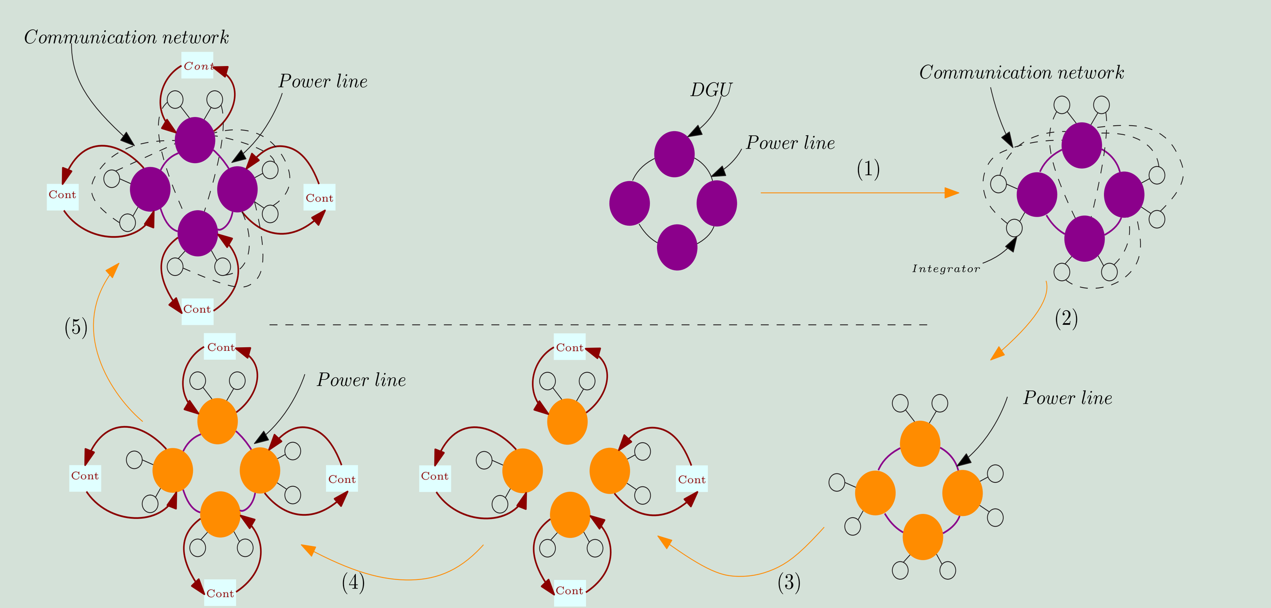
with $W = diag(\omega_1, \cdots, \omega_N)$, $\omega_i > 0$, *for all* DGU_i.

The MG model is augmented with two distributed integrators

$$\Sigma \begin{cases} L_t\dot{I}_t = -R_tI_t - V + \boldsymbol{u}, \\ C_t\dot{V} = I_t - R_G^{-1}V - \mathcal{L}^{pow}V - I_L, \\ \tau_\phi\dot{\phi} = W^T\mathcal{L}^{com}WI_t, \\ \tau_\gamma\dot{\gamma} = -W^T\mathcal{L}^{com}W\gamma + (V - V^{ref}) \end{cases}$$

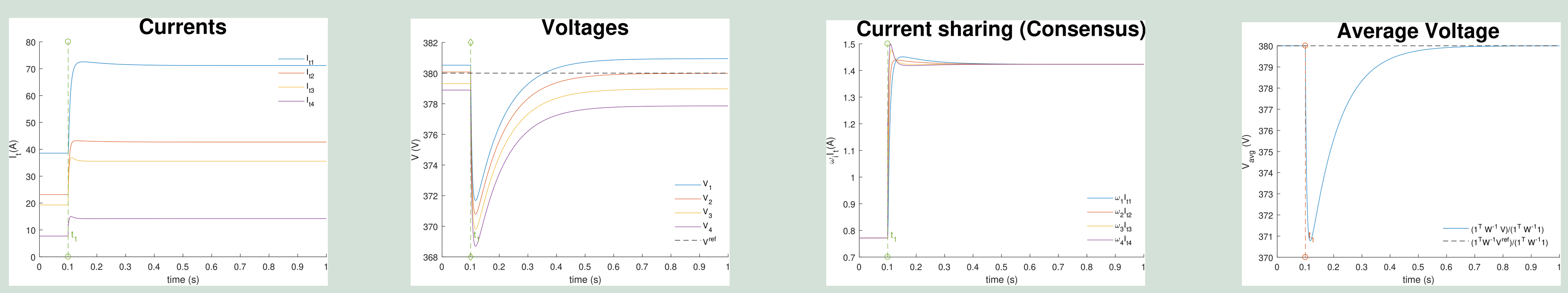
- *control law to define*
- *physical network*
- *unknown loads*
- *communication network*

Distributed Control Design Methodology & Simulation



(1)- Augmented system
(2)- Simplify the coupling by variable transformation
(3)- Design local controllers with passivity conditions
(4)- Using passivity property global stability is proved
(5)- Apply the inverse of the variable transformation and stability is conserved.

Scenario: we consider a MG composed of four DGUs and power-lines. The system is at steady state then at time instant $t = t_1$ an unknown current demand variation occurs.



The simulation results show, clearly, the effectiveness of the proposed method; objectives are achieved and stability is ensured.

Conclusion

A distributed-based control, including integral actions to achieve both proportional Current Sharing and Average Voltage Regulation in DC power-networks has been proposed. The nominal closed-loop system is proven to converge globally to a desired steady-state, independently of the current demand and the initial conditions of the MG. The simulation results clearly show the effectiveness of the control method.

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