Adaptive Droop Control System for Automatic Voltage Restoration in DC Microgrids

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DC microgrid

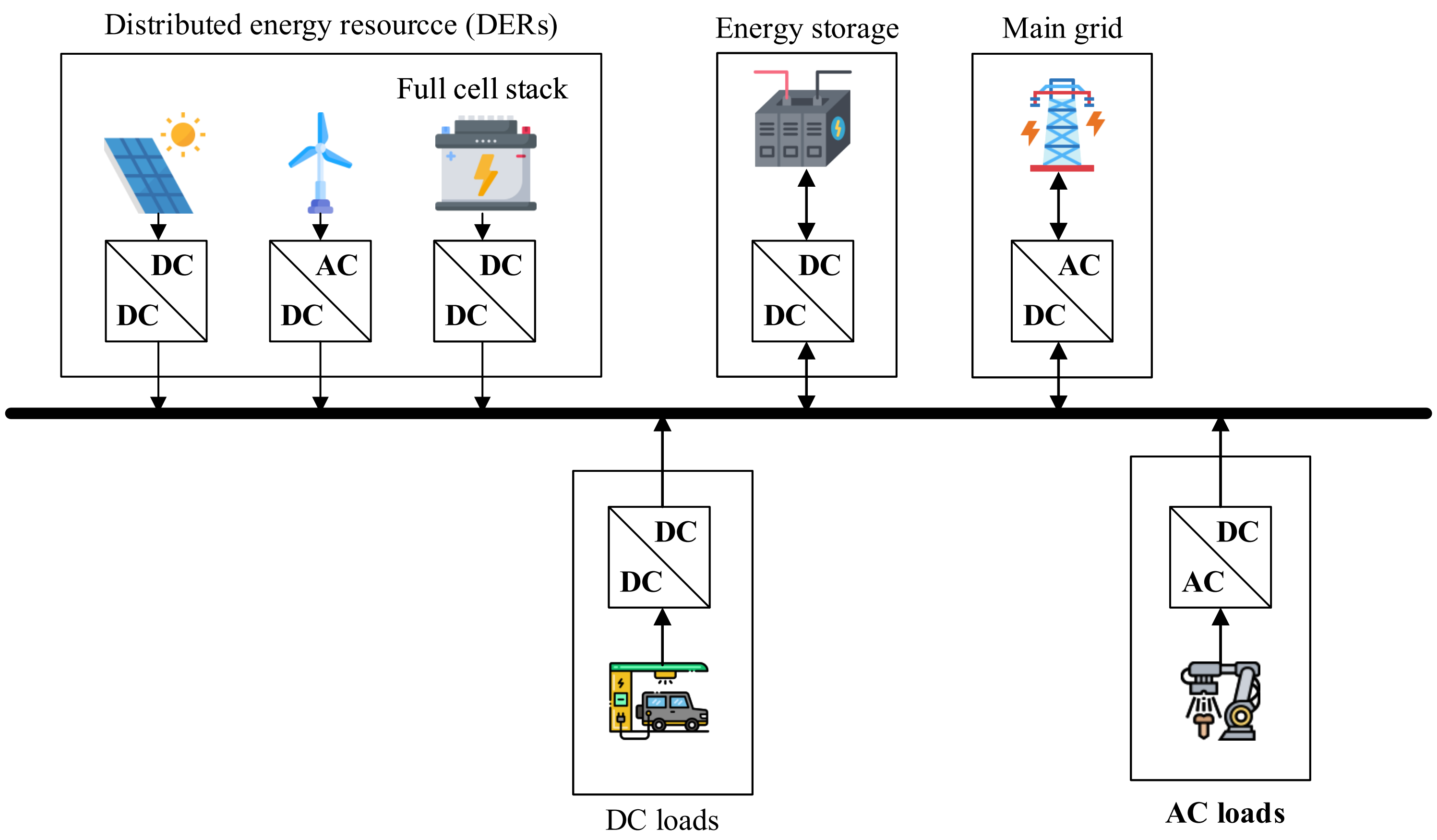
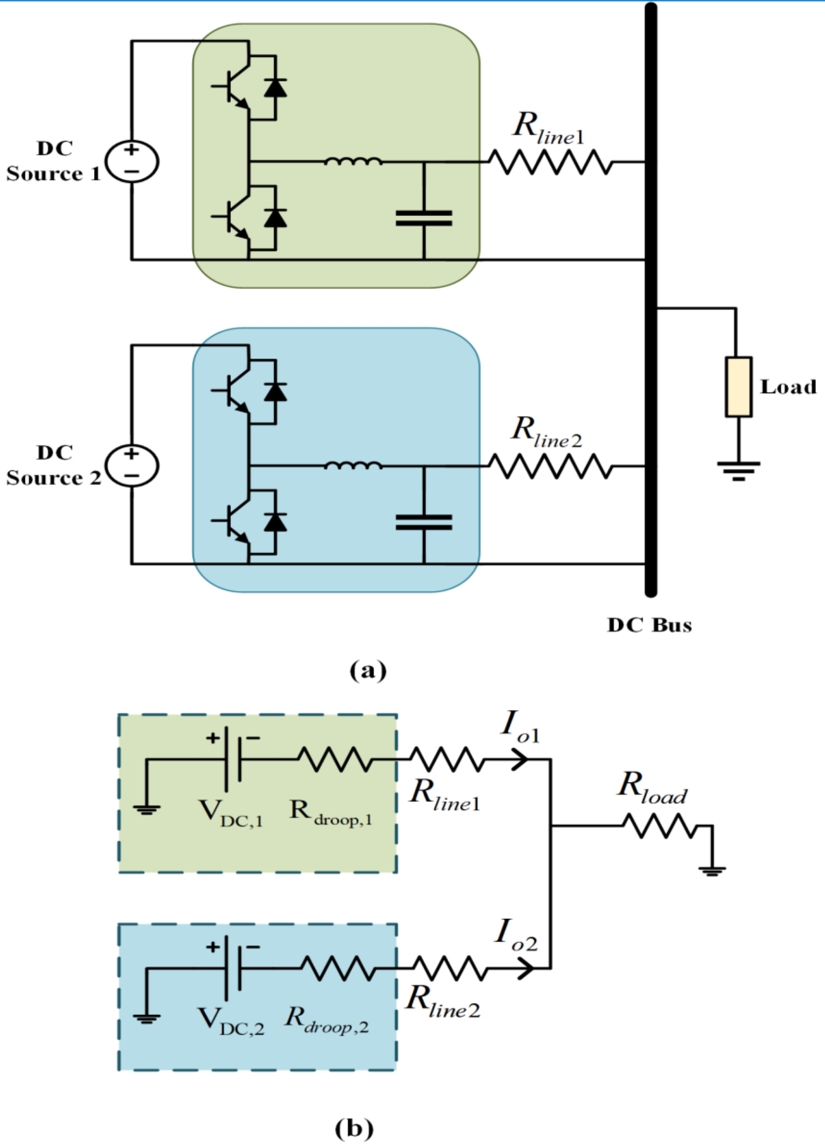


Fig. 1. Configure for DC-MGs to integrate power source

DC microgrids consist of several components, which include DC sources (such as solar panels and wind turbines), DC loads (such as lighting and appliances), energy storage systems (such as batteries and capacitors), and power electronics (such as generators and inverters), depicted as Figure 1. The DC sources and energy storage systems provide the energy supply, while the power electronics are responsible for converting and regulating the generator voltage and current.

DC microgrid modeling

Fig. 2. (a). Simplified model of a DC microgrids and (b). Thevenin transformation for this model.



We proceed to analyze the characteristics of this method. First, we model a DC microgrid consisting of two generators and one load using the Thevenin transform (Figure 2). In the traditional droop control, the relationship between voltage and current at the output of each generator is expressed as follows

$$V_{out,i} = V_{dc-ref} - I_{out,i} R_{droop,i} \quad i = 1,2$$

Droop curve in DC microgrid

This balance in power sharing is achieved by regulating the power output of each generator based on its deviation from the operating point, which is calculated using the equation:

$$R_{droop,i} \le \frac{\Delta V_{dc,max}}{i_{O,i}^{max}}$$

$$\Delta V_{dci} = \left| V_{dc}^{*} - V_{dci} \right| \le \Delta V_{dc,max}$$

$$I_{out,i} = \frac{V_{dc-ref} - V_{bus}}{R_{droop,i} + R_{line,i}}$$

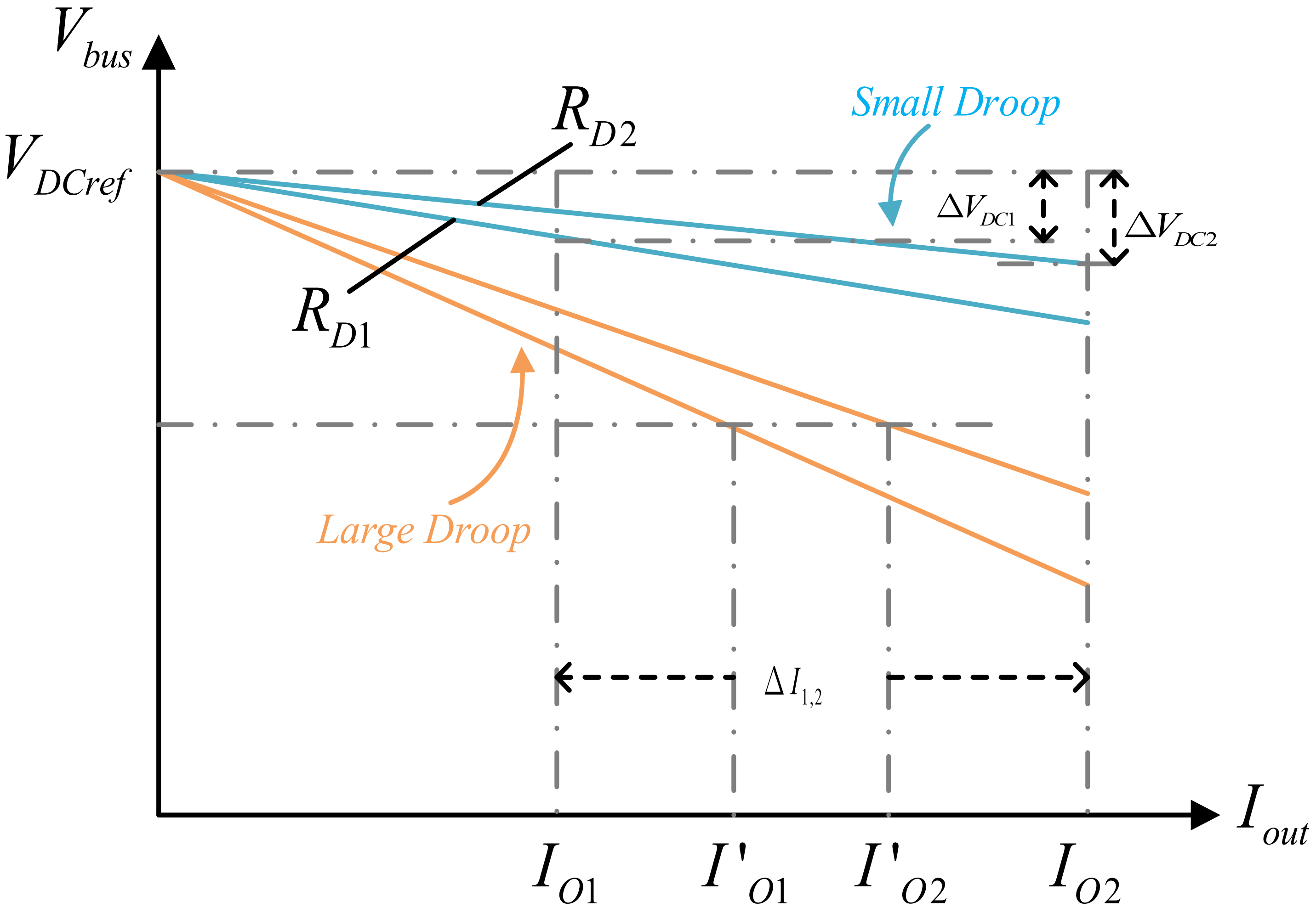


Fig. 3. Droop curve in a DC microgrids with traditional Droop controller

Droop curve in DC microgrid

The current difference between the two generators is derived as

$$I_{C12} = -I_{IC21} = \frac{V_{out,1} - V_{out,2}}{R_{line1} - R_{line2}} = \frac{I_{out,1}R_{line1} - I_{out,2}R_{line2}}{R_{line1} + R_{line2}}$$

$$\frac{I_{out,1}}{I_{out,2}} = \frac{R_{droop,2} + R_{line2}}{R_{droop,1} + R_{line1}}$$

The voltage difference when shared between the two generators is

$$\Delta_{V12} = \frac{(R_{droop,2} + R_{line2})(V_{bus,ref} - V_{bus}) - (R_{droop,1} + R_{line1})(V_{bus,ref} - V_{bus})}{(R_{droop,1} + R_{line1}) + (R_{droop,2} + R_{line2})}$$

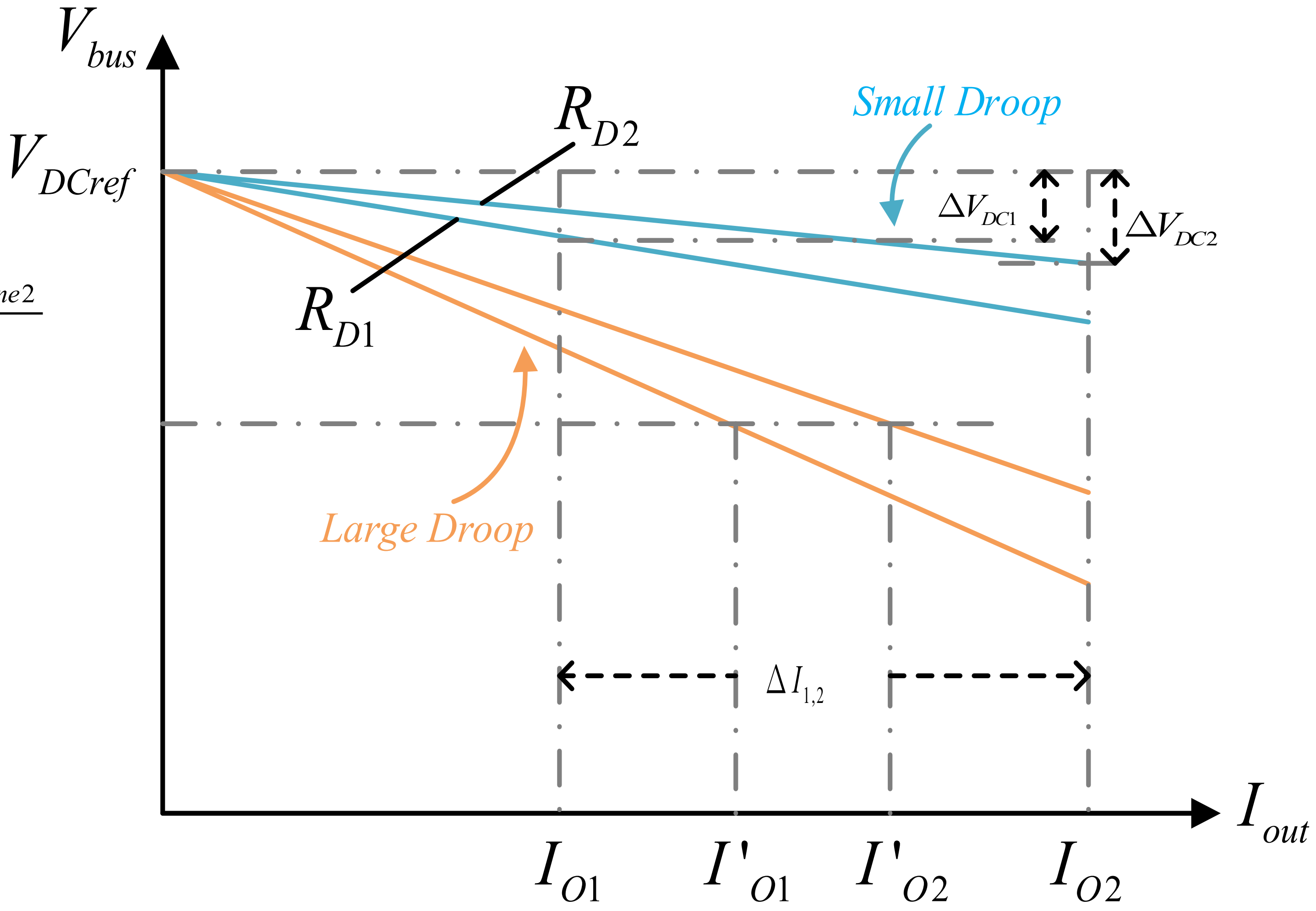


Fig. 3. Droop curve in a DC microgrids with traditional Droop controller

Proposed droop in DC microgrid

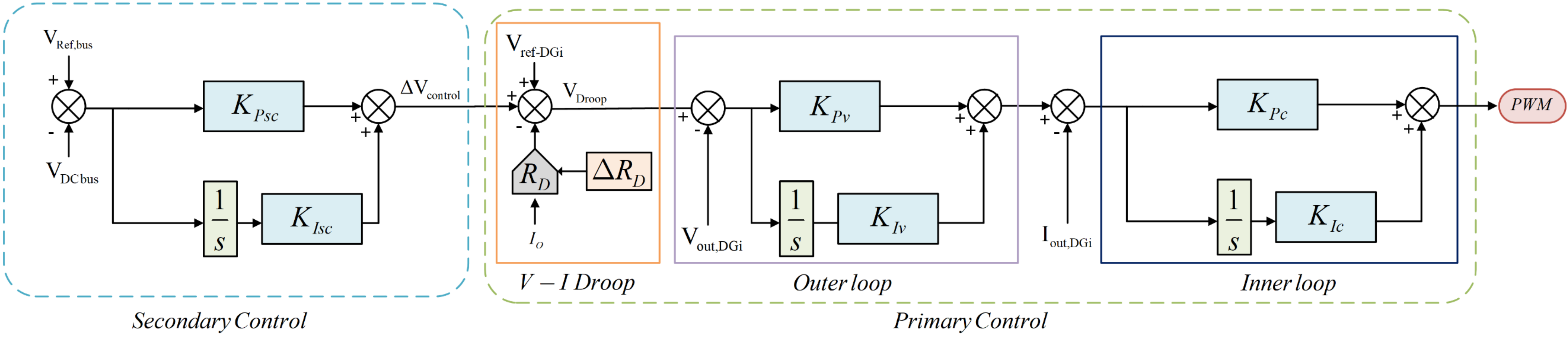


Fig. 4. Block diagram of the controller according to the proposed method

The primary controller :

$$V_{out\_ref,i} = V_{dc-ref} - I_{out,i}(R_{droop,i} \pm \Delta R_{droop,i});\ i = 1,2$$

$$\Delta R_{Droop} = 0.5(R_{droop,1} - R_{droop,2})$$

Proposed droop in DC microgrid

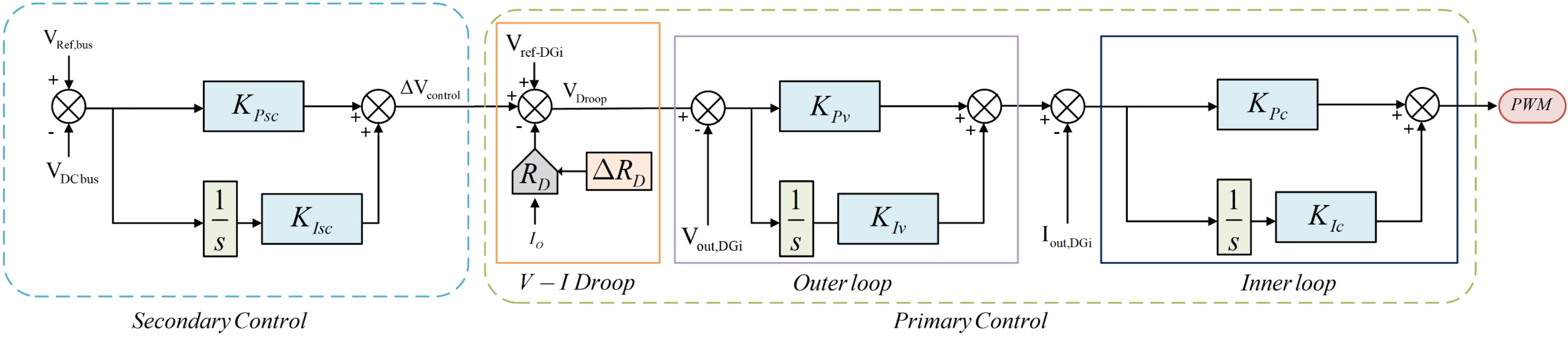


Fig. 4. Block diagram of the controller according to the proposed method

The secondary controller

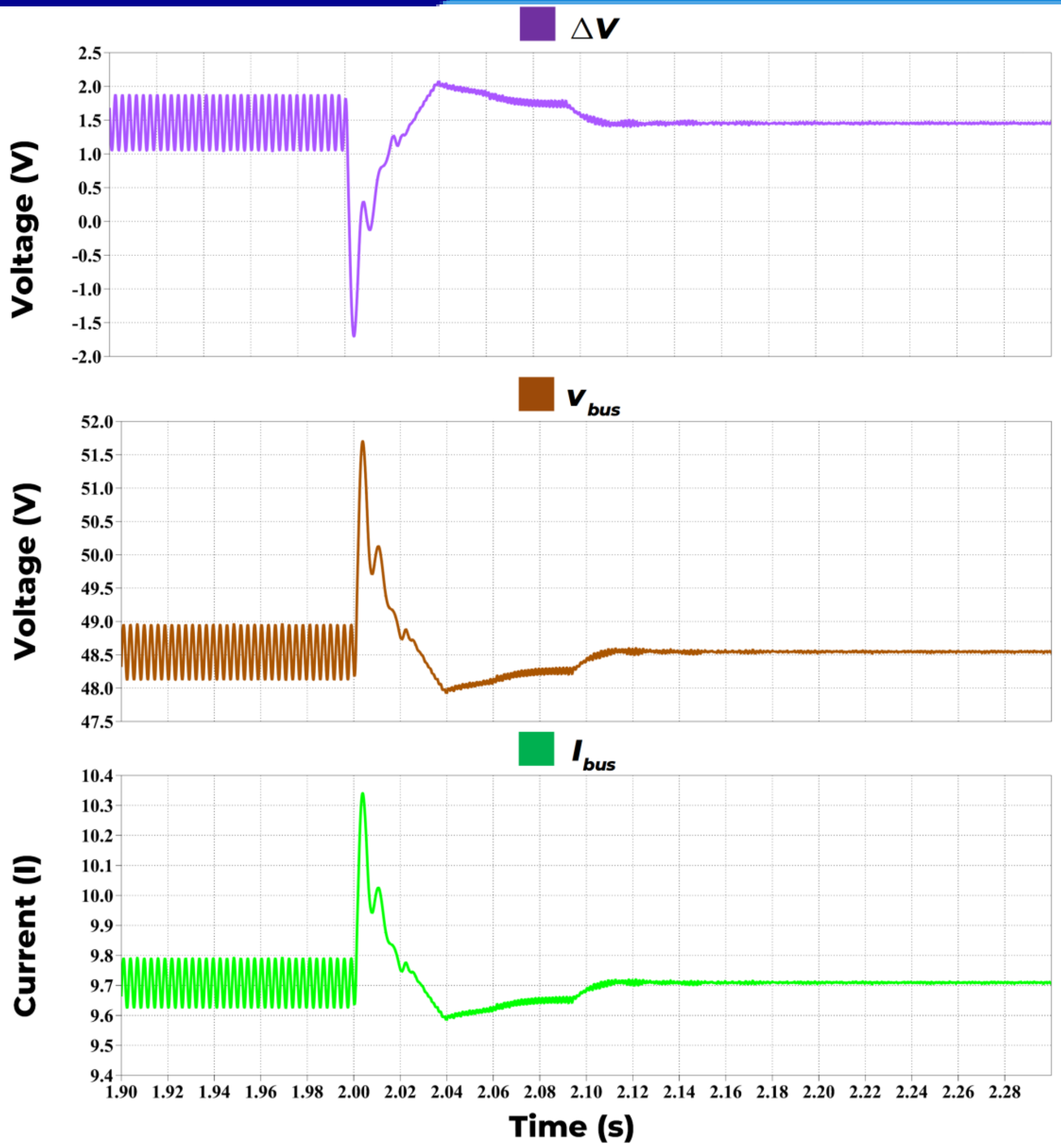
$$V_{out\_ref,i} = V_{dc-ref} + \Delta V_{control} - I_{out,i}(R_{droop,i} \pm \Delta R_{droop,i})$$

Simulation Result Case 1

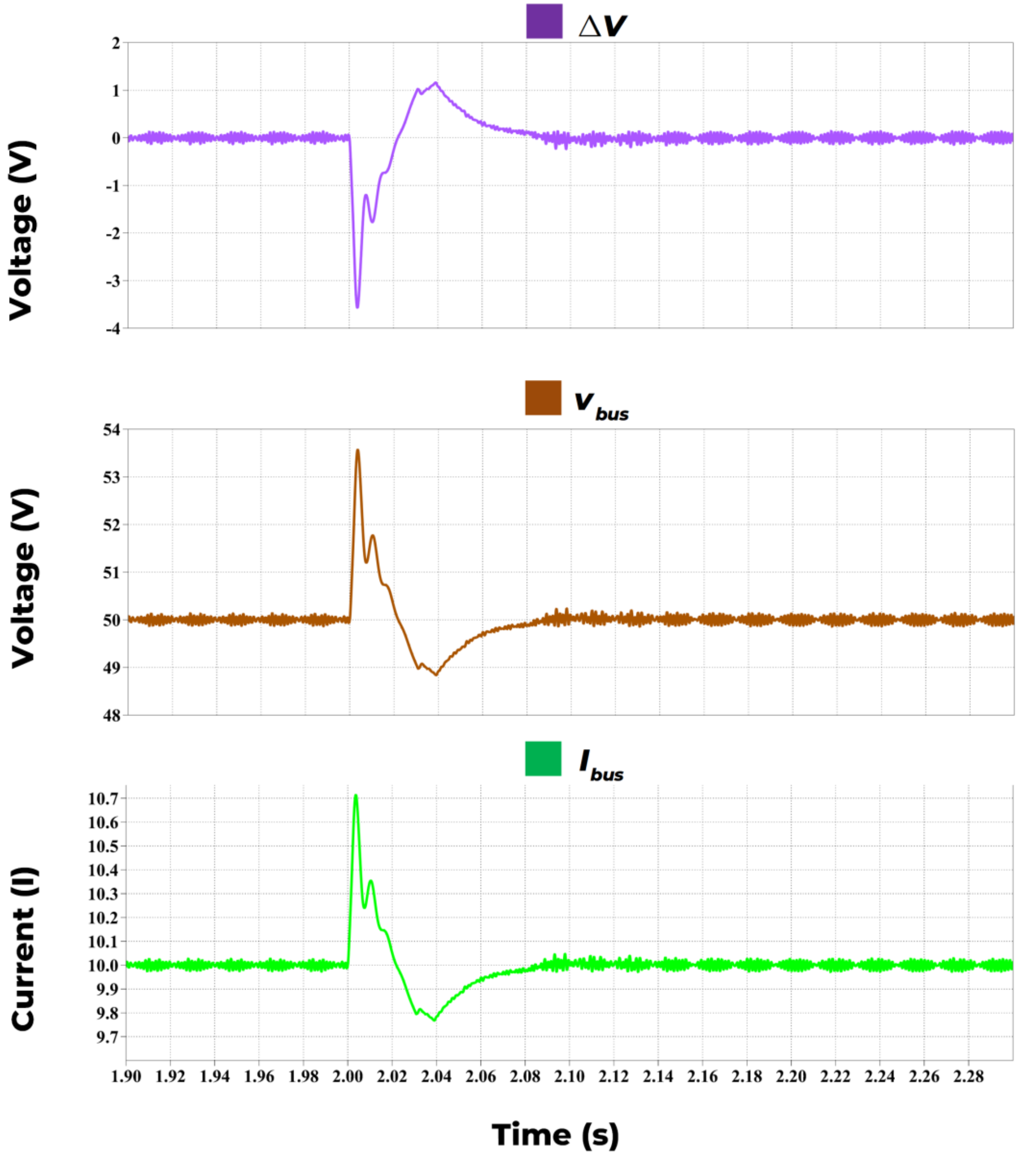
Case 1 — Abrupt Source Voltage Changes

- At $t = 2.0$ s: Generator 1 input rises 60 → 65 V, Generator 2 drops 60 → 55 V.
- **Traditional droop:** bus voltage 48–49 V (below 50 V), 0.15 s settling, ~1.5 V steady error.
- **Adaptive droop:** bus voltage maintained at 50 V, faster 0.08 s settling, only ~0.1 V steady error.

Simulation Result Case 1



Traditional Droop



Proposed Droop

Simulation Result Case 2

Case 2 — Step Load Additions

- At $t = 2.5$ s and $t = 3.5$ s, two loads are added sequentially.
- Bus voltage remains around 50 V.
- Small overshoot/undershoot occurs but is quickly corrected.
- Steady-state deviation is nearly zero after each step.

Simulation Result Case 2