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Synchronous Reference Frame current control of Aalborg-type PV inverters

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Presentation outline

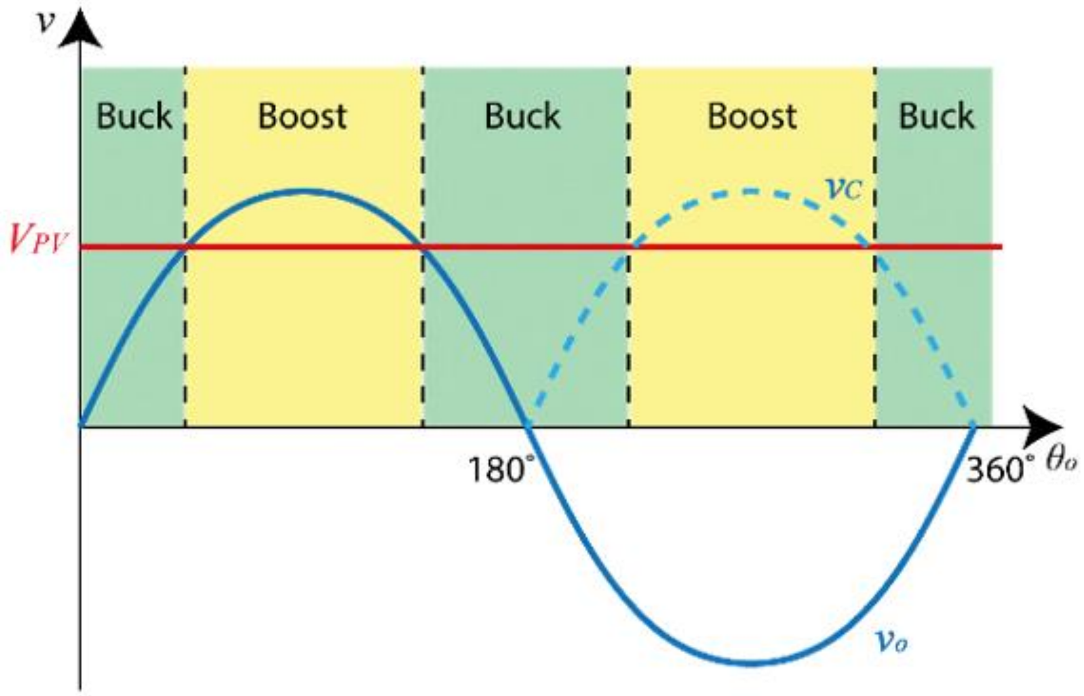
1. Introduction
2. Background
3. Contribution
4. Proposed approach
5. Simulation results

Transformerless PV inverters with voltage step-up

- Transformerless photovoltaic (PV) inverters
  - High efficiency (H5, HERIC, NPC, …)
- Normally combined with a voltage step-up (Boost) stage
  - ensures that the DC-link voltage is adequate to inject power to the grid
  - performs Maximum Power Point Tracking (MPPT) of the PV source
- Step-up stage traditionally separate from the inverter stage
- Topologies that combine them have appeared in recent years

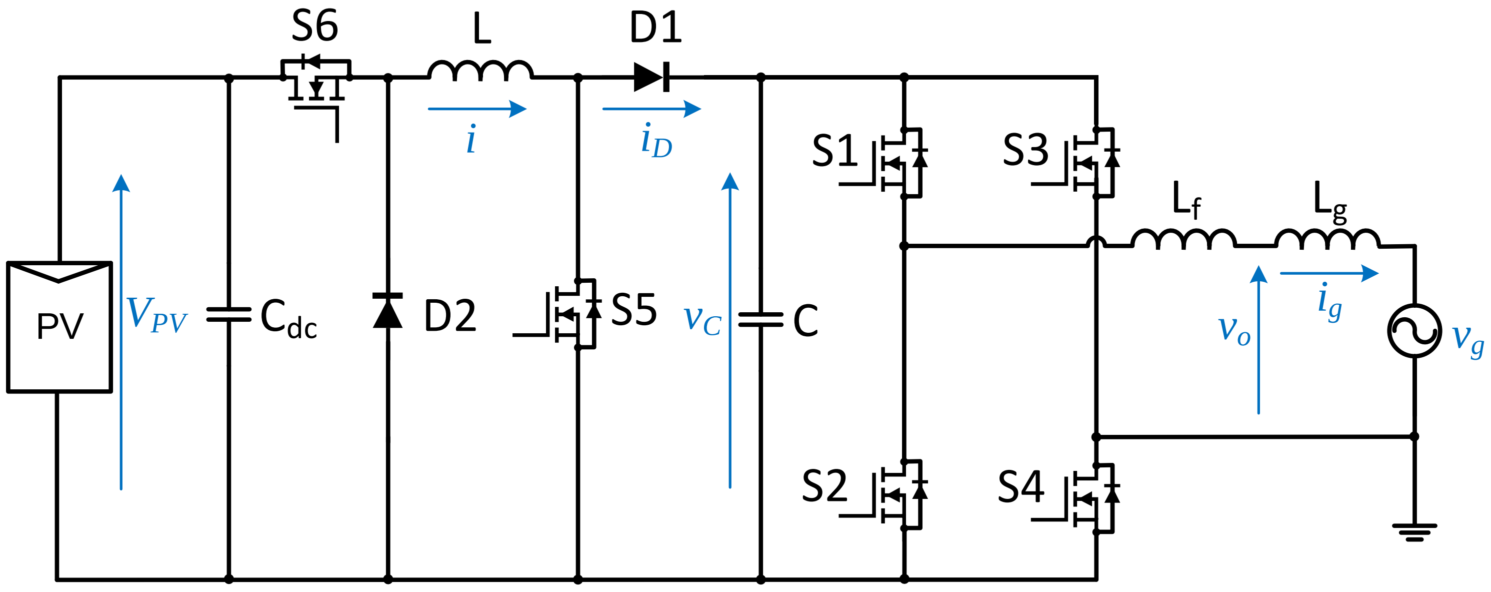
Dual-mode time-sharing topologies

- Operate in Buck or Boost mode for portions of each half-cycle.
- In Full-bridge versions, the DC-link voltage waveform has the form of a rectified sine-wave.
- An H-bridge simply "unfolds" it to supply it to the grid.



Full-bridge Aalborg inverter

- Elimination of one inductor, as compared to other topologies of the same family
- Operation of only one power switch at high frequency
  - S6 for Buck mode
  - S5 for Boost mode
- Offers high efficiency



Characteristics of existing control approaches

- The control variable is the Buck/Boost inductor current, instead of the grid current, due to the difficulty of controlling the latter in Boost mode.
- The Buck and Boost stages are controlled independently; different controllers are used for the Buck and Boost modes of operation.
  - Transitions cause oscillations on the output current waveform
- The PI current controllers operate in the stationary reference frame.
  - Introduction of phase shift (lag) – Need for high gains
- The reference current for the Buck PI controller is sinusoidal, while for the Boost PI controller it follows a $\sin^2(\omega t)$ form.
  - Greater phase shift at double frequency

Significant grid current distortion

This paper:
New current control approach

- Operates in the **Synchronous Reference Frame (SRF)**
  - known to avoid the aforementioned problems with respect to delays
- Uses a **common** controller for Buck and Boost operation
  - minimizes the effects of the transitions between the two modes.
- Achieves high output current quality even at unfavourable conditions
  - low PV voltage
  - low power
- Comparative simulation results in MATLAB-Simulink are presented
- Total Harmonic Distortion (THD) of the grid current is reduced by two to three times as compared to the existing alternative

Fundamentals of the proposed approach

- SRF controller
  - Operating based on a classical DQ structure.
  - Phase-Locked Loop (PLL) providing the angle of the measured output voltage, which is used for the Park transformations.
- The controlled current is the inductor L current, *i*.
- Converted to a respective alternating current, i_{ac}, by multiplying it by the sign of the output voltage.
- An All-Pass Filter (APF) generates the quadrature component of i_{ac}, to be used as feedback for the Q current controller.

Transition between the Buck and Boost modes

- Controller is common for the Buck and Boost modes of operation.
- Generates a single voltage control waveform, which is used to modulate the switches corresponding to both modes.
- The control waveform is sinusoidal, but its amplitude can exceed the value of 1 without causing the undesirable effects of over-modulation.
- Instead, for the time intervals that v_{ctrl} exceeds the value of 1, the Boost mode is enabled.
- The feedback current is adjusted so that the DQ current controllers are not affected by the transition between the Buck and Boost modes of operation.

Boost mode

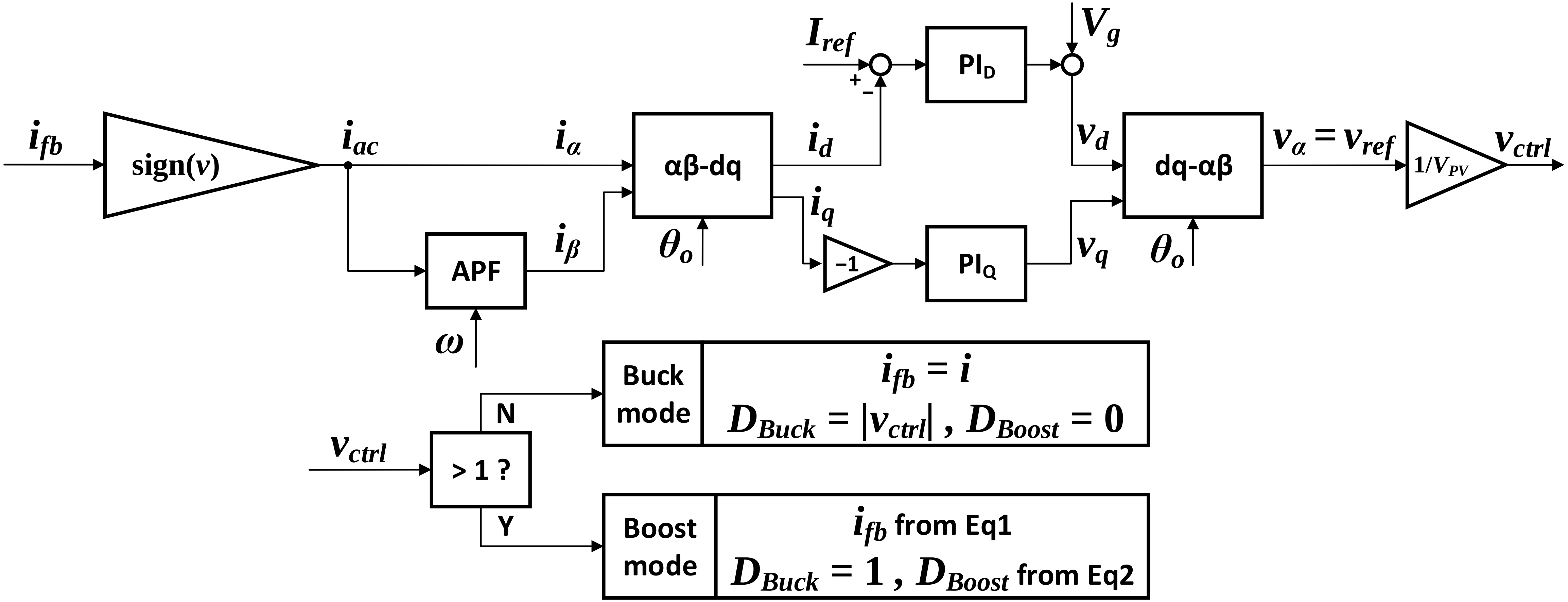
- The inductor current i exhibits a $\sin^2\vartheta$ form.
- The DQ current controllers must still act on approx. constant feedback currents, thus the input to the αβ-dq transformation must be sinusoidal.
- In order to achieve that, the measured current i is multiplied by an appropriate quantity before being converted to i_{ac} and passed to the APF:

$$i_{fb} = i \cdot \frac{E - L \cdot \frac{V_o}{E} \cdot I_{ref} \cdot \omega \cdot \sin 2\theta_o}{|v_o + \omega \cdot L_f \cdot I_{ref} \cdot \cos\theta_o|} \qquad \text{(Eq1)}$$

- Duty cycle D for the Boost converter:

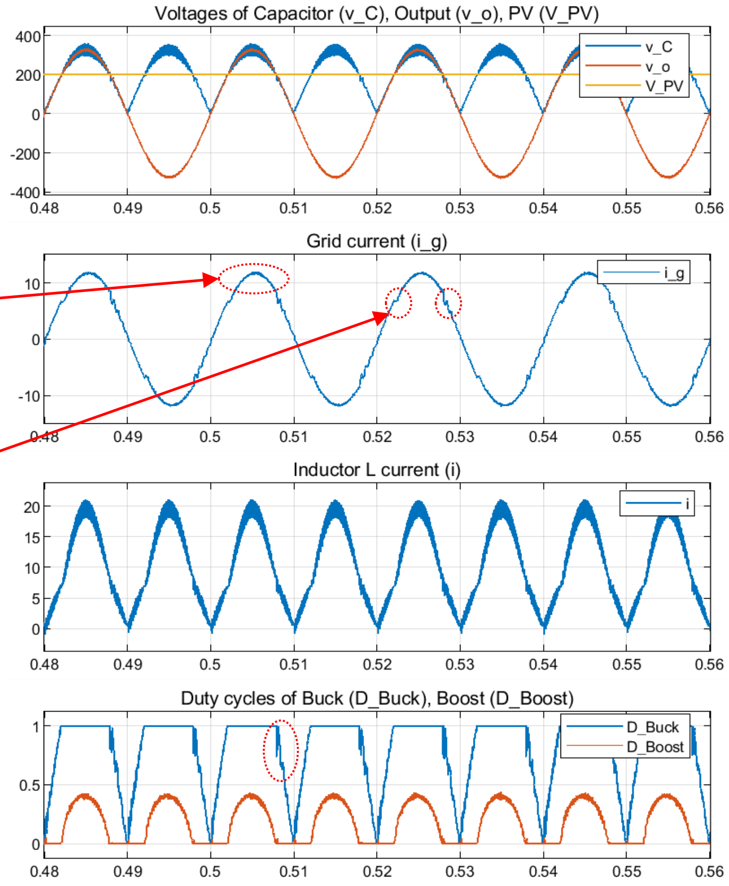
$$D = 1 - \frac{E - L \cdot \frac{V_o}{E} \cdot I_{ref} \cdot \omega \cdot \sin 2\theta_o}{|v_{ref} - \omega \cdot L \cdot I_{ref} \cdot \cos\theta_o|} \qquad \text{(Eq2)}$$

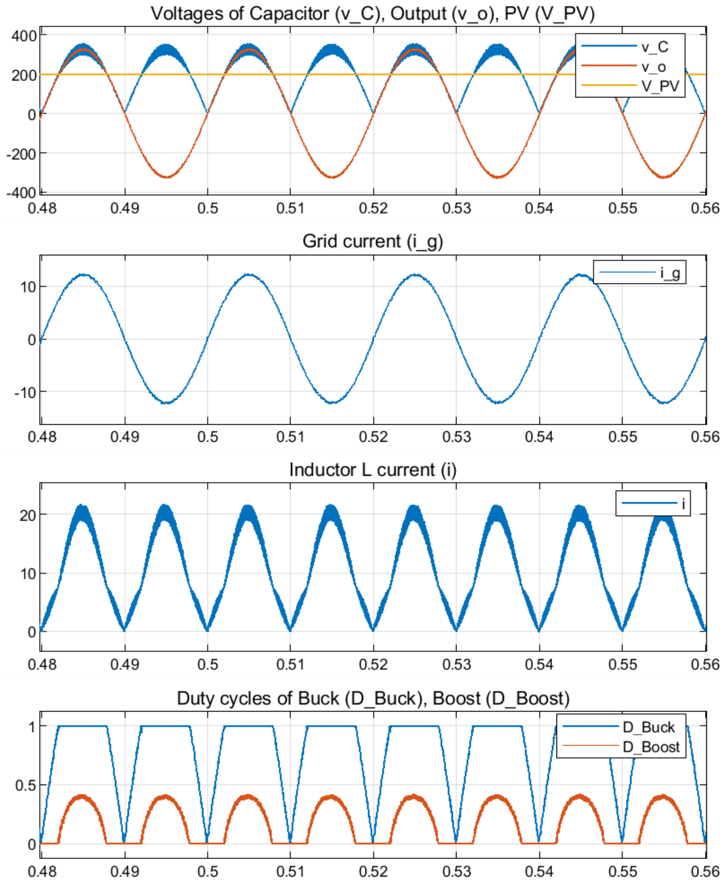
Block diagram of the proposed approach



Simulation results
Nominal PV voltage & power

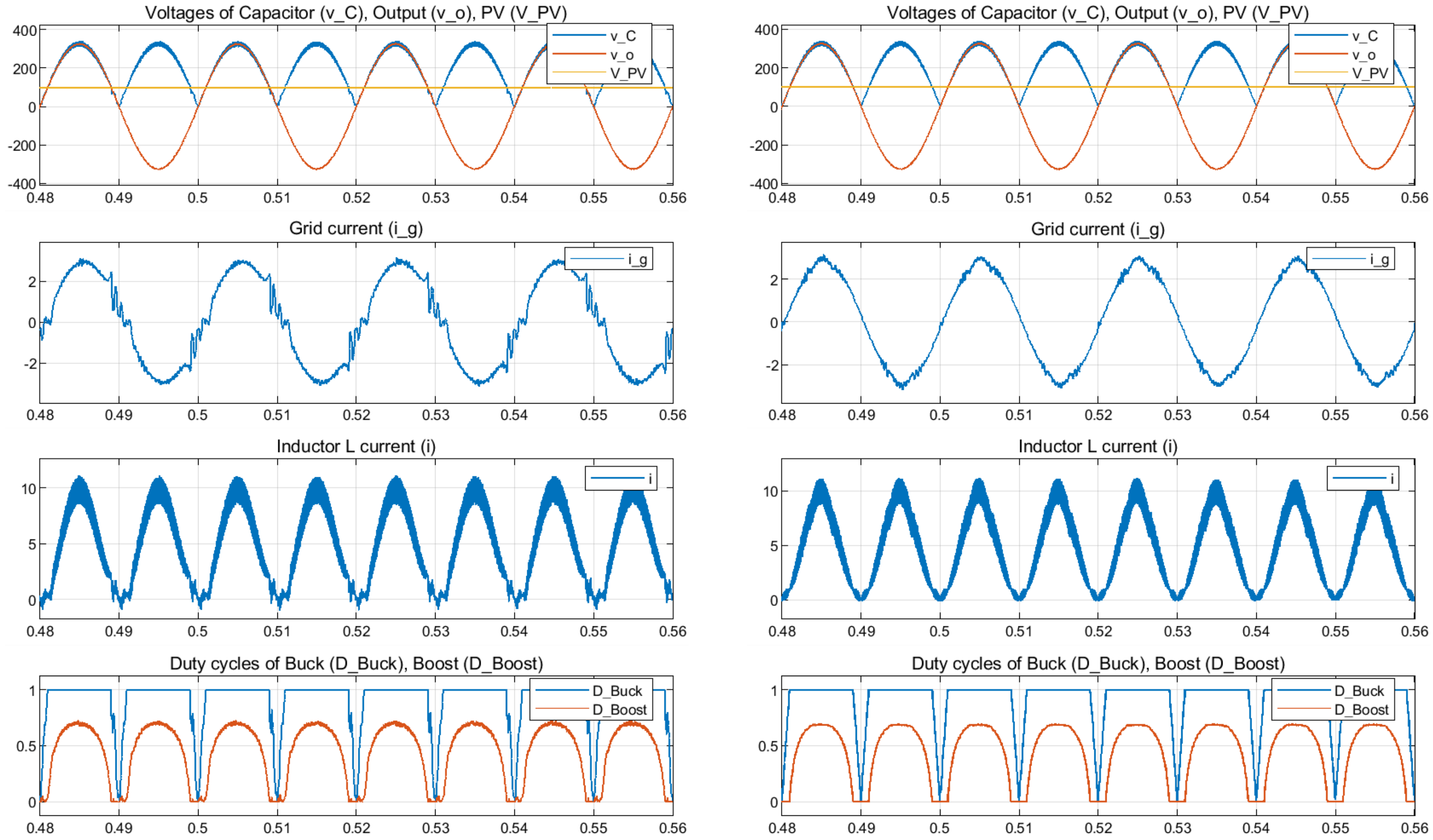
- V_{PV} = 200 V
- P = 2 kW
- Effects:
  - **Phase lag** due to stationary frame current control
  - **Current oscillations** at the transition between Buck-Boost modes
- THD_I =
  - Existing: 4.1%
  - Proposed: 1.3%
- THD reduction: 68%





Simulation results
Low PV voltage & power

- V_{PV} = 100 V
- P = 500 W
- Effects are more intense
- THD_I =
  - Existing: 12.5%
  - Proposed: 4.6%
- THD reduction: 63%



Conclusion

- A new current control strategy for Aalborg-type dual-mode time-sharing PV inverters has been proposed.
- The proposed strategy
  - operates in the synchronous reference frame, and
  - uses a common controller for the Buck and Boost modes
- Suppresses the different types of distortion that appear when the inverter is controlled with existing stationary-frame control methods.
- Significantly improves the quality of the inverter output current, as illustrated for a wide range of operating conditions.

Acknowledgement

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THANK YOU!

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