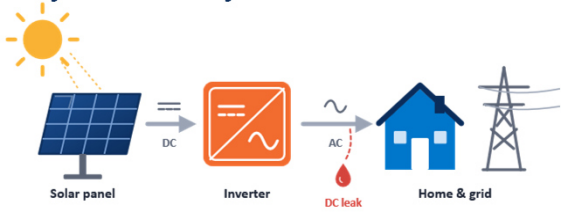
# Fixing Solar's Hidden DC Leak

*A smarter way of switching a solar inverter keeps DC out of the grid, even with a capacitor ten times smaller.*

Measured-Level PWM for DC-Injection-Free Grid Integration of a Sixfold-Boost 13-Level Common-Ground Switched-Capacitor Inverter

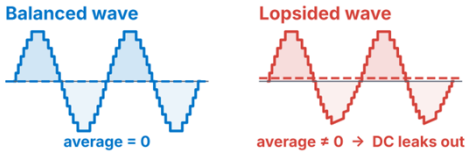
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## Why should anyone care?




Rooftop solar panels make DC. An inverter turns it into the AC our homes and the grid run on. If the AC wave it makes leans to one side, a little **DC leaks into the grid**.

That DC slowly **heats and saturates transformers**, confuses protection relays and corrodes buried metal. Grid rules allow no more than **0.5% of the current** (IEEE 1547).

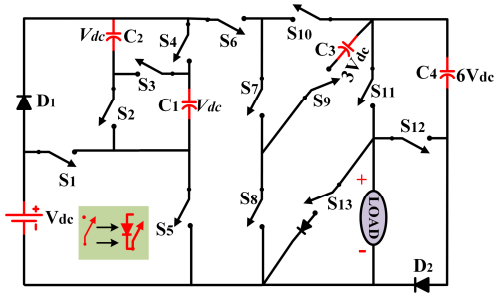



*Sketch: when the negative half of the wave shrinks, its average is no longer zero.*

*Think of a playground swing that goes a bit further forward than back. It drifts. A lopsided AC wave drifts too, and that drift is DC.*

## The inverter

Our 13-level inverter boosts one solar input **six times** with switched capacitors. The panel stays tied to ground, so **no leakage current** flows through its frame.




*13 switches, 2 diodes, 4 capacitors and only 7 gate drivers. Capacitor C4 makes every negative step.*

## Where the leak comes from

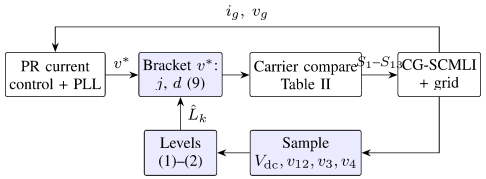
In each negative half-cycle, capacitor C4 feeds the load on its own and its voltage sags. All six negative steps sag with it, so the **two halves of the wave are no longer equal**.

Standard PWM assumes perfect steps, so the mismatch turns into DC and even harmonics. A smaller capacitor makes it worse.

## Our fix: switch by the real steps

Measured-Level PWM (ML-PWM) stops trusting ideal steps. In every 200-µs switching period it:

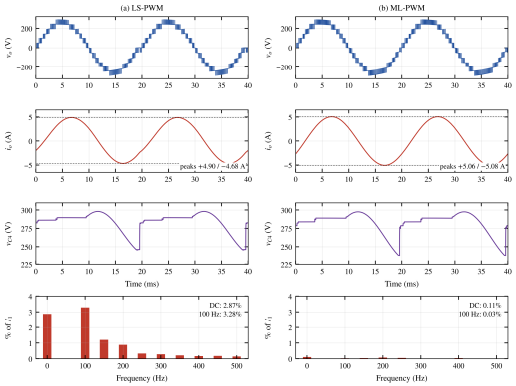
1. measures three capacitor voltages,
2. works out the true height of all 13 steps,
3. picks the two steps on either side of the target, and
4. blends them so the average lands exactly on it.




*Only the shaded blocks are new. The switching table, device stress and capacitor self-balancing stay the same.*

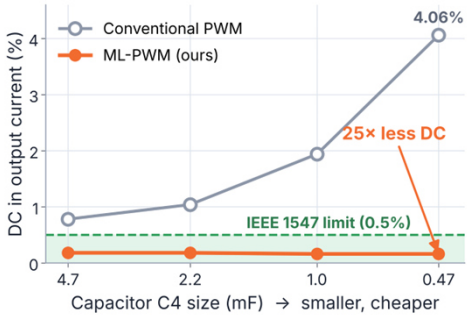
It costs about **25 arithmetic operations** per period and **no extra power hardware**.

## Same circuit, two modulators




*(a) conventional level-shifted PWM, (b) ML-PWM, C4 = 0.47 mF. The DC and 100-Hz bars all but vanish.*

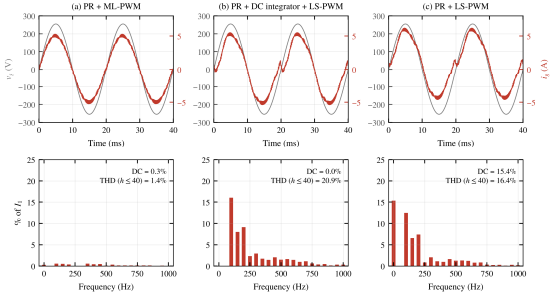
## The leak, fixed




| 25× | 10× | 1.4% | 94.7% |
|---|---|---|---|
| less DC | smaller capacitor | grid-current THD | peak efficiency |

Conventional PWM breaks the limit at every capacitor size. ML-PWM stays at **0.16–0.18%**.

## Connected to the grid




*\(a) ML-PWM, (b) conventional PWM with a DC integrator, (c) conventional PWM.*

A DC integrator removes the DC but leaves 20.9% THD. ML-PWM reaches **1.38%** with a plain controller, and PLECS loss models show **the same efficiency**.

## In one line

The lopsided wave is a control problem, so it can be fixed in software: ML-PWM keeps DC out of the grid with a capacitor ten times smaller, at no cost in efficiency.

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