SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Power Electronics Program Kickoff

M4 Inverter:
Modular, Multifunction, Multiport & Medium Voltage Utility Scale SiC PV Inverter

TEXAS The University of Texas at Austin · TOSHIBA TOSHIBA INTERNATIONAL CORPORATION · Wolfspeed · Argonne NATIONAL LABORATORY · ercot · OPAL-RT TECHNOLOGIES

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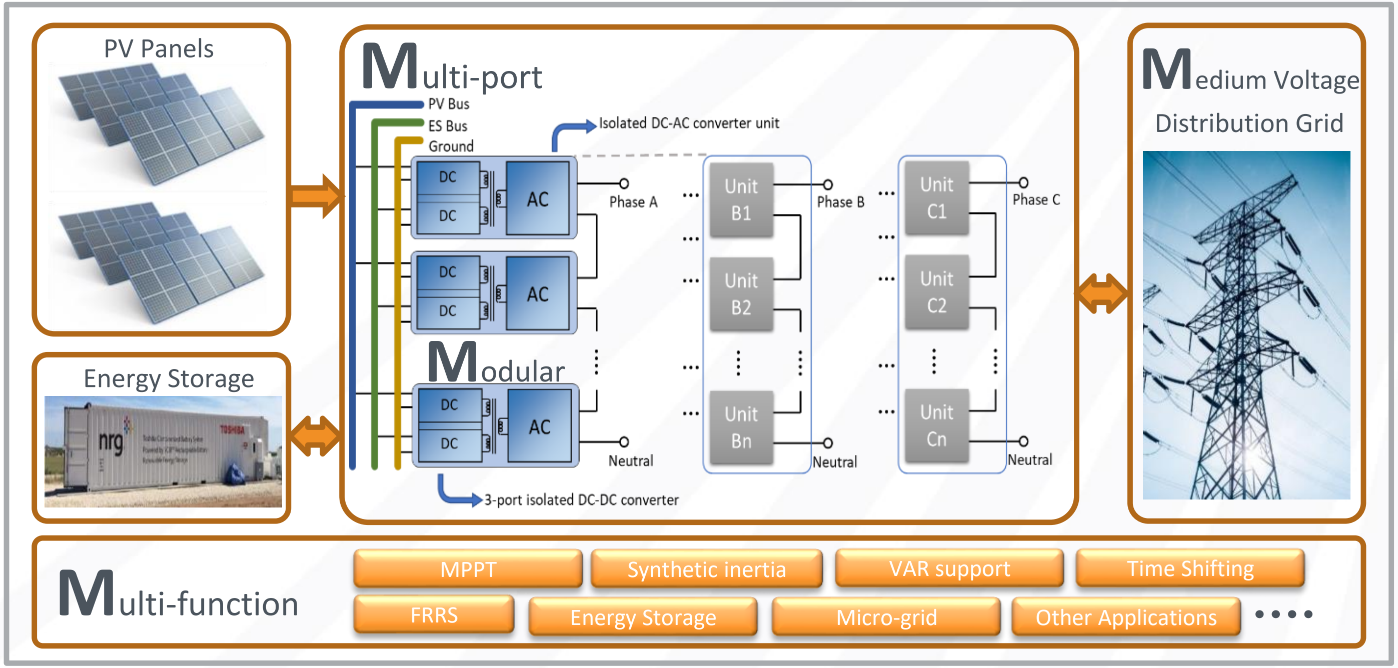
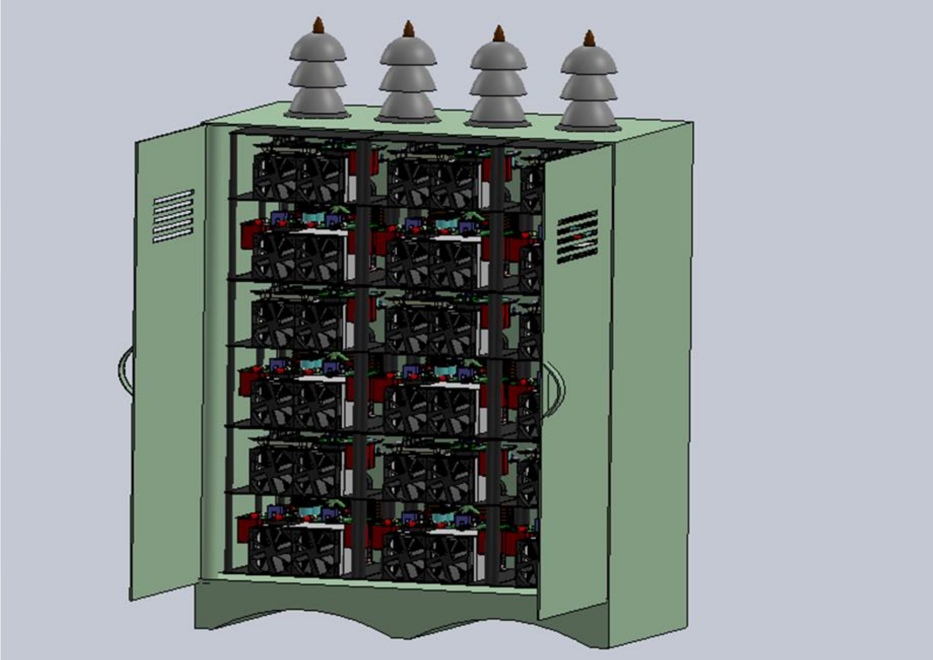
What is an M4 Inverter

Modular | Multi-port | Medium-Voltage | Multi-function



Major Innovations

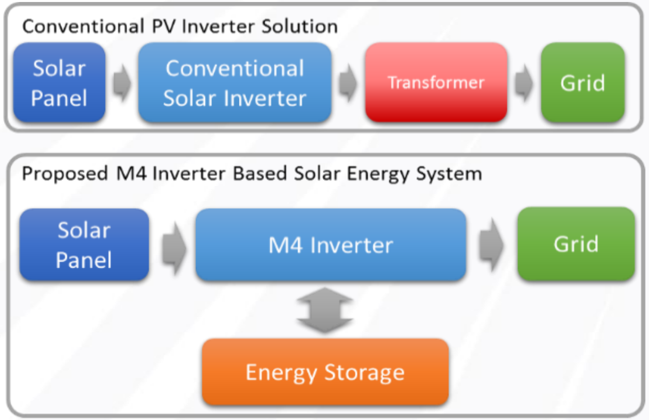
1. Elimination of Line Frequency Transformer
2. Novel Tri-Active Half Bridge (TAHB) Multiport Inverter
3. Advanced SiC Power Module
4. Modular Architecture
5. High Voltage Battery Energy Storage System with high C charge/discharge rate
6. Multi-functionalities of the M4 Inverter



1 MVA M4 Inverter

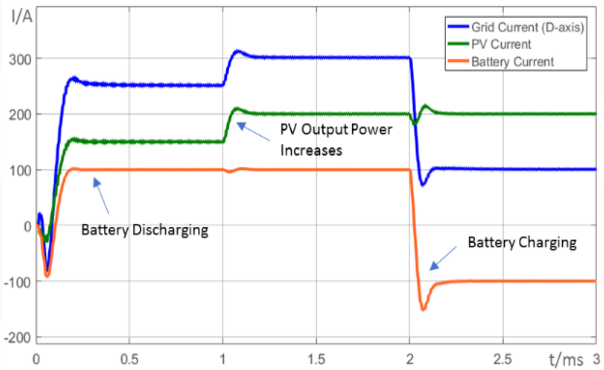
#1: Elimination of Line Frequency Transformer

- $20/kVA cost reduction
- 1% loss reduction
- 50% size reduction
- 30% Installation cost reduction
- 10% O&M cost saving



#2: Multiport Inverter

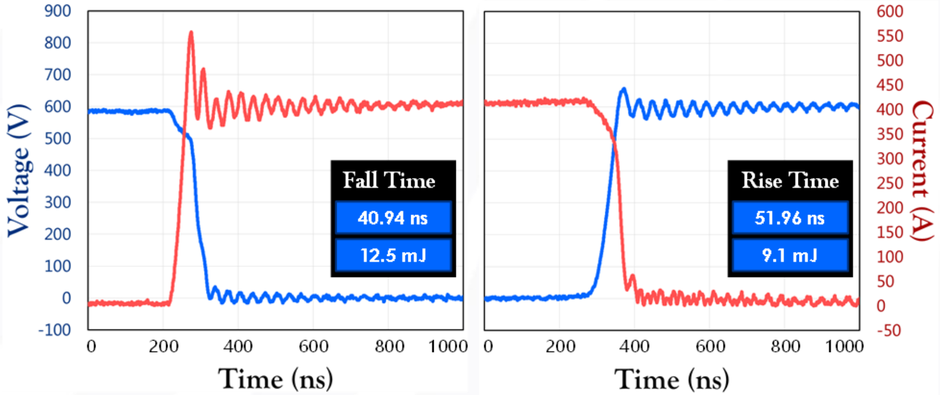
- High frequency 3-winding transformer
- Single-stage DC/AC conversion
- Zero-voltage switching
- 2% higher efficiency than IGBT solution
- Controllable power flow between each port.
- Modular design for N+1 redundancy



#3: Advanced SiC Power Module

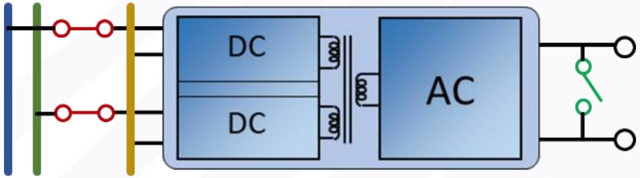
- Ultra-low loss, low inductance packaging
- High-frequency, ultra-fast switching operation
- Zero reverse-recovery current from diode
- Zero turn-off tail current from MOSFET
- Normally-off, fail-safe device operation
- Ease of paralleling
- AlSiC baseplate and Si3N4 AMB insulator, enhancing ruggedness with respect to thermal cycling

- **1700V/2.3 mohm HT-3XXX**
- **900V/2.5 mohm HT-3XXX**

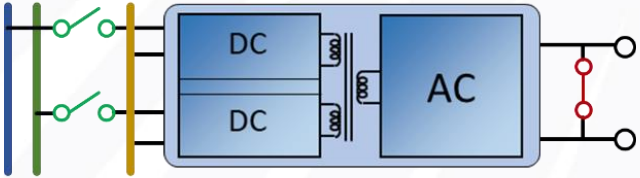


#4: Modular Architecture

- Mass production to reduce manufacturing cost
- X+2 redundancy
- Fault isolation mechanism
- Evenly distributed thermal stress
- Adaptive lifetime extension
- Hot-swappable installation for reduced O&M
- Easy and fast replacement
- Fast DC cap replacement
- Converter unit reuse to lower ownership cost



(a) Normal operation

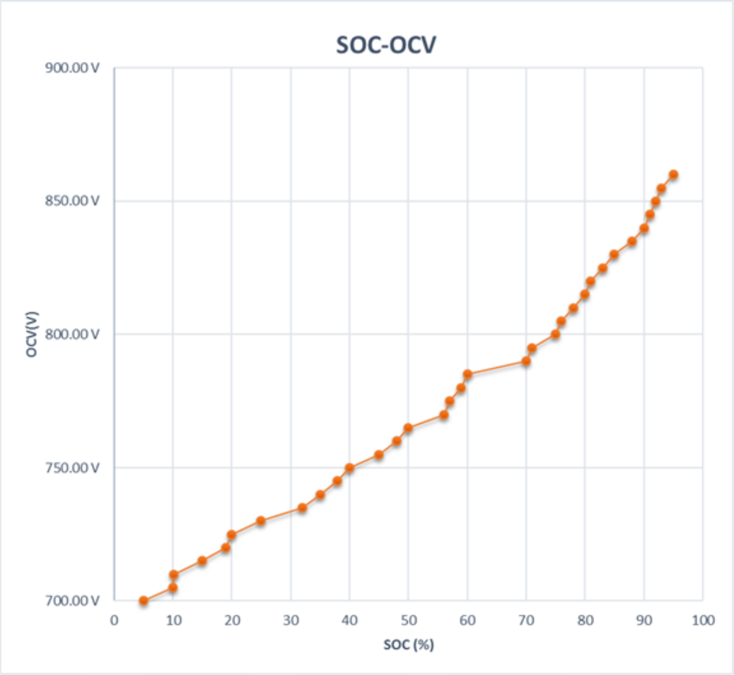


(b) Unit failed

#5: Advanced Battery Energy Storage System

- SCiB™ lithium titanium battery
- Excellent operating characteristics with respect to safety
- Long lifetime (15000-20000 cycles or 15 years)
- Rapid charging and discharging rate (up to 8C)
- Battery voltage self-balance
- Tight integration of the BMS with M4 Inverter for better system protection

Proposed 900V Battery System



Cost Benefit Analysis: Pathway for LCOE Reduction

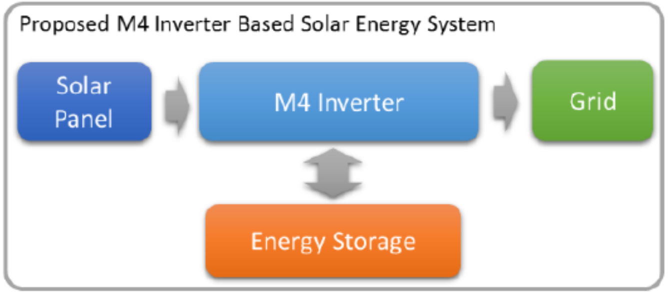
Table 1: Summary of the M4 Inverter innovations and their impacts on LCOE reduction.

LCOE Reduction Strategy in the M4 Inverter	Estimated LCOE Reduction Potential
#1 Elimination of LFT and associated BOS and O&M	6.8%
#2 1% higher efficiency	2%
#3 Higher reliability to 35 years	15%
#4 Lower O&M cost by 50%	15%
#5 Built-in utility scale inverter for storage	3.8%
#6 Optimize the Inverter rating to 50%	1.9%
#7 Additional functionalities	63%
#7.1 STATCOM functionality	4%
#7.2 Time shifting	Currently not attractive in reducing LCOE
#7.3 ERCOT Fast Responding Regulation Services (FRRS)	59%
#4 Synthetic inertia	TBD
Total LCOE reduction potential	>100%

ERCOT Fast Responding Regulation Services (FRRS)

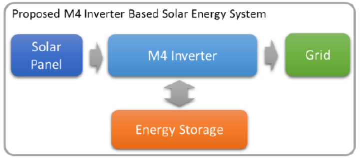
- LCOE calculation change

$$LCOE_{Benchmark} = \frac{sum\ of\ initial\ system\ cost + O\&M\ cost\ over\ lifetime}{sum\ of\ electrical\ energy\ produced\ over\ lifetime}$$



$$LCOE_{Improved} = \frac{sum\ of\ initial\ system\ cost + O\&M\ cost\ over\ lifetime + new\ system\ cost - sum\ of\ benefit}{sum\ of\ electrical\ energy\ produced\ over\ lifetime}$$

ERCOT Fast Responding Regulation Services (FRRS)



$$LCOE_{Imp-F3} = \frac{sum\ of\ initial\ system\ cost + O\&M\ cost\ over\ lifetime + new\ system\ cost - sum\ of\ benefit}{sum\ of\ electrical\ energy\ produced\ over\ lifetime}$$

$$= \frac{sum\ of\ initial\ system\ cost + O\&M\ cost\ over\ lifetime + (M4\ extra\ cost + battery\ cost) - (Income\ from\ Reg\ service + LFT\ cost)}{sum\ of\ electrical\ energy\ produced\ over\ lifetime}$$

$$= \frac{\sum_{t=1}^{N_{Imp-F3}} \frac{I_b(t) + M_b(t) + [I_{M4e}(t) + M_{M4e}(t) + I_{batt-FRRS}(t) + M_{batt-FRRS}(t)] - [FRRS(t) + I_{LFT}(t) + M_{LFT}(t)]}{(1+r)^t}}{\sum_{t=1}^{N_{Imp-F3}} \frac{E_{Imp-F3}(t)}{(1+r)^t}}$$

$I_b(t)$	Benchmark investment expenditures in the year t
$M_b(t)$	Benchmark operations and maintenance expenditures in the year t
$I_{M4e}(t)$	M4 inverter extra investment expenditures in the year t
$M_{M4e}(t)$	M4 inverter extra operations and maintenance expenditures in the year t
$I_{batt-FRRS}(t)$	Battery in the FRRS function's investment expenditures in the year t
$M_{batt-FRRS}(t)$	Battery in the FRRS function's operations and maintenance expenditures in the year t
$FRRS(t)$	Income from FRRS in the year t
$I_{LFT}(t)$	LFT's investment expenditures in the year t
$M_{LFT}(t)$	LFT's operations and maintenance expenditures in the year t
$E_{Imp-F3}(t)$	Improved system's electrical energy generated in the year t in function #3
N_{Imp-F3}	Improved system's lifetime in function #3

Project Plan

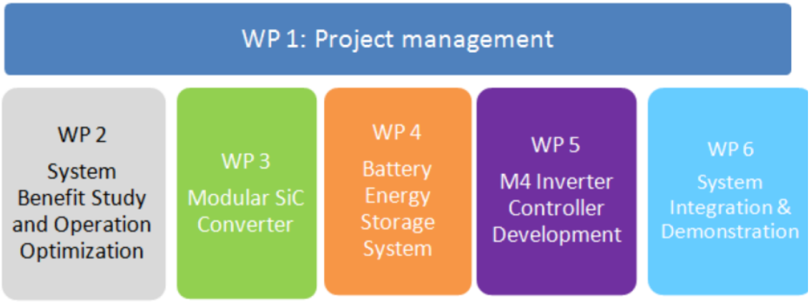


Fig. 1: Organization and work package structure of the proposed project

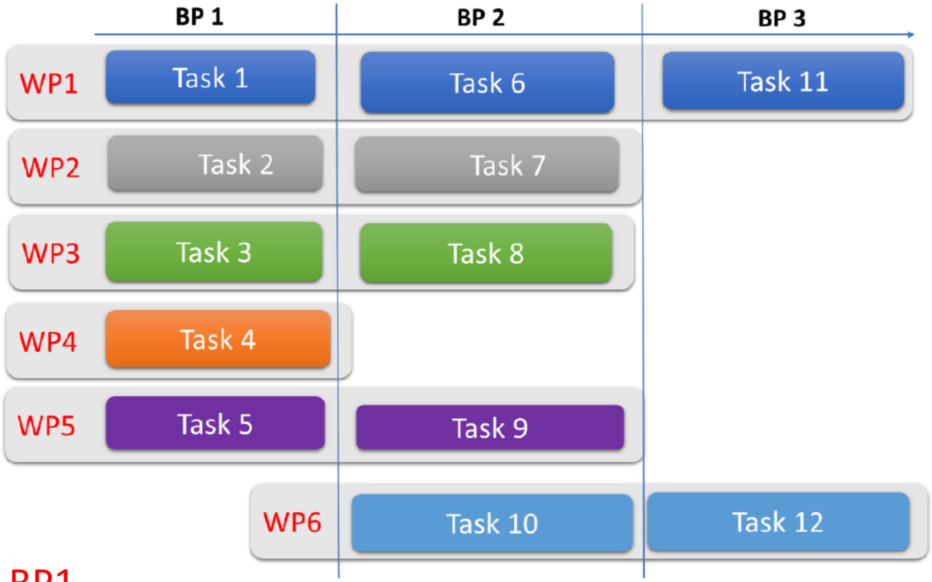
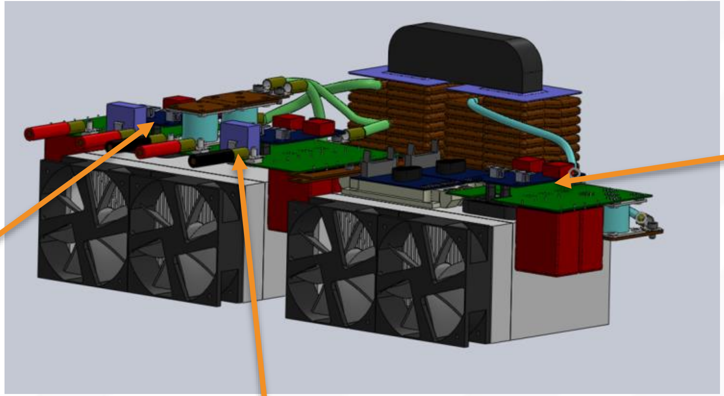


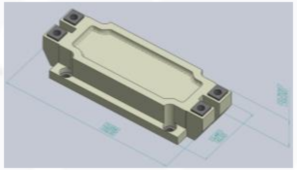
Fig. 2: High level schedules of each task

- Three Go-/No-GO Milestones are defined for BP1

Modular Converter Development Underway (Task3)

- BP1 Goal: > 95% peak efficiency
- BP2 Goal: >97% peak efficiency





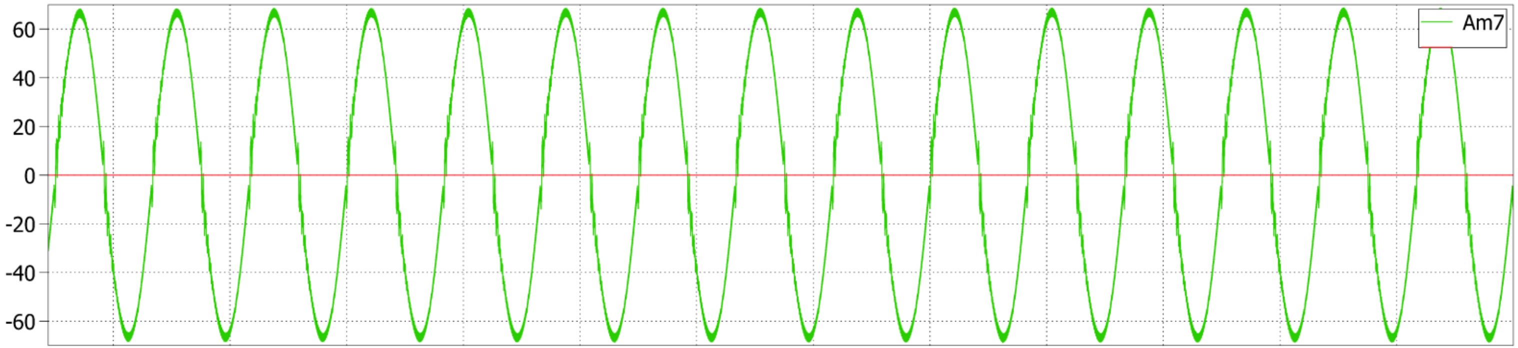
1700V IGBT

SiC driver

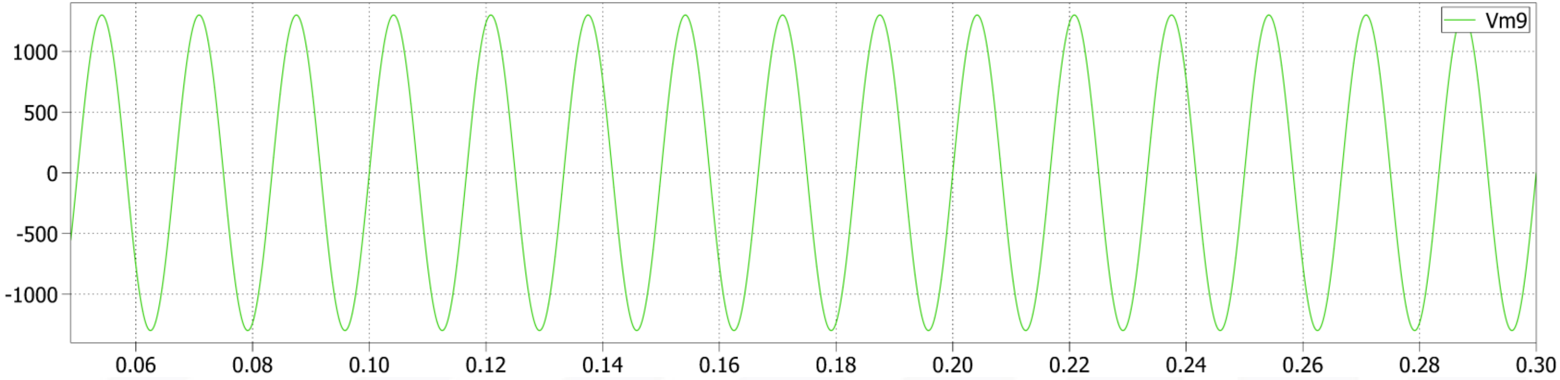
1700V SiC MOSFET

Offline Simulation (PF=1 100 kW AC Output)

Output Current
(60Hz)



Output/Grid Voltage
(60Hz)



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