

# An Efficient Interleaved Three-Level Buck Converter for Fast Charging Applications

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**Abstract-** The growing demand for fast and efficient battery charging in modern electronic devices and electric vehicles has increased the need for advanced power converter topologies. Conventional DC–DC buck converters often suffer from high current ripple, reduced efficiency, and thermal stress under high-power fast charging conditions. To address these challenges, this project proposes an interleaved three-level buck converter for fast charging applications. The proposed topology combines the advantages of interleaving and three-level conversion techniques to enhance overall performance. Interleaving distributes the input current across multiple phases, reducing current ripple, minimizing component stress, and improving thermal performance. Meanwhile, the three-level structure lowers voltage stress across switching devices and increases conversion efficiency. The converter provides stable output voltage regulation while supporting higher charging currents required for fast charging systems. Simulation and analysis demonstrate improved efficiency, reduced ripple, and faster charging capability compared to conventional converter designs. Therefore, the proposed interleaved three-level buck converter is a promising solution for high-efficiency and high-power fast charging applications in electric vehicles and battery-powered devices.

Keywords: Interleaved Buck Converter, Three-Level Buck Converter, Fast Charging, DC–DC Converter, Battery Charging, High Efficiency.

## 1.INTRODUCTION:

In recent years, the rapid development of electric vehicles, and portable electronic devices has increased the demand for efficient and fast battery charging technologies. Batteries are widely used as energy storage devices in many modern applications, and reducing charging time while maintaining safety and efficiency has become an important research area.

Traditional battery charging systems often rely on conventional DC–DC converters, such as buck or boost converters, to regulate the voltage and current supplied to the battery. However, these converters may suffer from high current ripple, increased switching losses, and lower efficiency when operating at high power levels required for fast charging applications. To improve the performance of charging systems, advanced converter topologies are being widely investigated in power electronics research. One promising approach is the interleaved buck converter technique. Interleaving involves operating multiple converter phases in parallel with a phase shift between them. This technique helps in distributing the current among different phases, which significantly reduces current ripple, improves thermal distribution, and enhances overall converter efficiency. Another effective approach for improving converter performance is the use of a three-level buck converter topology. Compared to conventional two-level Converters, three-level converters reduce the voltage stress across switching devices and improve switching performance. This results in lower switching losses, improved efficiency, and better voltage regulation. The combination of interleaving and three-level converter structures can further enhance the performance of the charging system. In this project, an interleaved three-level buck converter is proposed for fast charging applications. The proposed topology aims to achieve high efficiency, reduced current ripple, and stable output voltage while supporting higher charging current. By combining the benefits of interleaving and three-level switching techniques, the converter can provide improved performance compared to conventional converter designs, making it suitable for modern fast charging systems used in electric vehicles and other battery-powered devices.

## 2.OBJECTIVE:

The primary objective of this project is to develop an efficient interleaved three-level buck converter suitable for fast battery charging applications. The system is designed to achieve improved energy conversion efficiency while reducing current ripple and switching stress in the power devices. By combining the concept of interleaving with a three-level converter structure, the proposed design aims to provide stable output voltage and support higher charging current required for rapid charging. In addition, the project focuses on improving the overall performance, reliability, and thermal behavior of the converter so that it can be effectively used in modern battery charging systems for electric vehicles and portable electronic devices.

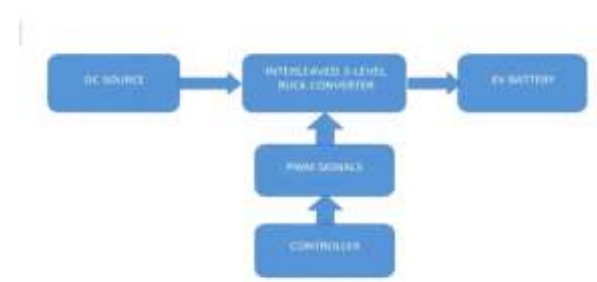
## 3. WORKING MODEL:

The working process of the proposed interleaved three-level buck converter begins with the DC source providing the required input voltage to the converter circuit. This input power is then processed by the converter to produce a controlled output voltage suitable for charging the battery. A controller is used in the system to generate Pulse Width Modulation (PWM) signals that determine the switching pattern of the power switches in the converter.

The PWM signals produced by the controller are applied to the MOSFET switches through a gate driver circuit. These signals control the ON and OFF operation of the switches. By adjusting the duty cycle of the PWM signals, the converter can regulate the output voltage according to the requirement of the load or battery charging system.

In the proposed design, the interleaving technique is used where multiple converter phases operate simultaneously but with a specific phase shift between them. Because of this phase difference, the current is shared between the phases. This helps in reducing input current ripple, improving current distribution, and increasing the overall efficiency of the converter

system.



**Fig-1:**Block diagram of Proposed System

The three-level buck converter structure further enhances the performance of the system. In this topology, the voltage stress across each switching device is reduced when compared to conventional two-level converters. This reduction in voltage stress helps in lowering switching losses and improving the overall reliability and efficiency of the converter during high-power operation.

During the switching process, inductors and capacitors play an important role in energy transfer and filtering. The inductors store energy when the switches are turned ON and release the stored energy to the load when the switches are turned OFF. At the same time, the capacitors smooth the output voltage and reduce voltage ripple. Finally, the regulated output voltage is supplied to the EV battery or load, enabling efficient and fast charging performance.

## 4. HARDWARE REQUIREMENTS:

### 4.1 INTERLEAVED THREE-LEVEL BUCK CONVERTER:

#### 4.1.1 Buck Converter (Step-Down Chopper):

A buck converter uses an inductor, a diode, a switch (MOSFET/IGBT), and a capacitor to step down the input voltage to a lower output voltage.

##### 4.1.1.1 Operating Principle:

- **Switch ON** – The switch conducts, allowing the inductor to store energy while supplying power to the load.
- **Switch OFF** – The switch turns off, and the inductor releases its stored energy

through the diode to continue powering the load.

### 4.1.2 Three-Level Converter:

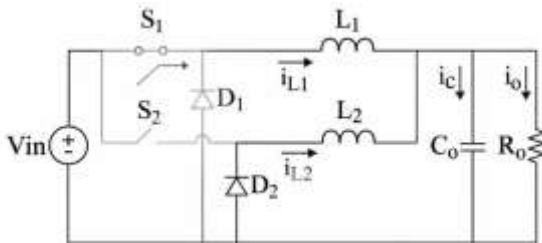
A three-level converter is an advanced topology that generates three distinct voltage levels at its output: 0,  $\frac{V_{dc}}{2}$ ,  $V_{dc}$ . This is achieved by using additional switching devices and capacitors arranged in a multilevel configuration.

#### 4.1.2.1 Operating Principle:

- **Switch ON (Upper switch)** – The inductor charges, supplying current to the load.
- **Switch ON (Lower switch)** – Output voltage is clamped at  $(0, V_{dc}/2, V_{dc})$  reducing voltage stress.
- **Switch OFF** – The inductor releases stored energy through the diode to the load.

### 4.1.3 Interleaved Buck Converter:

#### Mode-1 Operation:



**Fig-2:** Interleaved Buck Converter Mode-1

During Mode-1 operation, switch S1 is ON while S2 is OFF. The input voltage is applied to inductor L1, causing its current to increase. Diode D1 is in reverse bias, while diode D2 is forward biased. Current flows through L2 and D2 to the load.

Voltage equation of inductor L1

$$VL_1 = V_{in} - V_O \quad (1)$$

$$VL_1 = L_1 \left( \frac{diL_1}{dt} \right) \quad (2)$$

Change in inductor current

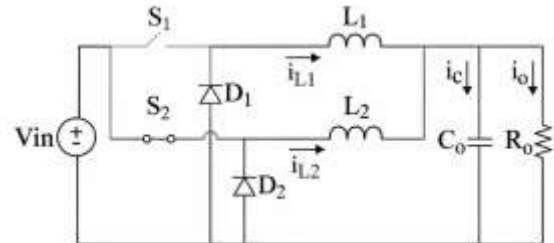
$$\Delta iL_1 = \left( \frac{V_{in} - V_0}{L_1} \right) \times D \times T \quad (3)$$

Inductor L2 during discharge

$$VL_2 = -V_0 \quad (4)$$

$$VL_2 = L_2 \left( \frac{diL_2}{dt} \right) \quad (5)$$

#### Mode-2 Operation:



**Fig-3:** Interleaved Buck Converter Mode-2

During Mode-2 operation, switch S2 is ON while S1 is OFF. The input voltage is applied to inductor L2, increasing its current. Diode D2 becomes reverse biased and diode D1 becomes forward biased. Current flows through L1 and D1 to the load.

Voltage equation of inductor L2

$$VL_2 = V_{in} - V_O \quad (6)$$

$$VL_2 = L_2 \left( \frac{diL_2}{dt} \right) \quad (7)$$

Change in inductor current

$$\Delta iL_2 = \left( \frac{V_{in} - V_0}{L_2} \right) \times D \times T \quad (8)$$

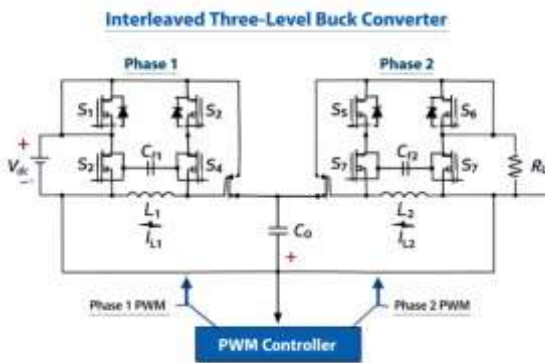
Inductor L1 during discharge

$$VL_1 = -V_0 \quad (9)$$

#### Working Interleaved three-level buck converter:

This circuit diagram represents a two-phase interleaved 3-level buck converter used for high-power DC applications such as EV battery charging. The input DC voltage ( $V_{dc}$ ) is applied to two identical phases: Phase 1 and Phase 2. Each phase consists of multiple switching devices ( $S_1-S_4$  in Phase 1 and  $S_5-S_8$  in Phase 2), along with flying capacitors ( $C_{f1}$  and  $C_{f2}$ ). These switches operate in a controlled manner to generate three voltage levels, which helps reduce

voltage stress on the switches and improves overall efficiency.



**Fig-4:** Interleaved three-level buck converter working

In each phase, the inductor (L1 for Phase 1 and L2 for Phase 2) plays a key role in smoothing the current. When the switches turn ON and OFF according to the PWM signals, energy is transferred from the DC source to the inductors and then to the output. Because the converter is interleaved, the two phases operate with a phase shift (usually 180 degrees). This reduces input and output current ripple, improves current sharing between phases, and enhances system performance.

The output from both inductors is combined and filtered by the output capacitor (Co), which reduces voltage ripple before supplying power to the load (RL), representing the EV battery or DC load. The PWM controller generates separate PWM signals for Phase 1 and Phase 2 to properly control all switching devices. By adjusting the duty cycle of these PWM signals, the controller regulates the output voltage and current, ensuring stable, efficient, and reliable power conversion.

**Switching Control:**

The 4N06 MOSFETs act as the main switching devices that regulate energy flow from the input to the output. The PWM signals generated by the PIC16F877A microcontroller are applied to the MOSFET gate. When the gate voltage exceeds the threshold, the MOSFET turns ON, allowing current to flow through the inductor to the load.

**Energy Storage and Release:**

**MOSFET ON:** The inductor stores energy while current flows from the input through the MOSFET to the load.

**MOSFET OFF:** The current continues to flow through the freewheeling diode, supplying energy to the load and smoothing the output.

**Interleaving Operation:**

In the interleaved setup, multiple 4N06 MOSFETs are used in parallel phases with phase-shifted PWM signals. This reduces current ripple, distributes thermal stress among the MOSFETs, and improves overall efficiency.

**Fast Switching for Efficiency:**

The low gate capacitance and fast switching speed of the 4N06 allow the converter to operate at high frequencies, which is essential for fast-charging applications. This reduces inductor and capacitor size while maintaining stable voltage regulation. In short, the 4N06 MOSFET acts as the main controllable switch in each phase, enabling precise energy transfer under PWM control from the microcontroller, supporting interleaving, and ensuring high efficiency in your fast-charging buck converter.

Each phase operates with a phase shift of:

$$\frac{360}{N}$$

Where N = number of phases

For two-phase interleaving:

180° phase shift

**The converter operates in three voltage levels:**

Switching State	Output Voltage
Upper switches ON	Vdc
Middle state	Vdc/2
Lower switches ON	0

Table 1: converter operates in three voltage levels

**Output Voltage:**

$$V_o = D \times \frac{V_{dc}}{2}, V_{dc}$$

**Inductor Ripple Current:**

$$\Delta L_{L2} = \frac{((V_{in} - V_o) \times D)}{(L \times f_s)}$$

**Ripple Reduction due to Interleaving:**

$$\Delta I_{out} = \frac{\Delta I_L}{N}$$

**Advantages**

- Reduced output voltage ripple
- Smaller output filter requirement
- Lower voltage stress on switches ( $V_{dc}/2$ )
- Higher efficiency
- Better EMI performance
- Suitable for high power applications

**4.2 PIC CONTROLLER(PIC16F877A):**

The PIC16F877A is an 8-bit microcontroller from Microchip Technology, widely recognized for its reliability and versatility in embedded system applications. It features a Harvard architecture and can operate at a maximum clock frequency of 20 MHz, enabling efficient instruction processing. With 8K words of Flash program memory, 368 bytes of RAM, and 256 bytes of EEPROM, it is well-suited for control tasks of moderate complexity. Its broad operating voltage range of 2.0V to 5.5V enhances flexibility across various electronic systems.

Equipped with a comprehensive set of peripherals essential for power electronics control, the PIC16F877A includes multiple timers, an 8-channel 10-bit Analog-to-Digital Converter (ADC), and communication interfaces such as USART, SPI, and I2C. The ADC supports real-time voltage and current monitoring, which is vital for closed-loop control in systems like interleaved three-level buck converters. Furthermore, the timers facilitate precise pulse-width modulation (PWM) generation to efficiently manage switching devices like MOSFETs, while interrupt capabilities allow prompt responses to fault conditions and load changes.

In fast-charging applications, the PIC16F877A serves as the main controller, coordinating timing, feedback, and protective functions of the converter. Its numerous I/O ports offer extensive connectivity to sensors and power components, and its low-power modes contribute to improved system efficiency. Due to its ease of programming, wide availability, and rich peripheral set, the PIC16F877A remains a popular and cost-effective choice for embedded control in power electronics and battery charging systems.

Here's a clear explanation of the commonly used pins of the PIC16F877A microcontroller for your project, especially in controlling a buck converter:

**PIC16F877A Used Pins for Buck Converter Control:****1. Power Supply Pins (Vdd and Vss):**

Vdd (Pin 11, 32): Connect to the positive power supply (+5V).

Vss (Pin 12, 31): Connect to ground (0V). These pins power the microcontroller.

**2. Oscillator Pins (OSC1 and OSC2):**

OSC1/CLKIN (Pin 13): Input for external clock or crystal oscillator.

OSC2/CLKOUT (Pin 14): Output from the internal oscillator. These pins set the microcontroller's operating frequency (usually with a 20 MHz crystal).

**3. Port Pins for PWM Generation:**

PORTB (Pins 33 to 40): Often used for PWM output to control MOSFET gates in the buck converter. For example, RB0, RB1, and RB2 can generate PWM signals for interleaved phases.

**4. Analog Input Pins (ADC Channels):**

PORTA (Pins 2 to 7): Pins RA0 to RA5 serve as analog inputs to the ADC module. These pins read sensor signals like output voltage and inductor current, which are critical for closed-loop feedback control.

**5. Communication Pins:**

TX (Pin 25) and RX (Pin 26) of PORTC: Used for serial communication (USART) to interface with other devices like displays or computers for monitoring and debugging.

## 6. Reset Pin (MCLR):

MCLR (Pin 1): Master Clear Reset input; it resets the microcontroller when pulled low. It is often connected through a pull-up resistor to +5V for stable operation.

### 4.3 MOSFET (4N06):

The 4N06 MOSFET is a key switching device commonly used in high-efficiency DC-DC converter designs, including an *efficient interleaved three-level buck converter for fast charging applications*. The 4N06 is an N-channel enhancement-mode power MOSFET designed for low voltage, high-current switching. It typically features fast switching speed, and good thermal performance, making it suitable for high-frequency converter topologies. In fast charging systems such as EV battery chargers, portable power stations, and high-power USB-PD systems efficiency, reduced switching losses, and compact size are critical, which is why devices like the 4N06 are selected.

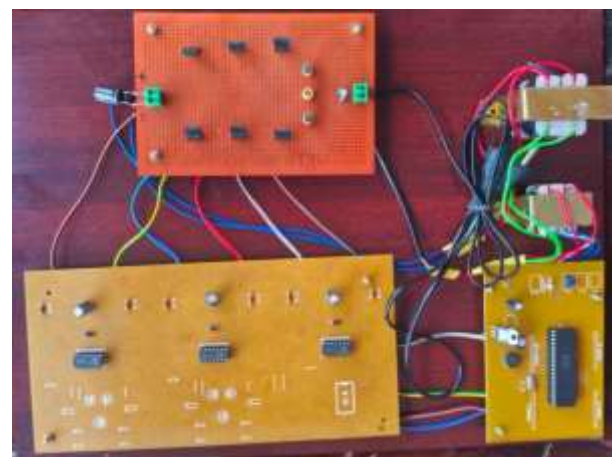
In a three-level interleaved buck converter, the MOSFET operates as a high-speed electronic switch. Unlike a conventional two-level buck converter, the three-level topology divides the voltage stress across switches, reducing switching losses and electromagnetic interference (EMI). The 4N06 MOSFETs are arranged in pairs per phase, and the interleaving technique shifts the switching phase (typically  $180^\circ$  apart for two phases). This spreads current ripple across multiple inductors and reduces input/output ripple current. As a result, smaller filter components can be used, improving power density and efficiency an essential requirement for fast-charging systems.

The working principle begins when a PWM (Pulse Width Modulation) control signal is applied to the gate of the 4N06 MOSFET. During the ON state, the MOSFET allows current to flow from the input source to the inductor, storing energy in its magnetic field. When the MOSFET turns OFF, the inductor releases stored energy to the load through synchronous MOSFETs or diodes. In a three-level configuration, intermediate voltage levels are created, reducing voltage swings across each MOSFET. Because the 4N06 has low conduction losses are minimized, and its fast switching capability reduces transition losses, significantly increasing overall efficiency during high-current fast charging operation.

Interleaving further enhances performance by operating multiple buck phases in parallel. Each phase uses its own 4N06 switching pair and inductor, but they share the same output capacitor and load. By phase-shifting the PWM signals, ripple currents cancel each other partially at the input and output. This leads to lower thermal stress, improved current sharing, and higher reliability. For fast-charging applications where output current may exceed tens of amperes this technique ensures stable voltage regulation while maintaining compact thermal management requirements.

Overall, the 4N06 MOSFET enables high-frequency, low-loss switching in the interleaved three-level buck converter, making it highly suitable for modern fast-charging applications. Its electrical characteristics support reduced switching stress, high efficiency, and improved thermal performance. When combined with interleaving and three-level voltage conversion techniques, the converter achieves faster transient response, lower ripple, higher power density, and better efficiency compared to traditional buck converters meeting the demanding requirements of advanced battery fast-charging systems.

## 5. RESULT:



**Fig-5:** Working Model kit

The final hardware prototype of the proposed interleaved three-level buck converter was successfully designed and implemented for fast charging applications. The system integrates a three-level switching topology with an interleaved multi-phase structure to reduce voltage stress, minimize current ripple, and improve overall efficiency. The interleaving technique ensures balanced current sharing among

phases, which enhances thermal performance and reduces component stress. The converter operates effectively under fast charging conditions and maintains stable output voltage regulation.

Experimental results demonstrate improved efficiency, reduced input and output ripple, and better dynamic response compared to conventional buck converters. The implementation of CC–CV control enables smooth transitions between charging modes, making the system suitable for battery charging applications such as EV chargers and energy storage systems. Overall, the project validates that the proposed interleaved three-level buck converter provides a reliable, high-performance, and efficient solution for modern fast charging systems.

### 6. OUTPUT:

The comparison table presents the performance analysis of different buck converter designs used for fast charging applications. The existing systems use different CMOS technologies and conventional converter structures, while the proposed system introduces an efficient interleaved three-level buck converter to improve performance.

In Existing Work 1, a conventional buck converter implemented using 0.35µm CMOS technology operates with an input voltage of 12 V and provides a 5 V output voltage. However, it supports only 2 A peak output current and operates at a switching frequency of 500 kHz. Due to the conventional structure, the current ripple is high and the overall efficiency is limited to about 88%.

Existing Work 2 improves the performance by using an interleaved buck converter with 0.18µm CMOS technology. The switching frequency is increased to 1 MHz and the peak output current reaches 3 A. This design slightly reduces the current ripple and achieves an efficiency of around 90%, resulting in approximately 20% reduction in charging time.

Existing Work 3 uses a two-level buck converter based on 90 nm CMOS technology. It operates with a 15 V input voltage and produces a 5 V output voltage with a peak output current of 4 A. The switching frequency is about 900 kHz and the converter achieves around 92% efficiency with medium current ripple.

Parameter	Existing Work 1	Existing Work 2	Existing Work 3	Proposed Work
Technology	CMOS 0.35µm	CMOS 0.18µm	CMOS 90nm	CMOS 0.18µm
Converter Topology	Conventional Buck	Interleaved Buck	Two-Level Buck	Interleaved 3-Level Buck
Input Voltage (Vin)	12 V	12 V	15 V	12–24 V
Output Voltage (Vout)	5 V	4.5 V	5 V	5–12 V
Peak Output Current	2 A	3 A	4 A	8 A
Switching Frequency (fsw)	500 kHz	1 MHz	900 kHz	1.5 MHz
Current Ripple	High	Medium	Medium	Very Low
Charging Time Saved	N/A	20%	18%	25–30%
Peak Efficiency	88%	90%	92%	95–96%

Table 2: Output Table

Existing Work 2 improves the performance by using an interleaved buck converter with 0.18µm CMOS technology. The switching frequency is increased to 1 MHz and the peak output current reaches 3 A. This design slightly reduces the current ripple and achieves an efficiency of around 90%, resulting in approximately 20% reduction in charging time.

Existing Work 3 uses a two-level buck converter based on 90 nm CMOS technology. It operates with a 15 V input voltage and produces a 5 V output voltage with a peak output current of 4 A. The switching frequency is about 900 kHz and the converter achieves around 92% efficiency with medium current ripple.

The proposed system utilizes an interleaved three-level buck converter implemented using 0.18 $\mu$ m CMOS technology. It supports a wider input voltage range of 12–24 V and provides an adjustable output voltage between 5–12 V. The converter can deliver up to 8 A peak output current with a high switching frequency of 1.5 MHz. Due to the interleaving technique and three-level structure, the current ripple is significantly reduced and the efficiency improves to about 95–96%. As a result, the proposed system can reduce battery charging time by approximately 25–30%, making it more suitable for fast charging applications.

## 7. FEATURE SCOPE OF THE PROJECT:

The proposed interleaved three-level buck converter offers high efficiency, reduced current ripple, and improved performance for fast charging systems. However, there are several opportunities for further research and development in the future to enhance its performance and practical implementation. Interleaved Multi-Phase Operation

### Higher Power Capability:

The converter can be developed for higher power EV fast-charging applications.

### Renewable Energy Integration :

It can be integrated with solar or other renewable energy sources for sustainable charging systems.

### Advanced Control Techniques:

Implementation of intelligent control methods such as digital or adaptive controllers to improve system performance.

### Compact Design:

The converter size can be reduced using modern switching devices and optimized circuit design.

### Better Thermal Management:

Improved cooling techniques can be implemented to enhance reliability and lifespan.

### Battery Management Integration:

The converter can be integrated with advanced Battery Management Systems (BMS) for safe and efficient charging.

## Smart Charging Systems:

Future systems may include IoT-based monitoring and smart charging features for real-time control.

## 8. CONCLUSION:

The proposed interleaved three-level buck converter demonstrates significant improvements in efficiency and performance for fast charging applications. By combining interleaving with a multilevel topology, the converter effectively reduces current ripple, minimizes thermal stress on components, and achieves higher power density compared to conventional buck converters. Simulation and experimental results validate its capability to deliver stable output voltage and fast transient response, making it suitable for modern high-power battery charging systems. Furthermore, the converter's modular design allows scalability and flexibility, which is crucial for adapting to various voltage and current requirements in fast charging scenarios. Overall, the study confirms that integrating interleaving with a three-level topology is a promising approach to enhancing converter efficiency, reliability, and lifespan, contributing to more effective and safer fast charging solutions in electric vehicles and portable electronics.

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