

High-Power Peak Shaving for Hydrogen Compression Systems using Ultracapacitors

Application

Hydrogen refueling stations require powerful compression systems to store hydrogen at high pressure. These compressor systems typically operate with highly dynamic load profiles that generate short-duration current peaks.

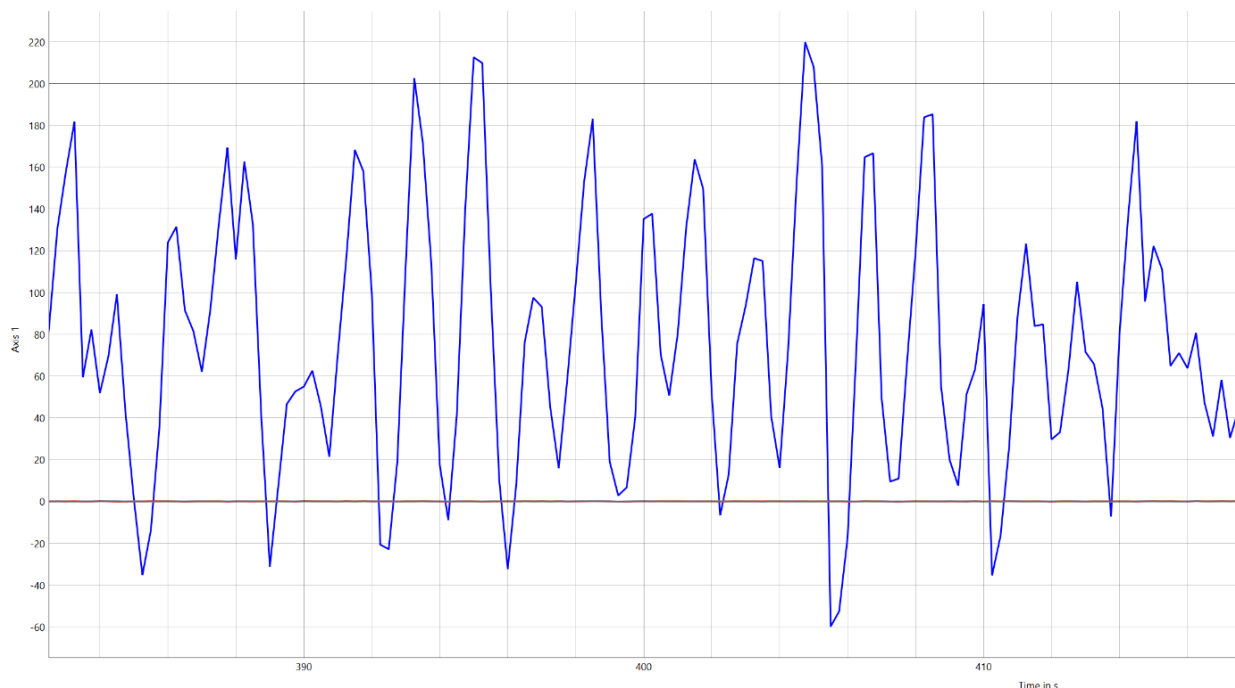
In this use case, a compressor island at a hydrogen refueling station operates on a three-phase 400 VAC / 50 Hz grid connection with a contractual current limit of 80 A per phase.

Challenge

During compression cycles, the compressor generates highly dynamic current peaks exceeding 200 A per phase for several seconds. These peaks occur repeatedly over multiple minutes during operation.

The compressor therefore requires more than twice the available contracted current from the grid connection. As a result, the grid connection fuses trip during operation, preventing reliable compressor functionality.

The graph below shows the measured current demand of the compressor without a peak shaving system installed.



Use case: Ultracapacitor peak shaving system

Limitations of Battery-Based Peak Shaving

Initially, a battery-based peak shaving solution was considered. Batteries are effective at delivering sustained average power, but they are less suited for highly dynamic peak loads.

The compressor load exhibits very fast current rises. Supplying these peaks using batteries alone would require significant oversizing of the battery system.

This would lead to several disadvantages:

- Higher investment costs due to increased battery capacity
- High C-rate operation
- Increased thermal stress
- Reduced battery lifetime under repetitive peak cycling

For applications with frequent high-power peaks, a battery-only solution is therefore not the most efficient approach.

Solution: Functional Separation of Energy and Power

The implemented solution is based on a functional separation between energy supply and peak power delivery.

Energy is provided by the grid connection or a battery system, while ultracapacitors deliver the short-duration high-power peaks required by the compressor.

The system consists of power converters in combination with ultracapacitor modules.

Ultracapacitors offer extremely high power density and very low internal resistance. This allows them to respond within milliseconds and deliver very high current peaks.

In addition, ultracapacitors can withstand millions of charge and discharge cycles with minimal degradation, making them ideal for applications involving frequent dynamic power peaks.

The power converters are needed to actively respond on these peak loads. The solution contains an ultrafast 120kVA AC/DC Converter that can actively inject current before grid current rises above 80A.

Use case: Ultracapacitor peak shaving system

System Architecture

In this architecture, the grid current is limited to the contracted value of 80 A per phase.

The system operates as follows:

- The grid supplies the base power within the contractual limit
- The ultracapacitor system delivers the short-duration dynamic peak currents
- The battery system supplies the average energy deficit when required and prevents ultracapacitors to get empty

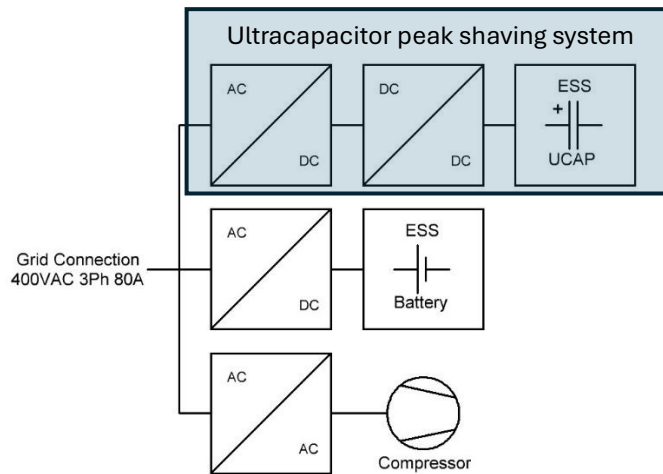


Figure 1: Block diagram of system



Figure 2: Example picture from Ultracapacitor peak shaving system

Use case: Ultracapacitor peak shaving system

When the load demand falls below the grid limit, available power from the grid or battery recharges the ultracapacitors through the DC link. This ensures that peak power capability is continuously restored without placing stress on the battery system.

Because ultracapacitors respond significantly faster than batteries, they absorb and deliver the rapid current fluctuations while the battery operates under smoother and more stable load conditions.

In some configurations, the battery system may even be omitted if the peak demand only slightly exceeds the grid limit.

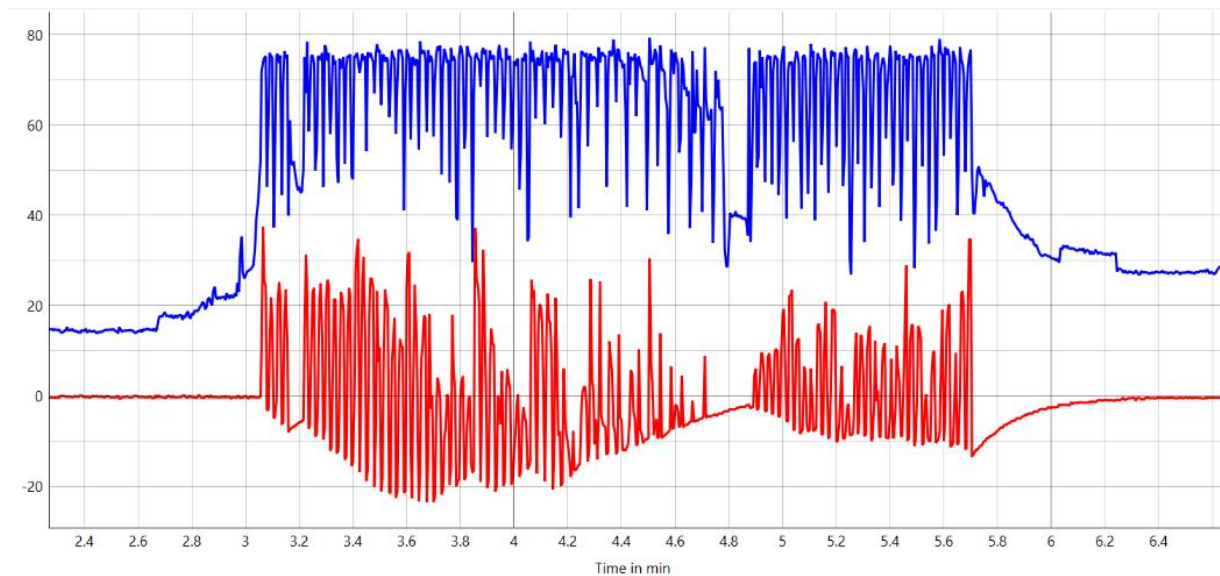
Alternatively, a fuel cell system could replace the battery as a steady energy source, since fuel cells are also well suited for constant power delivery.

Results

The measurements below show the system operating during compressor cycles.

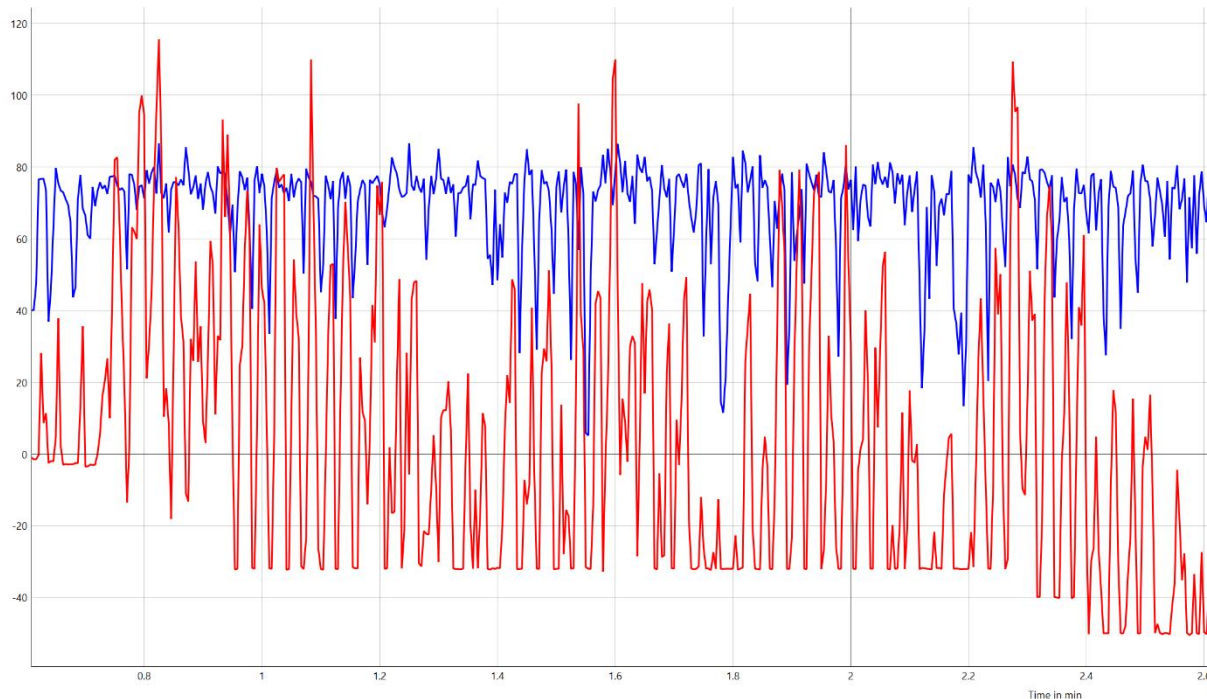
The **blue line** represents the grid current, while the **red line** represents the current delivered by the ultracapacitor peak shaving system.

Medium compression load



Use case: Ultracapacitor peak shaving system

High compression load



The measurements demonstrate that the grid current remains below the contracted limit of 80 A per phase throughout compressor operation.

The ultracapacitor system supplies the dynamic peak currents and continuously charges and discharges to maintain peak capability.

As a result, the compressor can operate normally without triggering the grid connection fuses.

Additional Benefits

Besides peak shaving, the system also provides several additional grid-support functions:

- Power factor correction
- Harmonic current compensation
- Three-phase current monitoring and compensation on highest current

These capabilities improve overall power quality and grid stability at the installation site.

Conclusion

By combining ultracapacitor technology with power electronics, the system enables reliable operation of high-power dynamic loads on grid connections with limited available power.

The functional separation of energy and power allows ultracapacitors to handle fast peak currents, while the grid or battery system provides the average energy demand.

This approach results in improved system efficiency, reduced stress on battery systems and reliable operation without requiring costly grid upgrades.

Use case: Ultracapacitor peak shaving system

Contact

If this application is relevant for your system or if you are dealing with grid limitations and dynamic peak loads, please contact our sales team for more information.