

# Renewable Source-Based Water Pumping Electrification in Mines

Current technologies and future trends.

**W**ATER PUMPING IS AN essential function in diverse industrial sectors, including manufacturing, mining, agriculture, oil and gas, and chemical processing. The global energy consumption of pumps is approximately 15%, and in the particular case of the mining industry, pumps can represent up to a 24% of the average consumption of energy, as shown in Figure 1. The use of water in the mining industry has some distinctive features compared to other industrial applications. Most of the large mines are located in arid or semiarid regions where water is scarce and there are few competing users, such as agriculture and towns. A mine itself



Digital Object Identifier 10.1109/MELE.2023.3348349  
Date of current version: 29 February 2024

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could be the largest water user in the sector. Therefore, to cope with water scarcity, it could be necessary to transport the water large distances to supply a mine. In general, a mine requires water in several processes, some of them critical, then, pumping is crucial to ensure the continuous operation of the industry. On the other hand, regarding the geographical location, as mines could operate in windy regions and/or regions rich in solar irradiation, e.g., copper mines in Chile and Australia, or chromite mines in South Africa, the use of renewable energies to supply pumps is an attractive option. In this article, we explore pumping requirements in the mining industry, its possibilities for electrification based on renewables sources, the limitations, and the prospections of this relevant industrial sector.

### Water Consumption in the Mining Industry

In mining industry processes, several tasks require water. The possible uses of water could include cooling, tailings, dust suppression, ore transportation, ore processing, potable water and sanitation, and so on.

The Water Accounting Framework (WAF), elaborated on by the Minerals Council of Australia, proposes a conceptual input-output model (see Figure 2) to account for

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water use in mining. In this model, the input, output, and other managed water (OMW) are defined in this section.

The input is the volume of water received from the environment or surrounding community to be used directly in a mine task or stored for later use in a task. This water crosses the boundary of the operational facility and includes water made available due to mining activities within the facility, such as groundwater accessed from pit dewatering or groundwater present in the ore. Examples of inputs are sea water, surface water, and groundwater.

The output is the volume of water removed (consumed, discharged, used, or lost) from the mine after it has been used for a task. This water crosses the operational facility boundary and is no longer available in the mine site. An output could include water discharge to the sea or to the surface, evaporation, or water delivered to a third party.

OMW refers to water that is actively managed (e.g., physically pumped, treated, diverted away from the operation, or that has material-evaporative losses) by the facility and flows from the source (OMW—inputs) to a destination (OMW—outputs) without being used in a mine task. OMW could include dewatering, stormwater management, and third-party water supply.

### Pumps in Mining

Pumps play a crucial role in mining operations by facilitating the movement of fluids and materials within various processes. They are used for tasks like dewatering mines, transporting slurry, managing tailings, and providing water supply. Different types of pumps, including

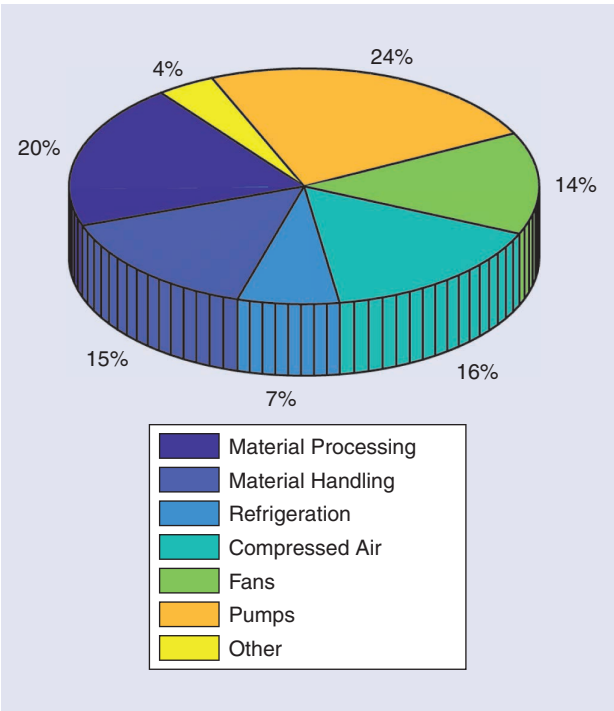


Figure 1. Energy consumption in mining.

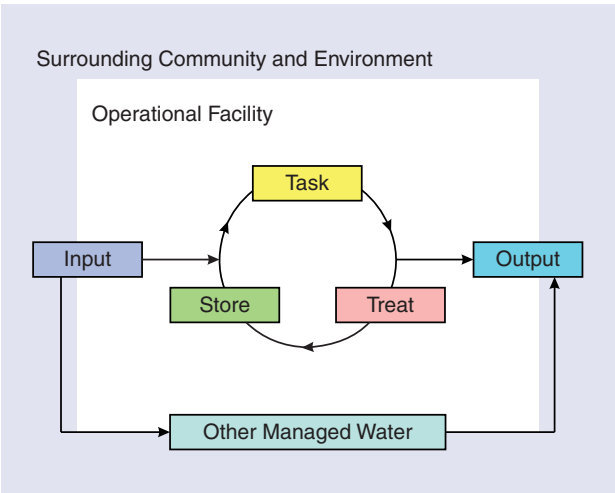


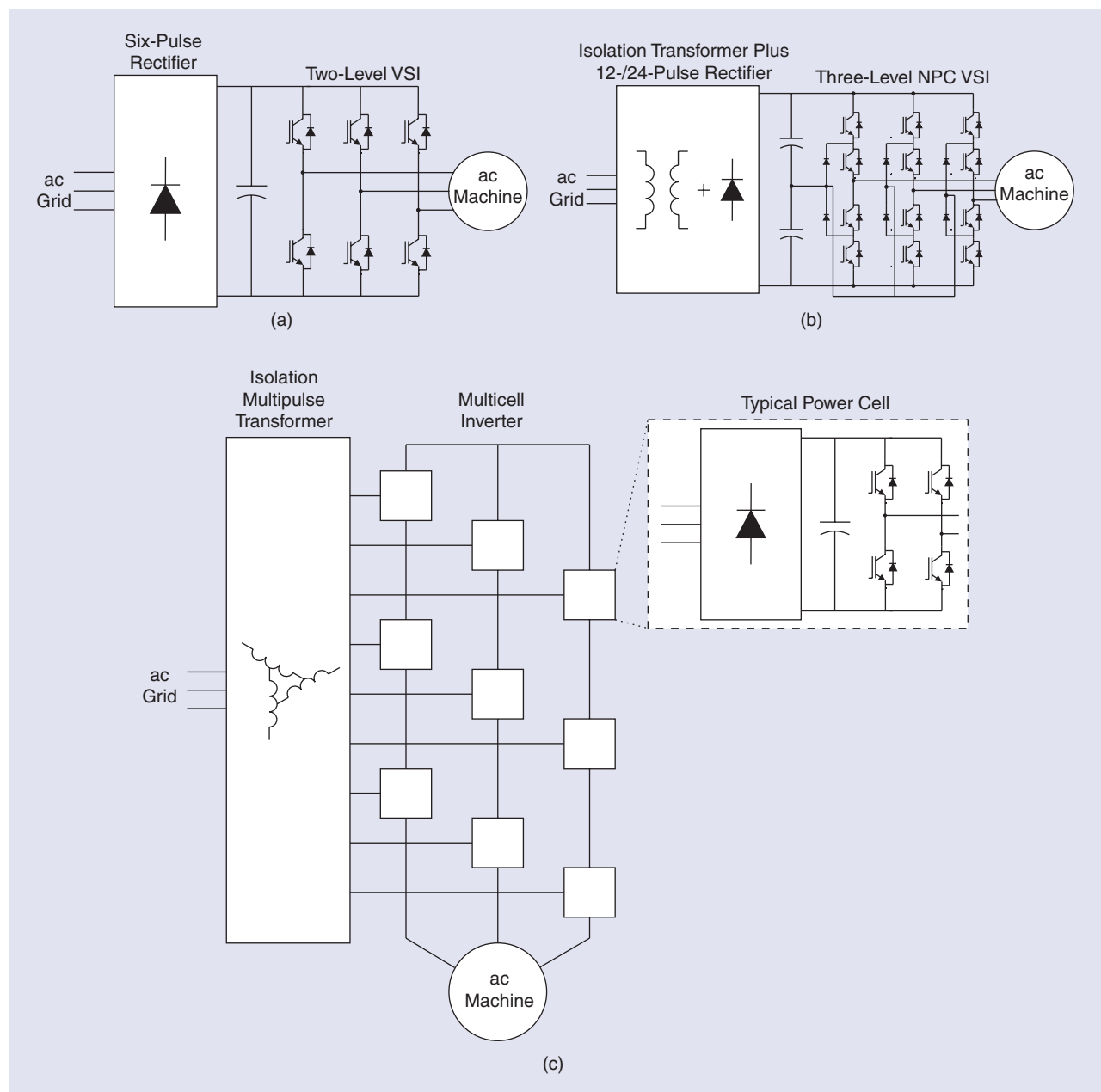
Figure 2. An WAF model of water usage in mining.

centrifugal, positive displacement, and specialized designs like slurry pumps, are employed to handle the diverse demands of mining environments. Proper pump selection and maintenance are vital for efficient and reliable mining operations. Moreover, as the different types of pumps found in mines have different characteristics and different demand profiles, duty cycles, and operating times, then, these characteristics may be integrated into the energy management of the entire mine site.

On the other hand, to obtain efficient pump operation, the typical solution is to employ a variable-frequency drive (VFD). A VFD adjusts the rotational speed of the motor to match the head and flow requirements of the

application, rather than running the pump at its maximum capacity regardless of actual demand. VFDs serve two primary purposes in energy efficiency. First, they can regulate an oversized pump by slowing down the motor, preventing unnecessary energy consumption. Second, in scenarios with varying duty demands, a VFD ensures that the pump operates at peak capacity when needed, while allowing it to run at lower speeds during extended periods of lower demand. This dynamic control optimizes energy use and minimizes waste.

The power converter topologies used in pumping VFDs differ depending on the power level. In the low-to-medium power range (up to a few hundreds of kilowatts), typically,



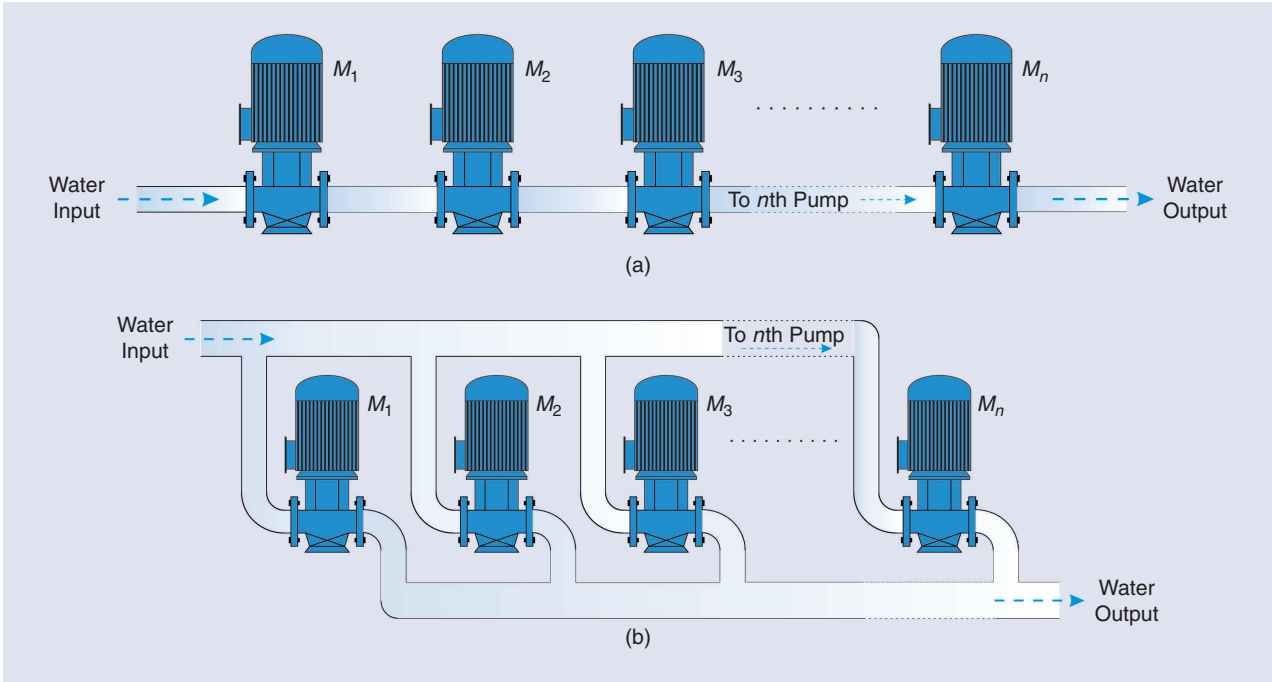
**Figure 3.** Examples of power converters used in pumping applications. (a) A two-level inverter. (b) Three-level NPC inverter. (c) Multicell inverter. VSI: voltage source inverter.

low voltage is used and the VFD is based on a two-level voltage source inverter. On the other hand, in high-power drives (above 1,000 kW), it is common to use a medium-voltage supply system, and multilevel inverters are preferred (e.g., three-level neutral-point-clamped inverters (NPC) and multicell topologies, among others). Figure 3 shows the typical power converter topologies used in variable-speed pumping systems.

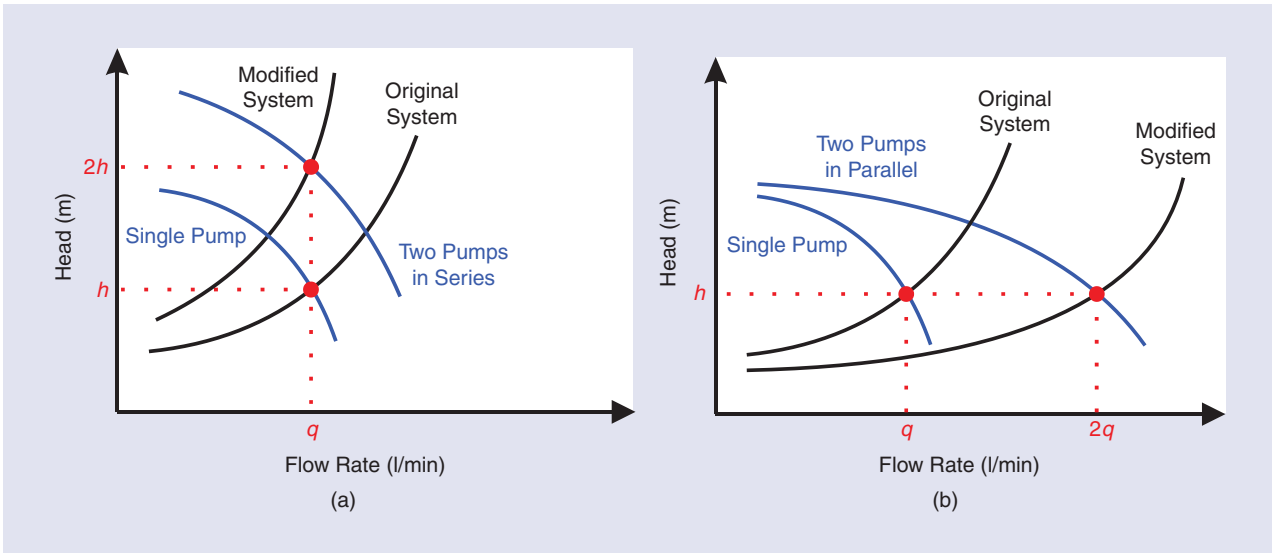
### Multidrive Pumping Systems

In the mining industry, some tasks could require important volumes of water or fluids to be transported long

distances. In such cases, a single pump is usually not enough to meet the requirements, and several pumps should be used. The pumps can be connected either in series or parallel, as depicted in Figure 4. In the case of series pumps, increment in the head (the maximum height that a pump can achieve against gravity) is obtained, whereas the flow remains constant. Opposite, in the case of pumps running in parallel, the flow will increase, but not the head. Figure 5 shows the operating curves of series- and parallel-connected pumps. Regarding the speed-regulation scheme, considering a system with  $n$  pumps, in series connections,  $n-1$  pumps usually run at



**Figure 4.** A multidrive pumping system. (a) Series pumps. (b) Parallel pumps.



**Figure 5.** Operating curves. (a) Series pumps. (b) Parallel pumps.

constant speed (directly connected to the grid) and one pump operates at variable frequency. In the case of parallel pumps, all of them are usually operated at variable speed.

In general, multidrive pumping systems offer a range of benefits. They can provide redundancy, ensuring uninterrupted operation, even in the event of a drive failure. The load can be evenly distributed among multiple machines, prolonging the life span of individual components. Additionally, they optimize energy consumption, adapt to fluctuating demands, and allow for easy adjustments in pumping capacity.

### Renewable Energy Integration in Mining Pumping Systems

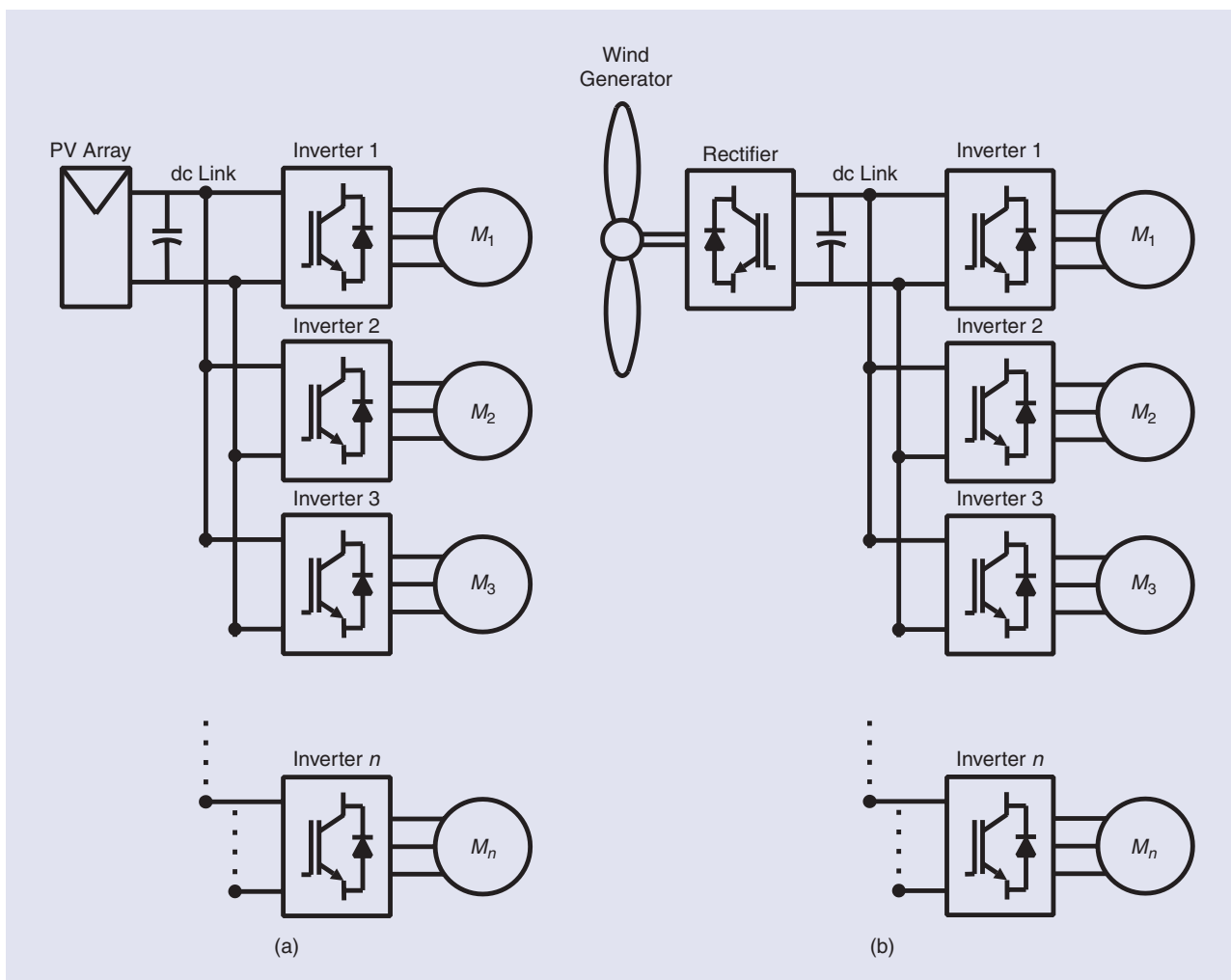
The integration of renewable energy sources in mining pumping systems marks a significant shift toward sustainability and environmental responsibility within the

**The power converter topologies used in pumping VFDs differ depending on the power level.**

mining industry. This transition involves the incorporation of clean, renewable energy sources to power the pumps used in various mining operations. The two key renewable energy options to be applied in mining pumping systems are solar photovoltaic and wind. The schemes of multidrive pumping systems supplied by solar and wind energy are shown in Figure 6. The main difference

is that a wind-energy-based pumping system will require a two-stage power converter; this is a rectifier (to convert the ac wind generator voltage into dc voltage) and an inverter (to convert the dc voltage into variable-frequency ac voltage), whereas a solar-energy-based system requires only the inverter stage because the energy generated by the photovoltaic modules is already dc.

However, the incorporation of wind and solar sources into pumping systems leads to a problem, which is that both generation systems are highly variable, and their



**Figure 6.** A multidrive pumping system. (a) Supplied by solar energy. (b) Supplied by wind energy.

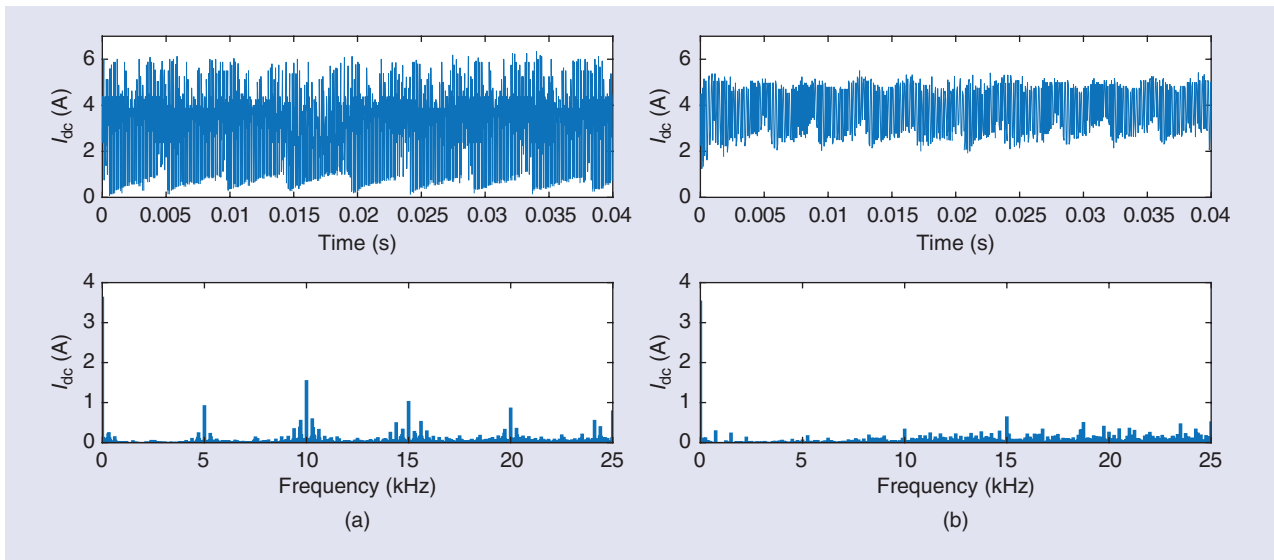
peak output does not necessarily line up with peak demand. Therefore, incorporating energy storage systems is a critical component for ensuring continuous pumping in mining operations when relying on renewable energy sources.

Energy storage serves as a buffer between energy generation and consumption. It allows excess energy to be stored when it's available (e.g., during sunny or windy periods) and discharged when demand is high or when renewable energy generation is low. The two storage options that best align with pumping systems are

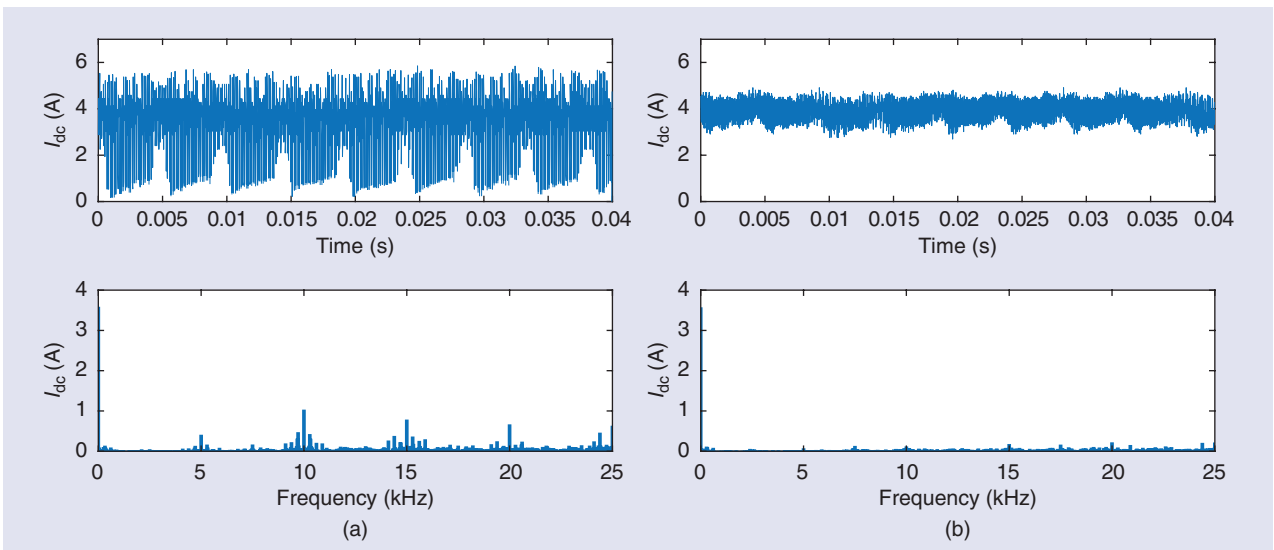
- ▲ **Batteries:** Lithium-ion batteries are commonly used for energy storage due to their high energy density, efficiency, and fast response times.

- ▲ **Pumped hydro storage:** This involves using surplus energy to pump water to a higher elevation, which can then be released to generate electricity when needed.

The size and capacity of the energy storage system should be determined based on factors like the energy demand of the pumping system, the expected variability in renewable energy generation, and the desired duration of continuous operation during low-generation periods. Energy storage should be integrated seamlessly with renewable energy sources. This involves using charge controllers and inverters to regulate the flow of energy among the renewable source, storage, and the pumping system.



**Figure 7.** Experimental dc-link current (top) and its frequency spectrum (bottom) for a system with three machines. (a) A conventional PWM. (b) PWM with phase shifting.



**Figure 8.** Experimental dc-link current (top) and its frequency spectrum (bottom) for a system with four machines. (a) Conventional PWM. (b) PWM with phase shifting.

## Operation of the Power Converters

In pumping applications, the control and modulation of power converters plays a pivotal role in optimizing performance and energy efficiency. Power converters act as intermediaries between the power source and the pump, allowing for precise control of voltage, current, and frequency. This enables the pump to operate at varying speeds and power levels, matching the specific demands of the application.

Control systems, which often incorporate microprocessors and advanced algorithms, oversee the operation of power converters. They continuously monitor parameters such as flow rates, pressure levels, and system conditions, and make real-time adjustments to the converter's output. This ensures that the pump operates at its most efficient point, minimizing energy waste and extending the equipment's life span.

Modulation techniques like pulsewidth modulation (PWM) are commonly employed. PWM controls power output by rapidly switching the voltage supplied to the pump. By adjusting the duty cycle of these pulses, the effective power delivered to the pump can be precisely regulated. Moreover, in multidrive pumping systems, it is possible to reduce the harmonic content of the dc-link current by phase shifting the PWM pattern generated by the individual inverters. This is verified with laboratory experiments as shown in Figures 7 and 8, where the dc-link current of systems with three and four machines are shown. The reduction of the dc-link current harmonic components is evident when the phase shifting of PWM carriers is applied.

## The Future of Mining Pumping Systems

The future of pumping for mining applications is poised for significant advancements, especially with the integration of renewable energy sources. Solar-powered pumping systems are expected to play a major role in mining applications. Advances in solar technology and decreasing costs of solar panels are making these systems increasingly attractive. They provide a sustainable and cost-effective alternative to traditional grid-powered pumps.

Hybrid pumping systems, which combine renewable energy sources like solar and wind with traditional energy sources, will become more prevalent. The integration of energy storage, such as advanced batteries, will become crucial for ensuring uninterrupted pumping operations. Energy storage systems can store excess

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energy generated from renewable sources, allowing for a consistent power supply, even during periods of low energy generation.

In conclusion, the future of pumping for mining applications, especially with the integration of renewable energy sources, will be characterized by a convergence of technological innovation, environmental consciousness, and a commitment to sustainability. These trends will not only enhance the efficiency and profitability of mining operations but also

contribute to a more responsible and environmentally friendly industry.

## Acknowledgment

The authors would like to acknowledge the support of the Chilean Agency of Research and Development through the Agencia Nacional de Investigación y Desarrollo (ANID)/Fondo de Financiamiento de Centros de Investigación en Áreas Prioritarias (FONDAP) project, Grant 1522A0006.

## For Further Reading

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