A white paper from Epiroc

How to solve the grid challenges and promote the electrification of mining operations

Authored by: Ritwik Majumder and Robert Saers

Epiroc

Executive summary

The electrification of surface mining calls for smart power management which in turn means that we must understand how electric surface drill rigs behave when connected to the electrical grid.

While this transition is a must, it does face several tough infrastructural challenges, including weak grids, remote grids, and grid contingencies. Besides the lack of good infrastructure, there are also issues when it comes to increasing the capacity of the grid. While renewable sources, like sun and wind, have the potential to add a lot of green capacity, they may face conditions where they aren't reliable. Furthermore, adding more power to the grid, even without capacity issues, will infer major capital spending. And operating MW-level machines in medium voltage distribution grids poses significant challenges.

To optimize the trade-off between increasing the available capacity in the grid and operating a profitable business, actors must learn how connected electric surface drill rigs behave. And how they must interact with other equipment in the mine to make sure the operations run as smoothly as possible.

In this paper we look at these issues, and how smart power management will help solve the challenges of peak power and energy requirements during the work cycles of the machines. Also, we point to how this matter is increasingly important as more and more mines are electrified.

Yet, while being highly challenging, we also show how power management is like a multi-tool that will optimize individual machines as well as aid in full fleet management. First and foremost, as a way to guarantee there is enough power to run the mining operations with the right reliability and predictability. Secondly, we will show how power management offers a straightforward way to cut capital spending by as much as 20% while significantly cutting operating costs.

And we stress how this must be a uniform action from everyone involved as this calls for two major changes:

1. All connected equipment must act to optimize the best overall result of the operations rather than trying to just maximize their part.

2. There must be a standardized framework for exchanging information between grid and machines to ensure that everyone speaks the same language and thereby secure the most energy-efficient and profitable operations possible.

Introduction

A well-known challenge, but on a much larger scale.

One of the main issues with electrification in mines is like one we face at home. We can run all our appliances, but using them simultaneously may blow a fuse. At home, this problem is resolved by flipping a switch. However, the consequences and solutions are much more complex in mines.

The analogy of blowing a fuse might seem silly, but it is valid. The risk of blackouts hinders electrification, and we must address this concern because the electrification of mining is essential for the green transition. This transition increases energy demands and has the added complexity of extremely varying demands. So, we must ask, how can we switch all these machines on without blowing a fuse?

This journey will have challenges, including mines located in areas with weak, remote, unreliable, and insufficient power grids. At Epiroc, we work tirelessly to enhance the energy efficiency of our rigs, ensuring that even the most challenging locations can be electrified.

A shared responsibility that benefits the entire world

At the same time, all stakeholders have a shared responsibility to optimize the electric infrastructure in and around mines. Advanced power management and standardized communications between equipment and the grid are needed, and a collaborative effort is required to switch from fossil fuels to electricity.

In this white paper, we explore the primary challenges associated with electrification in mining. While these may not be apparent today, they will require urgent attention as the pace of electrification accelerates.

It is worth noting that we see two different developments here. On the one hand, challenges related to electrifying machines will slowly reduce, while those concerning the power grid will increase.

Electrification is a global issue – and a must.

Connecting machines to the electrical grid profoundly changes mining, and such changes don't come lightly.

The enormous benefits of this shift are worth noting. There are numerous business advantages for mining companies, not the least of which are opportunities to enhance digitalization and automation, including power and energy optimization, that will significantly reduce operating costs.

For the industry, it's an opportunity to reduce its carbon footprint, which is essential considering the growing demand for metals and minerals. Extracting more while releasing less CO_2, for instance, is worth pursuing.

On a global scale, recurring challenges and hurdles must be tackled.

1

Significant capital investments. Electrification means costly upgrades to the electrical infrastructure and a new fleet of electrified machines and vehicles. Demonstrating how to optimize these investments is a must if they are to take place.

2

Some grids are in poor condition. The state of electric infrastructure varies around the globe. Even in countries with reliable grids, remote mines often struggle with limited grid capacity and poor reliability. It is essential to create the will to change.

3

Battery optimization
Batteries are quickly evolving, and there are constant improvements in terms of performance, service life, and longevity. Enhancing the productivity and profitability of battery-powered machines even more will greatly aid the electrification.

4

Upscaling production and business models.
All involved mining equipment manufacturers need to step up and provide electric alternatives. Upscaling must be finalized once the transition gains momentum to prevent lengthy delivery times. The industry needs to prepare and quickly adjust.

5

Bureaucracy and long planning horizons.
In a massive transition, the permit and compliance processes are complicated. Since most countries have their regulations, the global transition is rather a multitude of local ones. And the planning timelines are extensive. It can take years from the decision to electrify a mine until the project is completed. For industry players, it is essential to play the long game and have patience.

6

Machine performance
This shift is also about changing behaviors and mindsets. Electric machines must prove their worth by performing as well as or better than diesel machines to do that. Also, electrified and diesel machines will work side by side for the foreseeable future, which must be accounted for. Finally, and most crucial, machines must adhere to grid standards and operate in manners that support the grid.

Addressing local challenges will prove the benefits of electrification

For global acceptance, we must prove the case for electrification on a project-by-project basis. By illustrating to the world, especially prospective customers, how this transition results in improved business, a stronger competitive edge, and more sustainable operations, the industry can make significant progress.

There are three significant challenges to consider here.

Remote grids

Remote grids are like campfire versions of the national grid. Typically located in the wilderness, far from cities, major generation centers, or transmission infrastructure, they are unconnected to the national grid. They depend on their local power generation, including diesel generators and wind or solar energy, to operate.

Remote grids are common in the mining industry. They typically operate at low or medium voltage, while the national or regional grid is high voltage.

Consequently, remote grids have high fuel and maintenance costs; logistics and upgrades pose challenges, and redundancy and flexibility are limited.

Furthermore, due to the high energy demands of mining vehicles and equipment, being disconnected from the national grid complicates the ability to carry out mining operations with the right economics in a remote grid.

Weak grids

Weak grids are often found in remote or rural areas and places with aging infrastructure. Unlike remote grids, weak grids are connected to a national or regional grid. One might describe a weak grid as a nervous or anxious power system. When power is injected or extracted, the lights may flicker. There are voltage stability issues and high impedance, and the grid doesn't handle changes or sudden demands well. It is vulnerable to disturbances and instabilities—some have compared it to an old extension cord stretched too far. A way to indicate grid strength is the short circuit ratio, in other words, the grid's capability to supply fault current. In a weak grid, that capability is low.

Many weak grids have a high degree of renewable energy sources. While good, a downside of the weak grid is the lack of sufficient grid inertia and short-circuit power to ensure that power from solar or wind can be integrated without adding advanced power electronics or grid-forming inverters.

We must also acknowledge that solar power is limited on cloudy days. While we might enjoy a gentle breeze outdoors, grids require more than that to maintain a steady wind power supply. Thus, we must thoroughly evaluate how extensively renewable sources can be utilized to guarantee that operations can be kept on weak grids even when the weather is too good or bad to supply enough renewable energy.

Grid contingencies

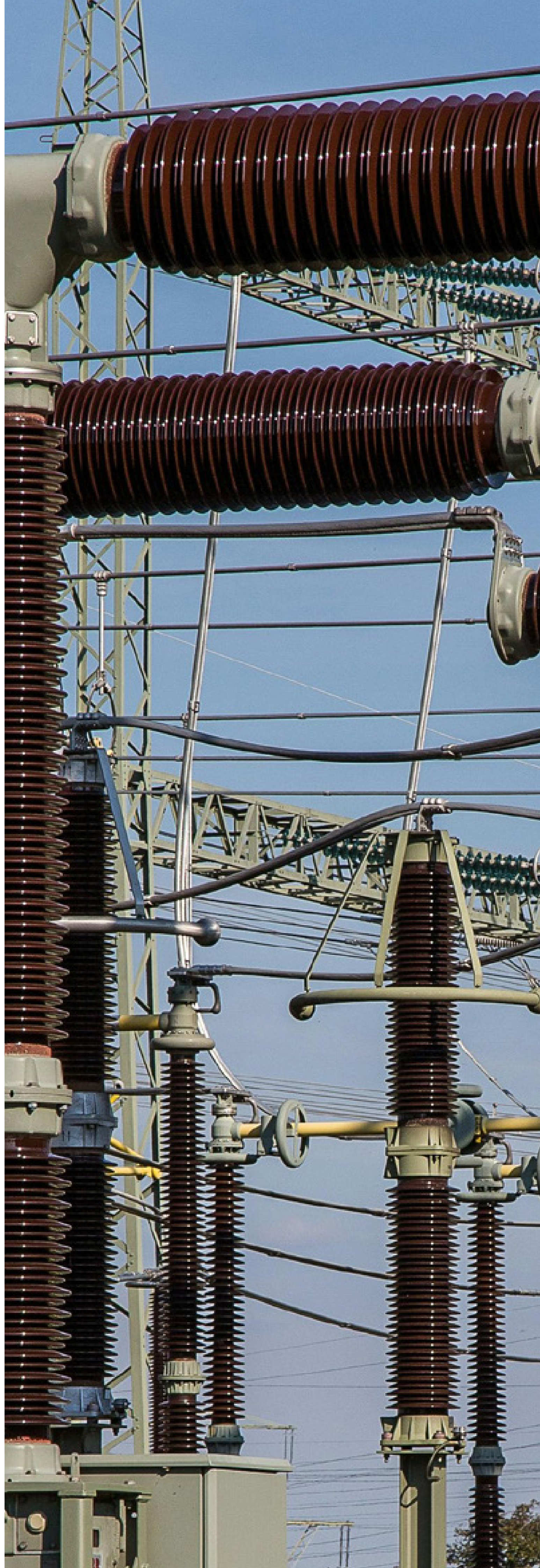
In simple terms, these are unforeseen events or failures that interrupt the electrical grid's operations. These range from generator outages and faults in transmission lines to transformer failures and significant increases or decreases in load.

It's imperative to have a contingency plan in place to ensure the grid's stability, resilience, and reliability, even if one major component fails. One must ask: what if something breaks? Then, of course, one should know how to handle all possible answers.

The stronger the grid, the easier this plan is to succeed. In layperson's terms, a strong and reliable grid offers several backup plans, enabling operation if one fails. In a weaker grid, fewer lifesavers exist, necessitating strict contingency planning with minimal room for error.

Three big challenges:

1. Remote grids
2. Weak grids
3. Grid contingencies



The machines show the way to the solution.

Ideally, all grids would be strong and stable; however, electrification efforts often encounter remote or weak grids and must account for various grid contingencies. Moreover, mining machines really test the grid.

When a machine starts, there's an inrush of current during energization. There's an instant and sharp peak in demand from zero energy consumption, which can be a few times the machine's rated power. Although not as high as the inrush, the drilling process requires high power. In contrast, the energy needs are significantly lower when machines are idling, tramming, or changing rods. Mine owners must choose the power capacity of their network. Should they invest in a grid that can manage peak demands or accommodate the average consumption? As a baseline, the grid mustn't collapse when the machines start, and operational stability must be ensured regardless of varying power demands from machines.

To complicate matters further, a mine has numerous and different types of machines. Starting and operating them simultaneously will lead to extreme peaks, followed by significant drops in power demand. Therefore, deciding whether to invest in an infrastructure that accommodates all peaks or average consumption is crucial.

The key: choosing the best way forward
While this might seem disheartening, it is the first step toward solving the grid challenges. Admitting the physical limitations of the current grid, looking at what can technically be done, and conducting a thorough financial assessment are steps that help mining companies make the right choice.

Investing in infrastructure that allows for the whole operation at any time incurs a high capital expenditure. Furthermore, this choice leads to high energy consumption and higher operational spending. Thus, the obvious question is: will we achieve the right revenue streams and profit margins this way, or should we make a different choice?

That insight and clarity are instrumental in making the right decision and acting upon it to address the grid challenges and optimize operations from every possible angle.

> *Operational stability must be ensured regardless of varying power demands.*

The primary key – advanced power management

Machines require power and face limitations from the power grid. Operators' optimization of these processes is known as power management, and like any form of management, it can be good or bad.

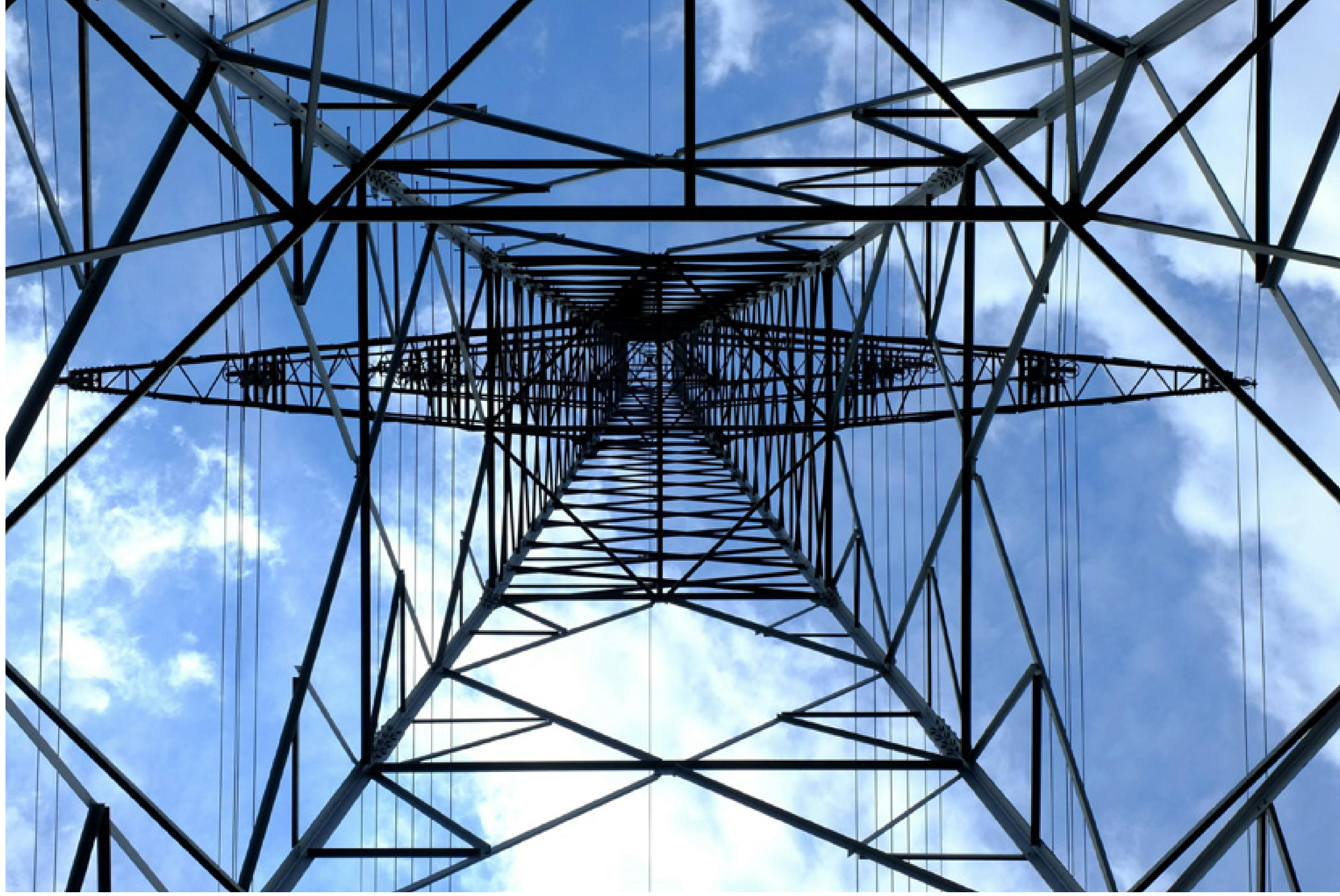
First, let's define what it isn't. If you can't provide enough power and turn a machine off, you use no power, and the machine doesn't operate. While that action eliminates power consumption, it doesn't relate to power management. You're just pushing the problem in front of you and losing revenue.

Instead, consider power management as a staircase. You must climb it, as staying on the bottom floor leads you nowhere. Naturally, the higher you get, the better.

- The simplest power management move is to delay. Here, you assess the operations and postpone some peaks to even out consumption. That hurts some of the production and some functions.
- Delaying does not resolve the issue, so the next step is maintaining operations while adjusting, for example, drilling with slightly less force and applying less torque. While not a complete operation, it is a significant improvement over delaying.
- Ideally, you can opt for advanced power management, where active and reactive power are optimized together. In brief, you obtain active power from the grid to operate your machine. Then, you can use converters and reactive compensators like capacitors in the machine to control voltage and inject reactive power. This enhances power flow capacity, stabilizes voltage levels, and improves operations overall. Both are already installed in Epiroc's machines.
- Then, you must go from doing this for one machine to overseeing the entire fleet. Depending on the grid and the desired and feasible energy consumption levels, you must determine how all machines should be managed. Perhaps one or more are critical and should be allowed to operate at full capacity, while others can function with delays or at reduced power.

The key? Finding the trade-off between productivity and power consumption.

The four steps of power management;
Delaying
Adjusting
Advanced Power Management
Fleet Level Power Management



Finding the right grid integration is essential

To achieve the appropriate machine functionality for power management, we need to follow a four-step grid integration process:

Grid monitoring: This is a status check of key parameters. In the event of a problem, we can perform a basic rescheduling of work cycles should the grid be unavailable due to an outage or insufficient power.

Grid relieving: Here, we actively adjust the timing of machine operations to ease the burden on the grid during contingencies that stress it. Two clear examples are delays in machine starts and shutdowns. Doing so makes it easier for the grid to manage the load better.

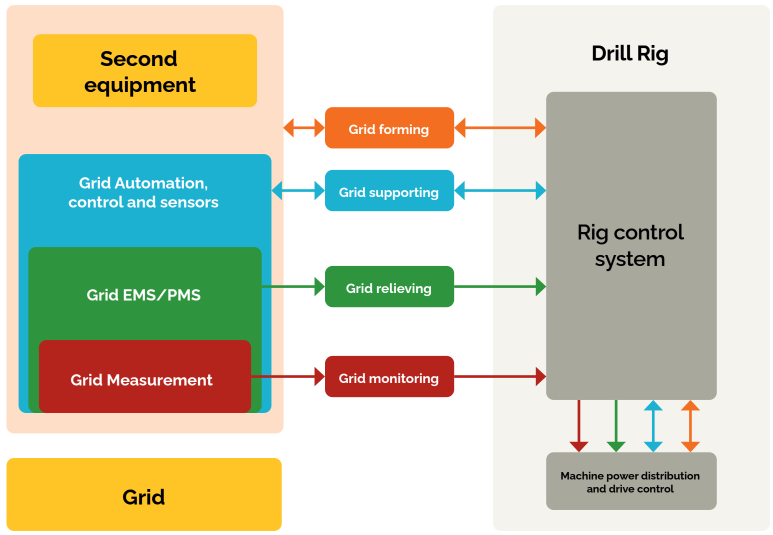
Grid support: We enhance the grid by utilizing various dynamic and steady-state functions for ride-through, constraints, and optimizations. This is achieved through smart controls that respond to grid variations and help.

Grid forming: We form and sustain a grid system with voltage and frequency control participation. This represents the highest level of integration, as we actively generate and uphold the fundamental flow of electricity, ensuring the system remains balanced and reliable.

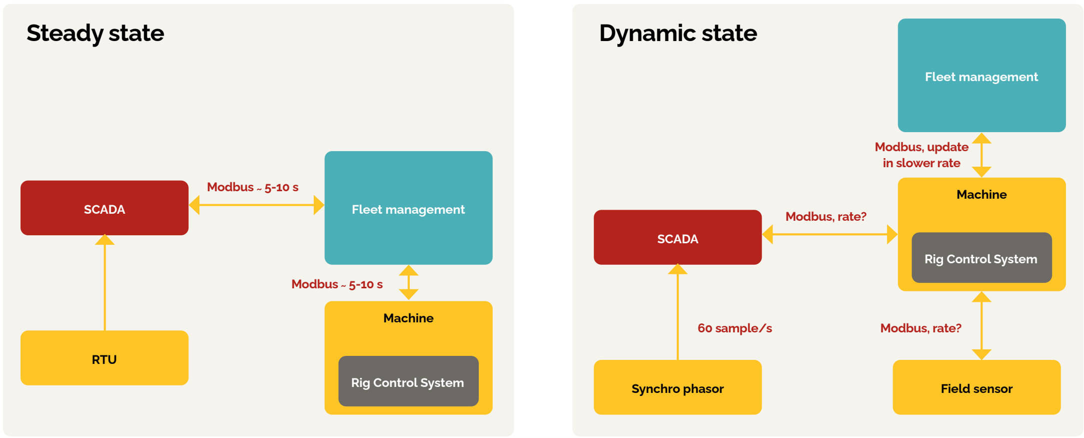
What grid integration looks like (schematics)

The embedded diagrams show how deeper integration pays off, but also requires more from us. The last diagram shows an alternative structure for integrating machines with SCADA and fleet management. Worth noting is explicitly:

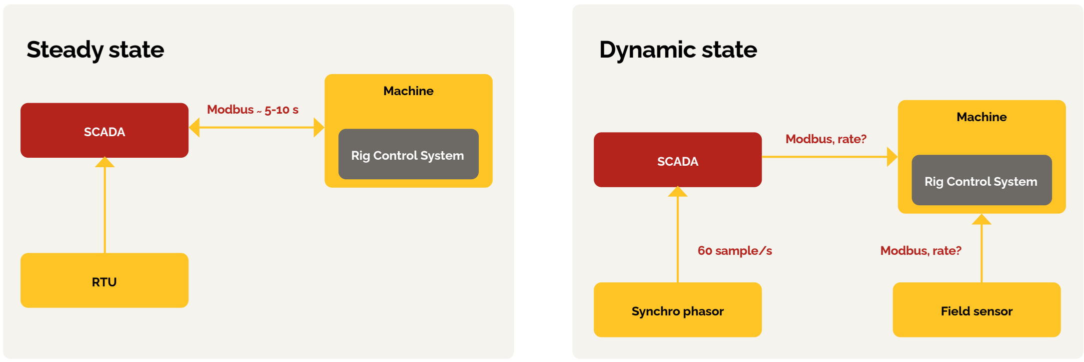
- When you integrate the machine with SCADA and fleet management separately, there is no need for any upgrades to the fleet management. However, only a machine with SCADA integration will implement the functions. Therefore, your machine becomes more competitive faster, but the impact remains limited.
- When you integrate SCADA into fleet management and machines with grid integration functions, you must add a new SCADA function to the fleet management system. This will provide new machines with grid-integrating functions, while others will use fleet manager commands. However, the impact is limited without an upgraded fleet management system.
- With direct SCADA integration into fleet management and machines, a new SCADA function is required for fleet management. The new machine will feature SCADA-integrating functions. While it's a more protracted and costly path, this solution is significantly more future-proof and, therefore, a better investment when feasible.



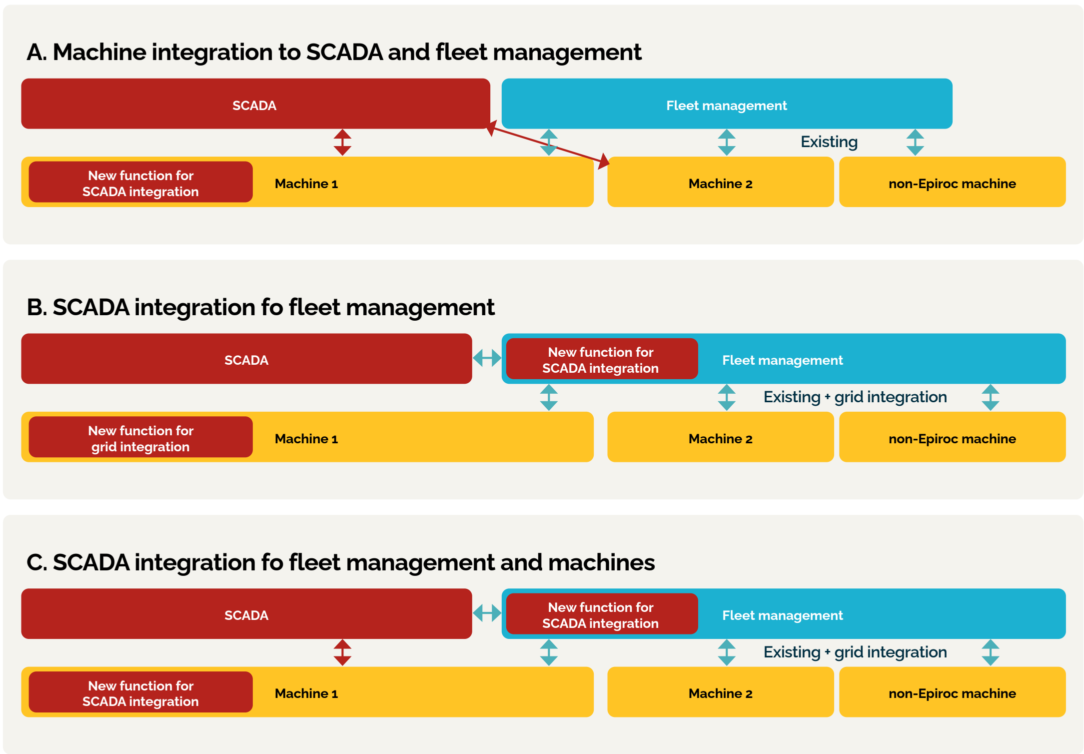
This figure represents different level of communication required for various degree of grid support e.g. monitoring need only grid measurement while grid relieving includes grid measurements and information from energy/ power management system.



Here, we see the measurement from a remote terminal unit to SCADA and then to the machine control system in steady and dynamic states. While SCADA handles steady-state quantities, retrieving dynamic changes from the grid to the machine through SCADA is harder.



This illustration shows how the fleet manager communicates from SCADA to the machine.



Here, we see an alternative structure for grid integration, in which we gradually move from a more limited integration (A) to a more profound and complete one (C).

Power management has financial upsides, too.

Power management ensures reliable, safe, and predictable operations that can handle peak power demands while maintaining a stable electricity supply.

However, power management is also the right choice for running more cost-efficient and profitable operations in the future. Electrification requires significant investments, as is evident from this short list*:

- Capital spending in the distribution system increased by 160 percent from 2003 to may 9 2023, with over a fifth occurring in the last year alone.
- During those same twenty years, investments in overhead lines, poles, and towers surged by 220 percent, while underground investments doubled.
- Investments in line transformers increased by 23 percent from 2022 to 2023.
- Substation equipment has increased 184 percent since 2003, and infrastructure on nearby customers' properties has increased by 84 percent.

Without being overwhelmed by numbers, we can summarize this as multi-billion-dollar investments with a sharply growing need for investment.

*) Reference: Grid infrastructure investments drive increase in utility spending over last two decades - U.S. Energy Information Administration (EIA) https://www.eia.gov/todayinenergy/detail.php?id=63724

Six reasons why power management pays off

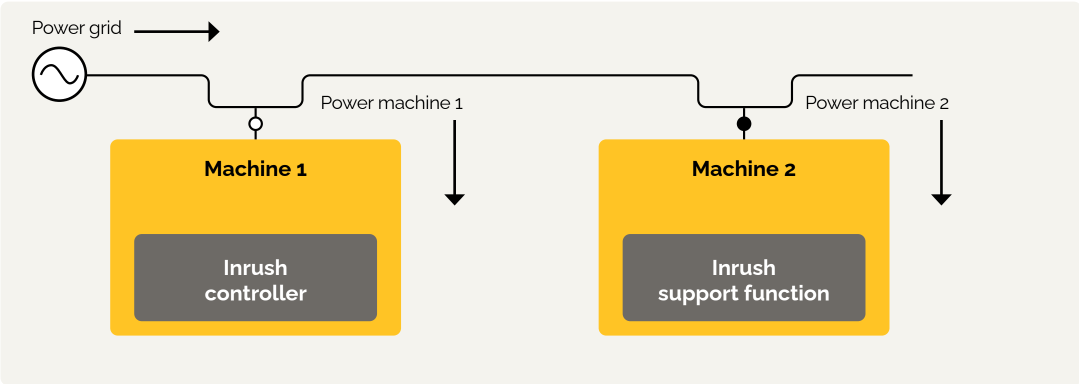
Power management is essential for addressing peak power and capacity issues and equally crucial to mitigating financial and cost-related peaks that may hinder electrification.

What this means in the grid is a better overall possibility for power management to pay off:

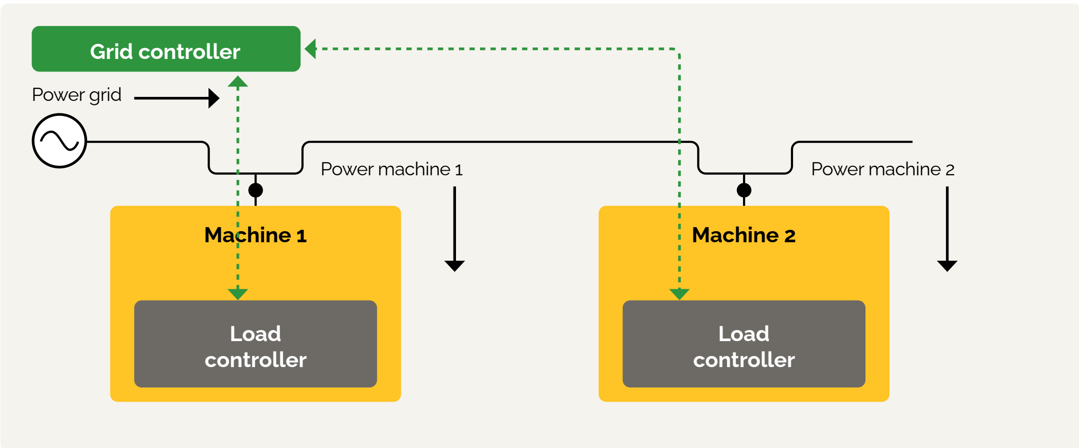
1. There's a **better power balance** to face power demands through generation and load management.
2. It **optimizes the power flow** continuously through changing generation and loads.
3. It improves **grid stability** by maintaining voltage with reactive compensation.
4. By prioritizing the power supply to critical operations, there is **excellent grid reliability.**
5. Coordinating Distributed Energy Resources (DERs) and active loads means **active grid control.**
6. Through proper voltage management and loss reductions, there will be a **significant reduction in operational costs.**

Every machine matters

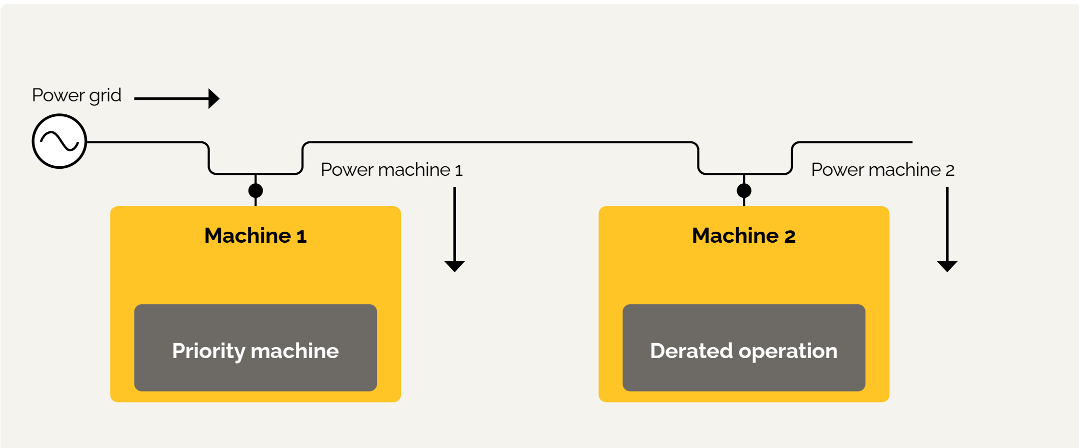
When turning to individual machines, we also see that power management adds to a much-improved cost side of operations by optimizing these areas and actions.



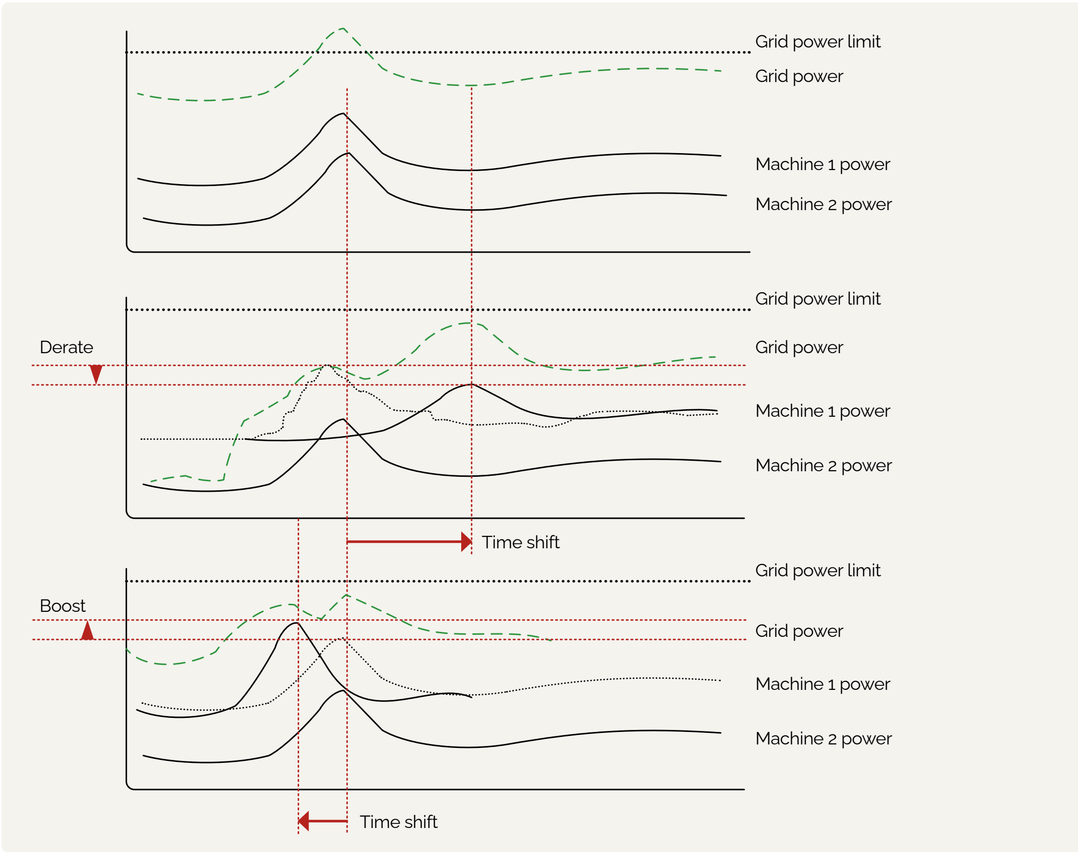
Inrush: Controlling this action when connecting and supporting other machines keeps the system stable in weak grids.



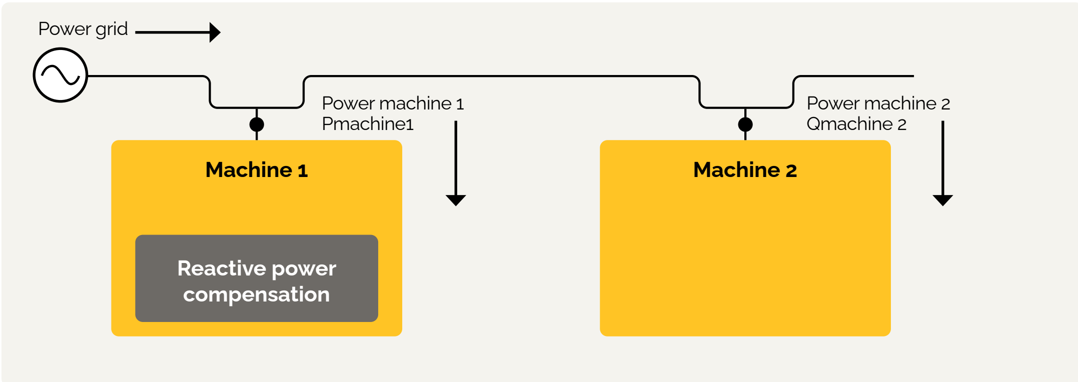
Load management control: New load connections are controlled through available generation and spinning reserves.



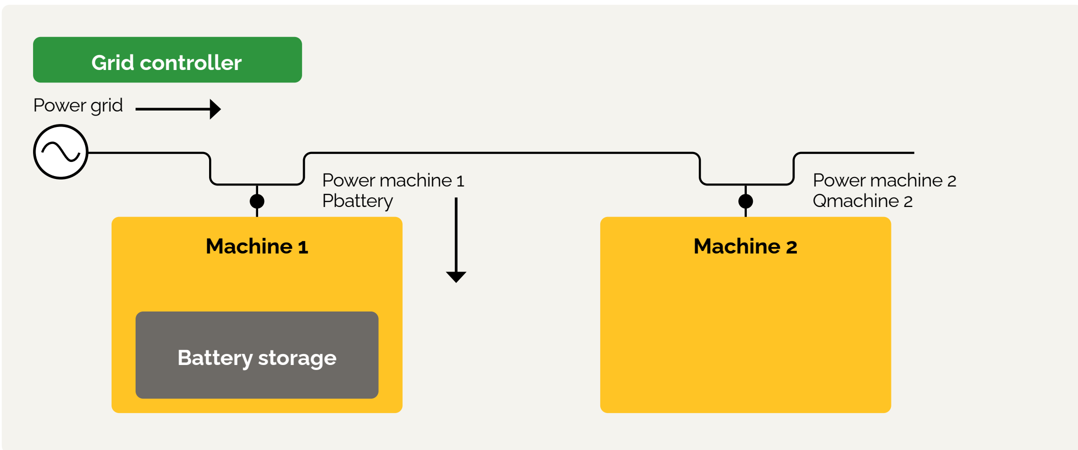
Power demand: By prioritizing and derating functions, you keep the power demand within grid capacity.



Peak power: By controlling this, it's easier to plan the use of multiple machines.



Reactive support: A double win here, as it reduces loss and enhances power capacity.



Storage: Using battery storage, we can perform peak shaving during high loading.

Putting it all together – a power management use case from a surface mine site

The basic electrical data
- Utility transformer: 22.9 KV / 7.2 KV 12 MVA
- MV line and machine supply: 7200 +/- 5% , 60 Hz
- Epiroc machine: Drill machine with induction motor, 1400 HP, 104.8 FLA, 1800 rpm
- Epiroc other machine option 900 HP 700 HP

Other machine in the same bus :
- Shovel 1: Average power demand 800-1200 kW, peak power 3400 kW, 7200
- Shovel 2: 2800 KVA, 7200 V, peak power 2100 kW
- Shovel 3: 3800 KVA, 7200 V, peak power 3000 kW
- Drill 1: 500-750 kW, 7200 V, peak power 750 kW
- Drill 2: 750-1000 HP, 7200 V, peak power 1000 HP

The total peak power is nearly 10,000 kW – which is close to 12 MW apparent power, i.e., close to the grid capacity.

We also have some power quality requirements:
- Voltage Variation +/- 5%
- Sudden Frequency Variation +/- 1 Hz
- Sustained Frequency Variation +/- 0.6%
- THD +/- 8%

What we know

Enhancing capacity, interconnecting, and upgrading the grid maintains power quality. By utilizing grid strength sensitivities, voltage and reactive compensation are achieved, and through various equipment functions, we will realize improvements in THD and the full impact of the machine.

The peak power requirements are nearly at full capacity. The feeder line must be at least 7 MW, while the transformer needs 12 MVA. To meet these requirements, we need to increase capacity. However, this is costly; we can lower those costs with smart machine functions and further by incorporating power management features into both the distribution grid and the mining machines. By adding new machines (4 MW), we need to upgrade the grid for an additional 5 MVA.

List of abbreviations

CO2	Carbon dioxide
DER/DERMS	Distributed Energy Resources/ Distributed Energy Resource Management System
FLA	Full Load Amps
Grid EMS/PMS	Grid Energy Management System/Power Management System
HP	Horsepower
KV	Kilovolt
kW	Kilowatt
MVA	Megavolt-Amperes
MW	Megawatt
Rpm	Revolutions Per Minute
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
STATCOM	Static Synchronous Compensator
THD	Total Harmonic Distortion

Here's how power management cuts these costs by 20%

Below is the assessed cost for upgrading the grid and how optimizing the mining machines can influence that.

	Capacity/ thermal upgrade	Voltage upgrade	Power quality upgrade	Reliability upgrade	Protection upgrade	Connectivity upgrade	Grid control upgrade
	Substation transformer	Capacitor bank	Phase balancing	Energy storage upgrade	Relay protection upgrade	SCADA	DER/DERMS
	Feeders (number and or rating)	On load tap changer	Distribution STATCOM	Smart inverter upgrade	Reclose upgrade	Communication	Microgrid
		Line voltage regulator		Load management			Deman response
Mining machine	Peak power limit	Reactive support	Compensation	Flexible operation/load management		SCADA integration	Load control

Here's a rundown of where power management has an effect*

Capacity/ thermal upgrade	Voltage upgrade	Power quality upgrade	Reliability upgrade	Protection upgrade	Connectivity upgrade	Total upgrade
New substation transformer $175k x 2	Capacitor bank $10k		Load management $5k	New Relay protection $20k	SCADAM & Com-munication $5k	Total ~ $450k for one extra machine during expansions
New feeder for 4km $5x4000=20k	Line voltage regulator $15k			New Recloser $25k		New substation $15-25k per MW $300-500k for 20 MW station
						$6000-10000k for 400 MW grid

By reducing peak power by 20%, we can reduce the grid infrastructure costs by $1,200,000-2,000,000.

*) Reference: 20220208 PSC Item 05c Transmission Cost Estimation Guide for MTEP22_Draft622733.pdf
https://www.eia.gov/todayinenergy/detail.php?id=63724

We must all work toward the same goal

While this white paper comes from Epiroc, we don't exist in a vacuum. Yes, our machines are perfectly integrated for seamless collaboration. However, numerous vehicles, machines, and other equipment consume electricity in a mine.

Advanced power management must consider this to optimize operations and cut capital spending in the grid. Simply creating energy-efficient machines is insufficient. Our equipment must communicate and interact with all other units to optimize and balance overall power consumption, and naturally, even out peaks and other occurrences that might cause outages or situations with insufficient power supply.

The same applies to batteries. We need to coordinate charging to minimize costs and disruptions. Optimizing the charging sequences of all machines produces a significant advantage. This enables batteries in vehicles to handle peak demands, known as peak shaving, which further reduces the burdens on the electrical grid.

It's in everyone's interest that everyone wins.
This interaction is essential for ensuring the right return on infrastructure investments and lowering the total cost of ownership while maximizing output. The former is especially important given the quickly growing need for electricity. Put simply, we must be smarter than just adding electricity; we must use what we have and can realistically and financially add in the smartest possible way.

Another sweet spot is improved power quality. When the grid experiences fewer contingencies, the voltage becomes more stable and consistent, which results in more efficient machines. Therefore, with more active and intelligent power management, you will receive more power for less. It's better, cheaper, and there will be a reduced footprint too.

While advanced power management is indeed crucial, the alternative is quite dire. There will be grid failures, more machine standstills and breakdowns, increased maintenance costs, and more volatile business dealings.

Standardization makes the transition easier

Maximizing the efficiency of all equipment that consumes electricity requires standardized interfaces. All units must always have a complete understanding and interaction to optimize their collective usage. Let's compare it to us humans. We can't understand each other if we all speak our languages. We might get the general idea, but won't understand the delicate nuances and details. So, to avoid getting lost in translation, power management relies on one universal language.

Because even the most intelligent machine won't make a difference unless all parties step up, we can save or adjust power consumption on a single machine independently, but this has a minimal effect on the grid unless all energy consumers communicate effectively and seek the big win rather than focusing on individual accomplishments.

It's time to end the waiting game.
Currently, this is a waiting game. The technology is new, and taking the first step may temporarily harm an actor's productivity and competitive edge.

We, as an industry, need to be brave here. It will be a testing and tough leap, but without it, we won't fully convince our clients or society to embrace electrification.

By collaborating within and across industries, we enhance opportunities to evaluate the need for new or upgraded infrastructure. We also optimize operations based on the varying conditions of grids.

If actors go it alone, we face a suboptimal future where we can't reap the full benefits of electrification and demonstrate how this transition is good for the planet and individual businesses. The use case shows real possibilities. Every graph shows an opportunity to progress without being stopped by an insufficient grid. Still, they also show the need to work together.

Where there's a will, there's a way.
While each machine is an individual unit with proprietary features, we must find a unified way to exchange information with the grid and all connected equipment. This call is aimed at everyone but should, at a minimum, attract mining OEMs, other manufacturers with operations in mines, and grid customers who own mines.

The result of our collaboration should be a standardized protocol for grid integration concerning electrified mining equipment, along with a plan to facilitate this change. There are technological challenges, but honestly, they will be resolved. More importantly, gaining traction for this transition is rooted in the adage: where there's a will, there's a way.

Electrification is the future; the only ones holding us back are ourselves. We need to accept that what ultimately serves us best is coming together with our key competitors. This collaboration makes us stronger and more capable of providing the world with far greater electrification possibilities than the current state of the grids would suggest. **And that's a good start.**

It's in everyone's interest that everyone wins.

With this white paper, Epiroc hopes to initiate talks, collaborations, and exchangings of ideas and thoughts with key customers and other stakeholders.

Our hope is to build on this by adding relevant use cases and find a united path toward a new era where we futureproof the electrified mining machines and optimize the infrastructure requirements.

All to make the transition from fossil fuels to electrification in mining as smooth as possible.

Epiroc

epiroc.com