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IT'S A MATTER OF CONTROL: **MANAGING HYBRID POWER SYSTEMS**

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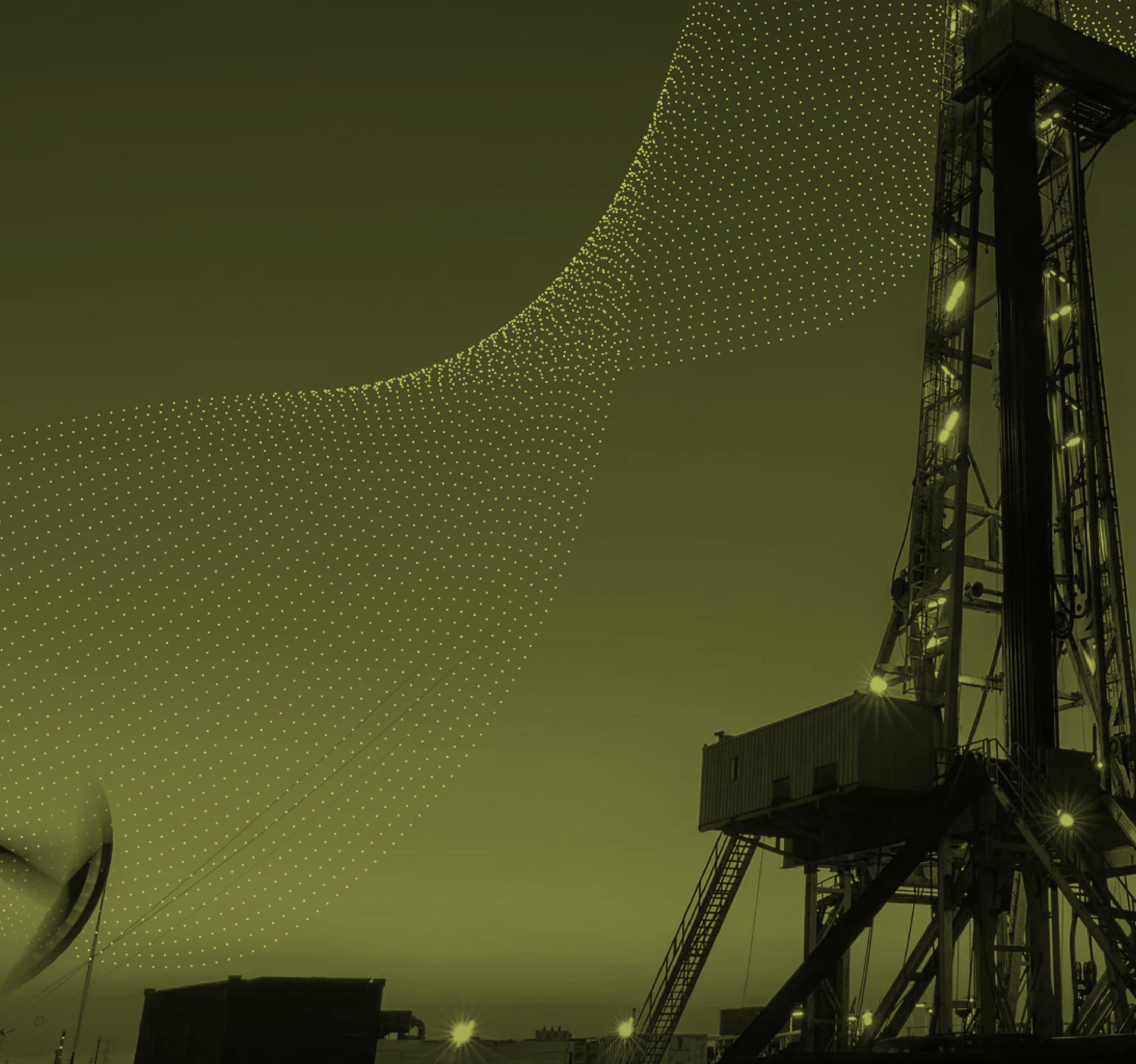

As power systems continue to evolve in complexity, particularly in maritime and industrial applications, the job of integrating the various technologies into one system becomes more complex. These systems, such as microgrids and hybrids, incorporate many different sources of power and subsystems, which require a hierarchy of control systems to manage the larger system as a whole.

The three main control platforms are the Energy Management System (EMS), the Power Management System (PMS) and the Battery Management System (BMS). Our purpose today is to explore the coordinated, if often misunderstood, roles each plays in an effective hybrid power system.

Every battery system has some form of BMS, even your phone. That battery icon that tells you that you have 2% power remaining? That's the BMS. Energy Management Systems are an increasingly common term in stationary, microgrid and utility-connected systems, and realistically any power system that is performing tasks like synchronization, coordination and load sharing is using a PMS. A quick run-through of a bit more detail of what each of these systems actually does and is responsible for will help provide some clarity.

BMS -- BATTERY MANAGEMENT SYSTEM

The function that the BMS performs is often misunderstood. Among the many misconceptions surrounding battery management systemssome of the most frequent notions are: The BMS is a complex protection scheme for the battery; the BMS is an element that channels all power to and from the battery; or the BMS is a trivial component -- simply looking at voltage and opening a contactor. Yet none of these is really an accurate description of the role or importance of the BMS.

An effective BMS has three primary functions:

- ***Monitoring and providing information*** to the outside world about battery status and proximity to limits.
- ***Indicating complex algorithms*** such as State of Charge (SOC), which is the remaining electrical ENERGY left in the battery, and State of Health (SOH), which is the difference between a used battery and a fresh one.
- ***Maintaining and taking care of each cell*** -- balancing each individual cell's performance relative to adjacent connected cells.

Ultimately, a battery system is really just a plain DC voltage source, and the BMS doesn't change that. The BMS monitors what's going on inside the battery and communicates with the other elements of the overall control system (e.g. EMS or PMS) about the battery's status and capabilities. Often the BMS does have control over contactors or breakers to isolate the system in the case of a problem or if system parameters fall out of bounds. But basically the BMS is looking at the thousands of sensors within the battery and amalgamating that information to tell the other systems about the battery's status so that they can decide how much or when to charge or discharge.

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COMPLEX ALGORITHMS SUCH AS SOC AND SOH

State of Charge (SOC) is the amount of charge in a battery – it's like a fuel gauge. Calculation of this parameter is highly sensitive -- particularly to aspects such as temperature and voltage. And to further complicate matters, these parameters and the overall ability to determine SOC are greatly complicated while current is flowing -- not to mention in the frequent case that current is flowing quite continually.

An industrial battery is a collection of hundreds, if not thousands, of individual cells. Each cell has its own state of charge and the BMS's job is to accurately consider, calculate and report how full or empty the battery is as well as other associated limits that should dictate when charging or discharging should stop.

All batteries degrade over time. State of Health (SOH) measures how much health the battery has left, how much it has degraded. SOH is what percentage (most typically of energy, i.e. kWh) is available today relative to when the battery was new.

The BMS is so important because it helps get the most out of the battery and ensures it is done safely and consistently. Any battery's cell chemistry and design provides a level of capability; each cell is slightly different and must be monitored and managed closely. The BMS is the system that ensures we are able to maximize the greatest amount of each cell's total performance envelope -- that the limits or thresholds of the overall system or of a single cell do not limit the ability or function of the overall system or impact safety.

> *A battery is only as strong as the weakest link in the chain.*

In essence, a battery is only as strong as the weakest link in the chain. If one cell is weakened, the others connected to it are only able to operate within that weak cell's capability. The BMS helps us maximize and nominally predict and manage that.

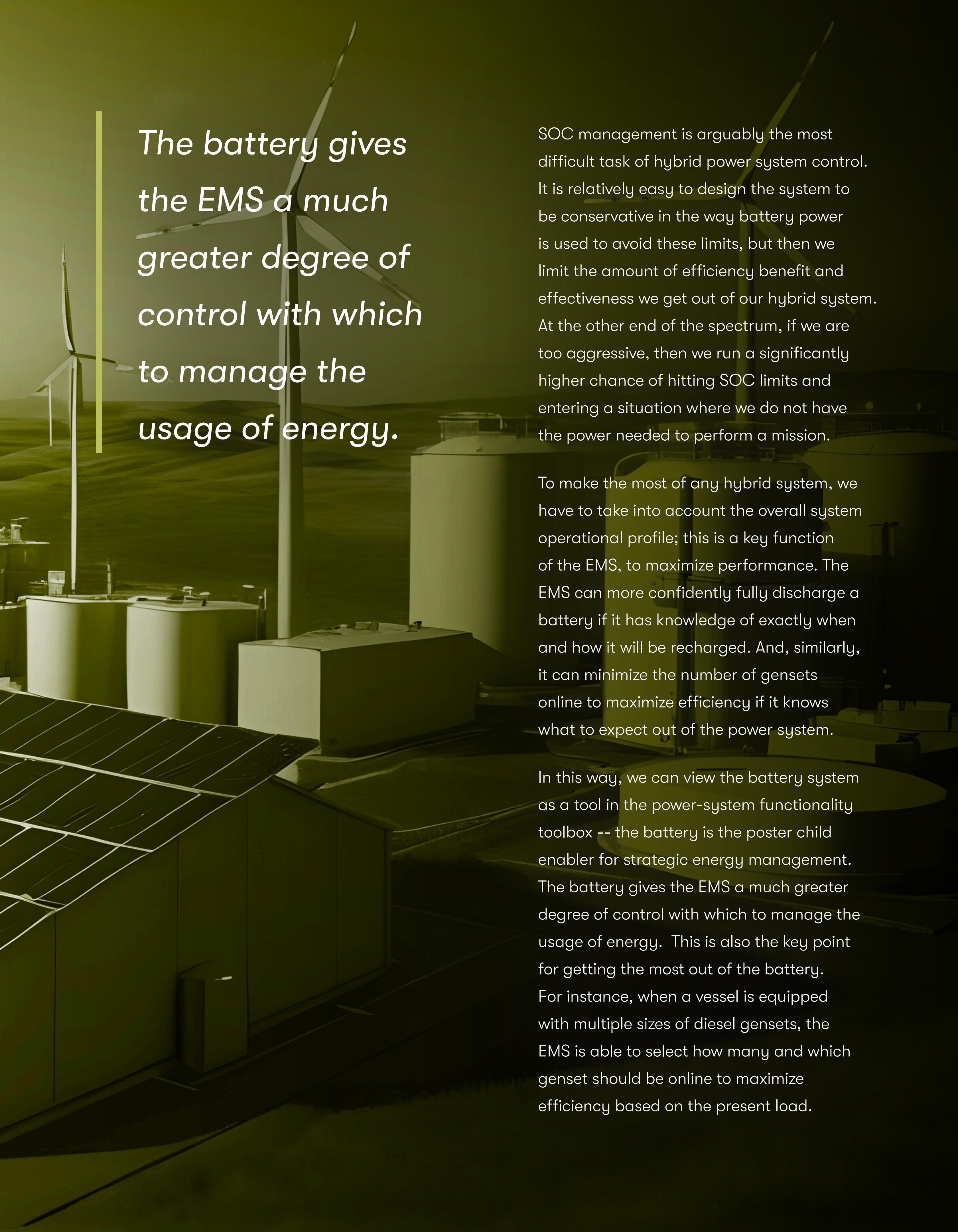
Importantly, the BMS is the operator's only real touchpoint with the battery. The battery itself, to the outside world, is really not much more than a DC voltage source. The other systems that interface with the battery do so through the BMS.

Given all of that complexity, we like to say that it's easy to build a BMS, but it's very very hard to build a good BMS.

EMS -- ENERGY MANAGEMENT SYSTEM

The Energy Management System manages the flow of energy between power sources and electrical loads. With the proliferation of batteries the EMS has evolved tremendously, since it essentially decides how and when a hybrid power system uses different power sources to ensure minimum fuel consumption and effective use of the batteries without hitting limits and hindering the total system capability. So for a system that integrates gensets, solar panels and batteries, the EMS decides when to pull power from which source; when to pull additional sources online, say during peak load times; and when to take sources offline, say when peak load dissipates. The EMS essentially optimizes the entire system for efficiency by optimizing each component piece.

One fundamental function of the EMS, and one that is particularly indicative of what it does, is SOC management. An accurate calculation of SOC is a key function of the BMS, but the EMS is responsible for deciding when we charge and discharge the battery relative to the use of other power sources; this ensures that we avoid situations where we need more energy out of the battery but it is at empty, or likewise we need the battery to accept charge but it is at full.



The battery gives the EMS a much greater degree of control with which to manage the usage of energy.

SOC management is arguably the most difficult task of hybrid power system control. It is relatively easy to design the system to be conservative in the way battery power is used to avoid these limits, but then we limit the amount of efficiency benefit and effectiveness we get out of our hybrid system. At the other end of the spectrum, if we are too aggressive, then we run a significantly higher chance of hitting SOC limits and entering a situation where we do not have the power needed to perform a mission.

To make the most of any hybrid system, we have to take into account the overall system operational profile; this is a key function of the EMS, to maximize performance. The EMS can more confidently fully discharge a battery if it has knowledge of exactly when and how it will be recharged. And, similarly, it can minimize the number of gensets online to maximize efficiency if it knows what to expect out of the power system.

In this way, we can view the battery system as a tool in the power-system functionality toolbox -- the battery is the poster child enabler for strategic energy management. The battery gives the EMS a much greater degree of control with which to manage the usage of energy. This is also the key point for getting the most out of the battery. For instance, when a vessel is equipped with multiple sizes of diesel gensets, the EMS is able to select how many and which genset should be online to maximize efficiency based on the present load.

PMS -- POWER MANAGEMENT SYSTEM

The PMS is the "oldest" of the three management systems and has been around for decades. The most advanced Power Management Systems include energy management functions but still focus on keeping the power on and not on how to use that power efficiently. The PMS is responsible for coordinating all functions of the electrical power system, matching supply with demand and providing all necessary synchronization and protection. The PMS sends start and stop signals to all gensets, it manages faults and reduces loads when reduced power is available. It is responsible for load sharing, blackout prevention and paralleling. The PMS will have direct visibility and control over all loads and sources. If the EMS is a supervisory control system that determines preferred configurations and power levels, the PMS is responsible for all of the low-level signals and sequences necessary for executing and managing those configurations and power distributions.

In its simplest form, a PMS starts and stops a genset to provide power to a stand-alone system. As complexity increases, and the system incorporates several gensets, solar panels, wind turbines and batteries, the power management system protects the individual power sources from things like overload, reverse power, over- and under-frequency, etc. (ANSI protections).

In addition to protecting individual power sources in systems with a variety of power sources, the PMS is responsible for functions like load sharing, synchronization, parallelling and blackout prevention, typically with the focus on keeping the busbar "alive" more than how the power is used. Specific applications call for specific features like ensuring you never blackout a system, exporting a certain amount of power from a power plant (Mains Power Export) or enabling Closed Before Excitation to comply with NFPA 110 that requires a power plant to be online within 10 seconds.

> *The power management system protects the individual power sources from things like overload, reverse power, over- and under-frequency.*

These systems have an inherent level of complexity. But while they don't necessitate an in-depth understanding of their most complex functions, it is important to understand and appreciate the role each plays in the success of a hybrid or electric power system.

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