Saft White Paper

Energy storage for remote sites:
Ensuring continuity of supply and increasing the penetration of renewables
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1. Introduction

There are many communities around the world where the remote location and harsh operating conditions make connection to a national power grid either impractical or uneconomic. These sites, which also include mining operations, oil and gas exploration projects and military bases, have until recently relied on fossil-fuel based generators to meet their electricity needs. For example, there are over 200 communities in remote areas of Alaska alone that rely on their local microgrids, and many more worldwide.

The continued use of fossil fuels presents a number of issues for remote sites, primarily the need to limit their emissions of greenhouse gases and diesel particulates. However, there are also significant financial and logistical challenges as the fuel required is expensive to purchase, transportation costs are high and generators require costly regular maintenance. Furthermore, for communities that are served by ice roads it is only possible to make deliveries within very narrow periods of the year.

These factors are driving the uptake of green, renewable, local energy resources such as wind turbines, solar panels and hydropower. However, the effective integration of high levels of intermittent and variable renewable energy can be problematic for remote sites with a typical power consumption ranging from a few tens of kilowatts (kW) to tens of megawatts (MW).

In this white paper, Saft explains how large-scale energy storage systems (ESS) based on lithium-ion (Li-ion) battery technology can help remote sites make the transition to renewable energy while preserving continuity of supply. It also presents a number of case studies.

2. Meeting the decarbonization challenge with renewables

2.1 Objectives

Remote sites using fossil-fuel generators have a large carbon footprint. Decarbonization of the energy mix is therefore a key objective for projects where renewable energy resources are being deployed to displace diesel generators.

Making the transition to renewables can enable significant savings in fuel costs related to the purchase price as well as the costs of transportation and storage. The distances involved and the difficulty of making deliveries increase all the logistical costs of using fossil fuel. The possibility to reduce the run time of diesel generators also leads to reduced maintenance costs.

Switching to renewable energy supported by energy storage reduces dependency on imported fuel. It also enhances the quality and reliability of the electricity supply, and provides the continuity essential for the running of a thriving business and to meet the needs of the community.

2.2 The challenges of the transition to renewables

There is a natural desire for the owner and operator of a remote microgrid to meet all of its electricity demand by using a mix of local renewable energy resources such as wind turbines, solar panels and hydropower. However, the inherently intermittent and variable nature of renewable energy means that some means of supporting the load is essential to maintain a stable grid should there be a sudden decrease in generation. In some microgrids this support would be provided by connection to the national grid. But there is no grid connection at a remote site. Therefore, the microgrid can remain dependent on fossil-fueled generators even as the penetration of renewable energy is increased.

It is also important to take into account that both loads and generation will undergo significant seasonal variations. Furthermore, the microgrid must achieve a stable supply in terms of both voltage and frequency. This is difficult to achieve without the system inertia provided traditionally by rotating generators.
2.3 Key design factors for remote microgrids

The target for a remote microgrid is to maximize the use of the available local renewable energy resources and to minimize the reliance on fossil fuels. It must also deliver a reliable, high-quality supply of electricity for the community. This requires the consideration of a number of factors:

- **Variability**: With sun and wind in particular, sudden changes can result in sharp drops in production – often by 50 percent in just a few minutes. There is also limited predictability of renewable energy generation at the required level of granularity.

- **Lack of dispatchability**: It is hard to turn renewable energy resources on or off or adjust their power output on demand.

- **Curtailment**: When fossil-fueled generators running at partial load must be used to compensate for variability in renewable output, the minimum operating point of those generators may result in over-generation during periods of high renewable output. In this case the only option to maintain system balance may be to reduce, or 'curtail,' the renewable generation.

- **Lack of inertia**: This results from the lack of synchronous generation. In the absence of a connection to the national grid, microgrids are vulnerable to sudden variations in power generation, such as when clouds cover solar panels or a diesel generator trips offline. This can result in the grid frequency dropping below its critical threshold in a few seconds, requiring drastic load shedding or drawing on spinning reserves.

- **Reliability and resilience**: Complex, sensitive industrial processes in mining and oil and gas operations rely increasingly on their information technology (IT) infrastructures. These processes require continuous, high-quality power. Any outage or disturbance, such as due to extreme weather conditions, can result in loss of production with severe financial consequences.

- **Remoteness**: There are long distances to transport fuel, equipment and spares. Access to site may be limited by local weather conditions.

- **Harsh climate conditions**: Remote sites are often subject to extreme climates, such as deserts, Arctic regions or tropical islands.

- **High capital and operational costs**: Capital expenditure (Capex) is usually increased for projects in remote locations due mainly to transportation and installation costs. There is also significant impact on operational expenditure (Opex) for consumables, spare parts and the need for trained maintenance personnel. The result is that Opex and Capex are often multiples of what might be expected for easy-to-access locations.

3. The role of energy storage for remote microgrids

Energy storage is playing an increasingly important role in optimizing both the technical and economic aspects of remote microgrids. Deploying a Li-ion energy storage system (ESS) helps to maximize the use of variable renewable energy resources while supporting grid stability, resilience and power quality. It also enables a low Opex.

3.1 Energy storage applications

An ESS can support a number of different applications within a remote microgrid:

3.1.1 Smoothing and load following

Energy storage can compensate for the short term variation of renewable generation, for example, when the output from solar panels drops rapidly due to cloud cover. It can also respond to changing loads, such as a sudden increase or decrease. To achieve this compensation, the Li-ion batteries discharge if there is a lack of available power from renewables. The batteries can also be charged to absorb excess power when the output of the renewable resources is greater than the load.

This operational profile subjects the ESS to very frequent charge and discharge operations. Many of these cycles are of short duration and with a limited depth of discharge (DoD). Even so, the cumulative energy charged and discharged from the battery can reach several times its nominal capacity over a period of 24 hours.
3.1.2 Spinning reserve

Spinning reserve is a similar concept to smoothing and load following. It usually compensates the sudden loss of generation, such as when a diesel generator trips offline, or if there is a major loss of balance between power generation and consumption.

The ESS battery must inject high power within milliseconds. This fast reaction is crucial in non-interconnected microgrids, especially where there is low inertia. Otherwise, the grid frequency could drop below the system's critical threshold in less than a second.

The ESS is therefore a major source of fuel savings as it can ramp up to full discharge power within milliseconds without burning any energy, unlike spinning generators operating at partial load.

3.1.3 Frequency response

In the same way as spinning reserve, the function of frequency response is to maintain the grid frequency within the acceptable preset limits by injecting or absorbing active power from the grid. In this case, the battery charge or discharge operation is linked directly to the grid frequency, rather than fluctuations in power generation and consumption.

3.1.4 Resilience

Energy storage also makes grids more resilient to external events such as severe weather or incidents involving the grid and generation assets. It is possible in theory to install a very large ESS that will sustain the loads of an entire microgrid for several hours, but this is a costly option and may be difficult to justify in cases where outages occur very seldom. It may be pertinent to use the storage capacity in priority to back-up critical infrastructure (hospital, water supply, ...). In practice, the most critical function of energy storage is to prevent system breakdown during the first minutes following an incident.

This calls for an ESS designed to provide rapid power to stabilize the grid frequency, and also to sustain the microgrid loads for periods of 15 to 30 minutes. It will therefore be able to bridge the grid outages that are statistically most likely to occur. As a minimum, the ESS should enable the controlled ramping-down of loads and/or the ramping-up of emergency power supplies.

3.1.5 Time shifting and arbitrage

It is possible that operators will seek to store any renewable energy they produce in excess of the load so that it can be ‘time-shifted’ for later use. This is a typical energy storage application for solar photovoltaic (PV) projects. It is also known as ‘arbitrage’, because this function enables the operator to store renewable energy produced at a low cost per kWh and later displace other sources of energy with a high cost per kWh.

The higher the economic value of the stored renewable energy, the more storage capacity will be installed. The aim is not to store each and every kWh produced. Rather, the objective is to optimize the amount of energy that can be directly injected to the grid, increase the amount that can be stored, shifted and used later when it is of greater value and reduce the amount of energy possibly lost. The value of shifted renewable energy can be very high, e.g. when it displaces local diesel generation. Achieving this balance depends on the cost of the ESS and the value of the renewable energy that would need to be curtailed when the battery is fully charged. This optimization, taking into account the naturally variable generation conditions throughout the year, is part of the sizing process discussed in the next section.

3.2 Power to energy ratios and discharge durations

The ESS applications outlined in section 3.1 require different storage durations ranging from 20 minutes up to 4 hours. They therefore need batteries with different power to energy (P2E) ratios. Typical P2E ratios and discharge durations are shown in Figure 1.

![Figure 1 – Typical Power to Energy ratios and discharge durations for different ESS applications.](image-url)
In practice, operators usually aim to combine two or more applications within one ESS. Different applications might be called upon, either in sequence or simultaneously, to support various use case scenarios. The need to fulfill these different applications makes battery sizing a somewhat complex and iterative process.

4. Sizing the optimum energy storage system

Any ESS is characterized primarily by its power rating (MW) and its energy storage capacity (MWh). However, there is more to determining the power and energy requirement of an ESS in a multi-function microgrid than projecting the site’s maximum power over a desired time duration. Correct sizing needs to anticipate the dynamic behavior of the battery under the given operating profile. This may need to accommodate a number of different use cases. The process also needs to anticipate battery aging and provide the flexibility to allow for future changes in the operational pattern, particularly as more renewables are deployed.

The sizing process must consider five interdependent parameters as shown in Figure 2:

- **Available power and energy**: Rather than nominal power and energy, it is vital to consider the available power and energy. Both are variable depending on the battery’s state of charge (SOC), temperature and age.

- **Energy throughput**: This is the cumulative energy in MWh discharged by the battery within a given time period, usually 24 hours. Successive charge/discharge cycles can lead to a daily energy throughput that is well above the rated battery energy. This has significant impact on thermal behavior and aging. Different battery technologies show different limits:
  - Electrochemical limits: Li-ion batteries can show accelerated aging if there is not sufficient time for the lithium ions to diffuse evenly in the negative electrode. Higher throughput can be achieved with shallow cycling (shorter cycles at low DOD).
  - Thermal limits: battery heating and the amount of heat to be extracted grow exponentially with higher current.
  - A battery may achieve a very high cycle life in laboratory testing, for example with a single deep cycle per day under controlled temperature conditions. In practice, cycle life can be significantly shorter if cycles occur within a shorter time period, under different power ratings, and if the thermal management is not able to remove the heat generated quickly enough.

- **Thermal management**: The target is to operate the battery within an optimum temperature range for performance and aging. Figure 3 shows the temperature modeling of a battery for a full charge/discharge cycle under full solar load. It plots the temperature measured at different points inside a battery container.

- It is not sufficient to control the environental temperature of the battery. Instead, it is essential to ensure that individual battery cells remain within set temperature limits. And, most importantly, the temperature must remain homogenous across what can often be several thousands of individual cells (see Figure 4). This will avoid premature and heterogenous aging.
A number of different factors impact battery temperature. These include inherent factors like internal resistance, energy efficiency and mechanical design. There are also external factors like environmental temperature and solar loading, and most importantly the operational profile characterized by power levels, energy throughput and rest times.

Thermal management also needs to consider design parameters like HVAC, fans and the thermal dynamics inside the container, as well as the container insulation.

In contrast, the energy used for cooling and heating can be significant. This applies particularly if the electrochemical system requires a constant low temperature to avoid accelerated aging. Careful consideration of design choices can optimize the energy consumption. This can include high-efficiency heating, ventilation and air-conditioning (HVAC) systems, implementing smart and highly granular fan management and by optimizing system parameters and set-points.

The AC/DC power conversion is typically the major contributor to the system’s round-trip efficiency. In particular, inverter efficiency can be relatively low at partial load. Careful selection of the power conversion building blocks and optimization of power controls contributes to achieving the best system efficiency.

Energy efficiency also depends on the operation pattern as shown in Figure 5. High power and dynamic cycling tend to decrease the energy efficiency as they require more intensive cooling. In contrast, a use pattern without any significant discharges (rather unusual for ESS) can show a poor energy efficiency due to the permanent self-discharge and auxiliary energy consumption cumulating over time, while only a few MWh are stored and released.

Energy efficiency: this measures how much of the initially stored energy can be recovered in discharge. Poor energy efficiency can have a major impact on the project’s Opex. A large amount of the stored energy could be lost due to the electrochemical inefficiency of the battery system, the conversion inefficiency of inverters and in powering system auxiliary equipment.

Battery energy efficiency is usually very high for Li-ion batteries, typically 96 to 98 percent depending on the power level. However, some batteries may show high rates of self-discharge, especially at high temperatures.
• **Battery aging:** This is the most complex parameter to consider because it depends on both the usage pattern and system management factors like thermal management and balancing. In order to assess how the battery will age under a given operational profile, two fundamental aging mechanisms must be considered:

  - Calendar aging - driven by the thermodynamic stability of the Li-ion system. This is also impacted by temperature (with an exponential relationship) and SOC (with a linear relationship).

  - Cycling aging - driven by the charge-discharge reaction kinetics of the Li-ion system. This depends on the number and depth of discharge (DOD) of the cycles, and also on the charge rate and the charge duration.

• **Expected lifetime:** This depends on the selected end-of-life criteria. A frequently used threshold is 80 percent remaining capacity, although this may not be appropriate if the requirements of the specific application can be satisfied, either fully or at least to an acceptable degree, with the battery retaining 70 or 60 percent of its initial capacity. In the latter cases, the cycle life can be significantly increased, as shown in Figure 6.

In order to decide on the optimum size for a battery solution, all these parameters need to be taken into account. This means that sizing depends not only on the given operational pattern. It is also linked inherently to the battery technology, and its dynamic characteristics, as well as the system design choices that determine the operating temperature and energy efficiency.

In order to perform iterative, optimized battery sizing for multiple operational patterns, Saft has developed and refined advanced modeling capability based on the Matlab-Simulink package. It provides modeling of the electrical and thermal characteristics of containerized energy storage systems under a given operational profile. This makes it possible to confirm that the battery will comply with its specification at any stage of its life in terms of electrical performance, aging behavior, auxiliary power consumption, etc.

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**5. ESS implementation**

Implementing an ESS for a remote site requires the consideration of a number of individual elements:

### 5.1 Power system components

The power system components include:

- **Power conversion system (PCS)** – including the bi-directional DC/AC inverters, transformers, MV switchgear. The selection criteria for the PCS must cover:
  - Suitable power level and voltage range
  - If required, grid-forming capability
  - If required, black-start capability
  - Compliance with applicable national and local electricity and safety standards
  - Proven vendor experience in the installation and servicing of systems in remote and demanding geographical areas

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**Figure 6:** Cycle life as a function of DOD and remaining capacity at end-of-life
• **Power management system** – this is very much usage case and specification dependent. It ensures that the battery can dispatch power in line with the needs of the application. It could also function as a power plant controller, including the dispatch of multiple power components beside the battery, such as diesel gensets or solar PV arrays.

Before undertaking any installation in the field, it is vital to validate that there is a good fit between the battery and the power system components in terms of:

- Communication
- Protection scheme
- Pre-charge circuits
- Physical arrangements (cables and connectors etc.)

### 5.2 Site implementation

Remoteness and climatic conditions often make implementation of a multi-MW ESS challenging. This can be due to the long distances involved and difficult accessibility - sometimes in narrow time windows dictated by seasonal weather conditions. There can also be a lack of available qualified manpower, suitable storage conditions for equipment and other essential services. Since all the project stakeholders are subject to these same challenges, adhering closely to a tight project schedule becomes even more critical than in other infrastructure projects.

### 5.3 Saft’s containerized ESS concept

Saft has developed a concept for a containerized, fully-integrated DC battery system for deployment at remote sites. Its key features are:

- Factory assembled with the Li-ion battery modules installed, together with HVAC, fire suppression systems (FSS) and battery management system (BMS).

- Functional testing of the battery system, including interface testing with the PCS is carried out in a fully-controlled factory environment by experienced personnel using specialized tools and equipment. This ensures full compliance with quality processes and procedures. This guarantees the highest quality and functional readiness of the containers when they arrive on-site.

- 20-foot ISO containers weighing less than 30 tonnes allow shipment by road and sea to almost any place in the world. This includes even the most remote sites - above the Arctic Circle, on remote islands, or in mountainous regions.

- Installation on-site can be planned precisely, and executed quickly.

- Because the batteries are shipped installed in their containers they are fully protected. This means that if there is any project delay, such as occurred in the Covid-19 pandemic, the batteries are able to withstand prolonged periods of storage without requiring specific precautions, infrastructure or maintenance operations.

Overall, the plug-and-play containerized ESS concept helps de-risk project planning as it is based on standardized, pre-qualified and tested building blocks.
The following section illustrates how Saft has addressed the various challenges encountered in system design, installation and operation by reference to three major ESS projects for remote sites.

6. Case studies illustrating major ESS projects for remote sites

6.1 Raglan Nickel Mine, Northern Canada: Managing an increase to 40 percent wind penetration

Glencore’s Raglan Nickel Mine is located in the remote Nunavik region, the most northerly part of Quebec, Canada. Sea access to the site is only possible for a few months of the year to avoid ice and to minimize the impact on the wilderness ecosystem.

Even when winter temperatures approach -30°C the mine’s 950 employees work round-the-clock to extract 1.3 million tonnes of nickel and copper ore annually.

The operation is very energy-intensive, requiring up to 18 MW of power. When the mine first opened in 1997 it relied entirely on imported diesel fuel. However, Glencore wanted to boost its environmental performance and self-reliance and recently deployed a microgrid that incorporates wind turbines along with a large-scale Li-ion ESS.

In 2019, the site received the Mercuriades Award of Excellence in the category of sustainable development strategy.

Raglan mine microgrid

<table>
<thead>
<tr>
<th></th>
<th>140 GWh</th>
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</thead>
<tbody>
<tr>
<td>Annual energy consumption</td>
<td></td>
</tr>
<tr>
<td>Max load</td>
<td>18 MW</td>
</tr>
<tr>
<td>Conventional power generation</td>
<td>35.2 MW diesel gen-sets</td>
</tr>
<tr>
<td>Renewable power generation</td>
<td>6 MW wind (2 turbines of 3 MW)</td>
</tr>
<tr>
<td>Energy storage</td>
<td></td>
</tr>
<tr>
<td>First phase (2014)</td>
<td></td>
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<tr>
<td>250 kW ESS/200 kW flywheel/ 200 kW fuel cell</td>
<td></td>
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<tr>
<td>Second phase (2019)</td>
<td></td>
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<tr>
<td>Saft ESS 3.3 MW / 1.6 MWh</td>
<td></td>
</tr>
<tr>
<td>Annual renewable generation</td>
<td>18 MWh</td>
</tr>
<tr>
<td>Wind penetration rate</td>
<td>40 percent instantaneous 13 percent year average</td>
</tr>
</tbody>
</table>

Note – What does ‘renewables penetration’ mean?

When we talk about the concept of renewables penetration for ESS sizing, we are looking at the total, instantaneous contribution of renewable resources (wind and solar) as a percentage of the global power (in MW) within a given grid or microgrid. This penetration rate varies over time depending on the load, the contribution of wind or solar generation (which vary according to weather conditions and possible curtailment) and power generation from conventional resources.

As an example: The load in a given grid at 15:00 hours is 100 MW. This load requirement is met by a combination of renewable and conventional generation resources: Renewables: 40 MW (wind) + 10 MW (solar) + 30 MW (hydro) – 5 MW (curtailment) = 75 MW. Conventional: 25MW from diesel gensets.

Therefore, the instantaneous renewables penetration is 75 MW out of the 100 MW = 75 percent.

In contrast, the daily, weekly or yearly penetration indicates the average contribution of renewables to the energy mix over time measured in MWh. This is indicated as a percentage of the global energy consumption of a given site or power system.
Microgrid objectives and challenges

Working on behalf of Glencore, the grid operator Tugliq Energy and engineering contractor Hatch developed the wind, diesel and energy storage microgrid to:

- Reduce energy costs, CO₂ emissions, and reliance on imported fuel
- Integrate wind power while maintaining grid stability and power quality
- Overcome severe wind power variability in Arctic conditions

A first phase microgrid was commissioned in 2014. It included a 3 MW wind turbine, a microgrid control system and three smaller-scale energy storage technologies, each of which can deliver 200 kW: a 250 kWh Li-ion battery, a 1.5 kWh flywheel and a fuel cell combined with an electrolyzer and a 1 MWh hydrogen tank.

For the second phase, commissioned in 2019, the aim was to double the wind penetration by adding an additional 3 MW wind turbine. The operational challenges associated with increasing the number of the wind turbines at the Raglan site from one to a theoretical total of six are explored in detail in this research paper:

https://www.researchgate.net/publication

This investigation shows that without storage the integration rate of wind power decreases as the number of wind turbines is increased. This is because a remote electric grid has to accommodate several constraints which reduce its overall capacity to absorb wind power. These constraints include:

- diesel generator-set minimum load ratio
- minimum operating time and fuel consumption curve
- grid stability issues regarding wind power variability and frequency control

The result is that the integration rate decreases from 97 percent with one wind turbine to 39 percent with six wind turbines, if no energy storage capacity is considered to compensate for the above-mentioned constraints. This is illustrated in Figure 9.

Figure 9 – The wind integration rate at the Raglan site would decrease as the projected number of wind turbines is increased.

Figure 10 – Comparison of load integration in the Raglan microgrid for two and six wind turbines.

1-Reference: https://doi.org/10.24084/repqi15.262
Installing the ESS has enabled the Raglan mine microgrid to maintain a high level of wind integration - around 97 percent – enabling annual renewable energy generation of 18 GWh. Without energy storage, Tugliq would need to curtail around 25 percent of its wind power to protect power quality, losing more than 4 GWh of wind energy per year. Since it came on line in 2019, the ESS has operated at a consistently high level of availability and reliability. The battery provides ramp control and diesel genset bridging to compensate for sudden drops of wind power. This is proven to:

- Support grid frequency and stability
- Avoid diesel ramping up and down (which would otherwise result in poor efficiency and high levels of wear and tear, requiring frequent maintenance)
- Reduce the amount of idle spinning diesel generation, enabling the temporary shut down of diesel gensets

Wind penetration at the Raglan site can reach up to 40 percent in periods of high wind generation, averaging at 13 percent over the year. Energy storage enables the following savings:

- 4.2 million liters of diesel a year
- 6,800 tonnes of CO₂

Figure 10 compares the generation mix of wind (blue) and diesel gensets (all other) with two and six wind turbines. This shows that the excess wind generation capacity is low with two turbines – this is anything above the black line. Therefore, the main challenge for the operator is to avoid grid instability and to minimize the need for the diesel gensets to start/stop and ramp up and down. Both can be addressed with a powerful ESS, typically about 50 percent of the maximum wind power, without the need to install several hours of storage capacity. In contrast, with six turbines, there is a substantial amount of excess energy which would be lost. In this case, one possibility would be to increase the site’s long term storage capacity. The alternative approach would be to shut down one or more of the baseline diesel gensets during times of high wind output, using the ESS for bridging power when they must be restarted.

Saft ESS for Raglan mine

The Saft ESS is based on an Intensium Max+ 20M cold temperature package. This high-tech solution was already proven to ensure the battery works effectively in the extreme cold conditions of two other Arctic microgrids: the remote communities of Colville Lake in Northwest Territories and Kotzebue in Alaska. The ESS helps Tugliq to cover periods when wind power output drops. This overcomes wind turbine variability, ensures a controlled ramping down of power and supports grid frequency and stability.

- Saft Intensium Max+ 20M G2 provides 3 MW power and 1.64 MWh energy storage
- ESS can fully cover an outage from either 3 MW wind turbine
- Fully-integrated containerized solution equipped and tested in Saft’s Jacksonville factory for fast and easy installation.
6.2 Cordova Fishing Community, Alaska: Reducing reliance on diesel-powered spinning reserves

Figure 11 – Cordova is a small town in Alaska located near the mouth of the Copper River.

Reference: Replacing Diesel in an Alaskan Community: Cordova’s New Battery Energy Storage System - Clean Energy States Alliance (cesa.org)

Cordova is a small town in Alaska, 240 km southeast of Anchorage. It lies near the mouth of the Copper River, a thriving salmon river. With no grid connection, the community relies on a microgrid managed by the Cordova Electric Cooperative (CEC). The town’s baseload is covered by 7.25 MW of run-of-river hydropower generation and a 10.8 MW diesel plant. Diesel generators meet much of the demand during the winter freeze, with a 1 MW diesel genset providing spinning reserve for the transitions to and from full hydropower and during peak summer demand.

CEC has pioneered the integration of an ESS into a hydropower microgrid. The aim was to improve its resilience and reduce its use of imported diesel fuel by making the most of its hydropower, especially in the spring and summer when the town’s fish processing plants ramp up production and hydropower is most available.

Microgrid objectives and challenges

CEC’s hydropower costs are around $0.06/kWh. In contrast, diesel generation costs can range as high as $0.60/kWh, depending upon fuel prices. Whenever possible, CEC aims to run on hydropower alone and is able to meet up to 78 percent of its annual demand this way.

Run-of-river hydro is a use-it-or-lose it resource. The unused water deflected from the turbines simply flows down the river and is no longer available for generation. This is not a problem as long as the hydropower generation exceeds the town’s load.

The situation changes during the spring. This is when several hundred workers arrive and fish processing plants ramp up production. CEC responds by making a transition from hydropower-only to a combination of hydro and diesel generation. When the hydro reserve drops below around 500 kW, a 1 MW diesel genset is started. Since the diesel must run at a minimum output of 500 kW, a 1 MW diesel generator is started. Since the diesel must run at a minimum output of 500 kW, this increases the amount of hydro generation that must be spilled.

The net effect during this transition period is that CEC can sometimes waste over 1 MW of water power while burning expensive diesel fuel at the same time. Depending on load patterns, the changeover can last anywhere from a couple of hours to several days.

CEC’s goal for integrating an ESS within the microgrid was therefore to continue operation on hydro-only as long as possible, using the ESS for spinning reserve, and to start the diesel generators only when the battery reaches a low state of charge.

Saft ESS for Cordova

For CEC, Saft delivered a turnkey containerized ESS solution that was proven to work effectively in the harsh and unforgiving Alaskan climate. This includes:

- ESS rated at 1 MW power with 1 MWh storage capacity
- Specification based on CEC’s recorded generation and consumption data
- Power converter based on ABB technology
- Housed in standard sized containers
- High-speed controller integrates with grid
- Incorporates battery management, active cooling, monitoring and power and communication interfaces
Operational experience

The ESS was installed in June 2019. Over the Thanksgiving Weekend holiday that year it enabled the microgrid to achieve a record of 94 percent hydro-generation, saving CEC $10,000 in only two days (see Figure 12). Then in December 2019 the microgrid achieved 84 percent hydro-generation, crushing all previous records.

In April 2020, CEC was able to transition to 100 percent hydro-generation three weeks earlier than in previous years.

A number of operating principles have been established:

- The ESS provides load following. That means following a sudden increase or decrease in load on the microgrid it will either inject or absorb power to maintain grid frequency.
- Used as spinning reserve, the ESS avoids unnecessary diesel operation and enables the use of hydrocapacity that would otherwise be spilled.
- The ESS ensures enhanced power quality (fast reacting) and system resilience (emergency).
- ESS and diesel operation are managed through SOC control:
  - For most of the time, the ESS operates between 30 and 70 percent SOC, with diesel generation off.
  - When the ESS SOC drops below 30 percent, the diesel genset starts automatically at an output of 400 kW to supply demand. Energy produced in excess of demand is used to charge the battery until it reaches 70 percent. It then shuts off again, except if the net load is greater than 400 kW.
- The precise control algorithm used by the microgrid to control the ESS is a result of overall system modeling based on historical load and production data. This simulates the battery’s operational pattern in terms of cycling, throughput and thermal aspects.
- Optimizing control ensures the best use of generation resources and prolongs battery life – see section 4. This is longest when used in grid balancing with small, shallow discharges. Optimized setpoints avoid larger SOC swings, hence the expected aging is less than one percent a year.

Economic advantages

The economic advantages for Cordova of installing the ESS are based largely on the very significant differences in the cost of hydro-generation ($0.06/kWh) and diesel generation ($0.60/kWh).

The initial projection for annual diesel savings was 35,000 gallons (132,000 liters). In practice this is now expected to be 70,000 gallons (265,000 liters). There are also significant non-fuel variables related to using diesel generation, such as lube oil, rebuild hours, regular and emergency maintenance. Historically, these costs have been an order of magnitude higher than hydro maintenance for CEC.

The likely battery life was estimated to be 15 years. The CEC use case obtains the highest value from grid balancing which requires little capacity – the trend is therefore towards a life in excess of 20 years.

Overall, the expected annual savings of the ESS over the long term are anticipated to be significantly in excess of the system cost. There are also substantial intangible holistic benefits for the local community that now enjoys a more resilient and reliable electricity supply with reduced reliance on imported fuel.

CEC is currently working with the US Department of Energy to implement new use cases including black start, system power factor correction and microgrid system response with and without BESS support. Looking ahead, CEC is investigating the opportunities to implement bulk storage (bulk hydro or pumped hydro) to harvest the full potential of its hydrogeneration in summer and to shift it to the winter. This will require a very low cost per kWh of storage to be economically viable, and may be achieved with a bulk storage solution with substantially lower power rates, response time and efficiency, performing a few charge/discharge cycles per year. The Li-ion ESS will remain a valuable asset for the system’s overall capability in maintaining efficiency, stability and flexibility for the microgrid.
6.3 Agnew gold mine Australia: Maintaining grid stability for a hybrid renewable energy microgrid with high wind penetration

Figure 13 - The Agnew Hybrid Renewable Power Station is Australia’s largest hybrid renewable energy microgrid and the first to incorporate large-scale wind energy at a mining site.

Gold Fields’ Agnew Gold Mine is an underground operation located 1,000 km northeast of Perth in the desert of Western Australia, where peak day time temperatures can reach 48°C. The site covers over 600 square kilometers and has the capacity to process 1.3 million tonnes of ore a year.

The remote location, almost 400 km from the nearest large town of Kalgoorlie, means that a grid connection is uneconomic, so the Agnew site has to generate its own electricity. Historically, the mine has relied on third party infrastructure and supplementary diesel gensets for its electrical power. However, Gold Fields is committed to using sustainable and innovative power solutions to decarbonize its operations. It therefore engaged EDL in a 10-year agreement to build, own and operate Australia’s largest hybrid renewable energy microgrid. With an investment of AU$112 million it is Australia’s first mine to utilize large-scale wind energy. The Australian Renewable Energy Agency (ARENA) has provided the project with AU$13.5 million in funding under its Advancing Renewables Program.

The first project phase involved the construction of a 4 MW solar farm and a 21 MW gas/diesel engine power plant. This was followed by five wind turbines for 18 MW of generation, a microgrid controller and Saft’s 13 MW/4 MWh ESS. Energy storage is critical to enable the EDL microgrid to maintain power quality as it integrates an increasing level of volatile and unpredictable wind and solar energy. Gold Fields is planning to use the project as a technical blueprint for future mining microgrids.

### Agnew microgrid

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<table>
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<tr>
<td><strong>Annual energy consumption</strong></td>
<td>110 GWh</td>
</tr>
<tr>
<td><strong>Max demand</strong></td>
<td>18 MW</td>
</tr>
<tr>
<td><strong>Conventional power generation</strong></td>
<td>21 MW gas / diesel engine power plant (9 x 2 MW gas, 2 x 1.6 MW diesel)</td>
</tr>
<tr>
<td><strong>Renewable power generation</strong></td>
<td>4 MW solar PV 10,710 panels (2019) 18 MW wind power, 5 turbines (110 m high, 140 m rotor diameter) (2020)</td>
</tr>
<tr>
<td><strong>Energy storage</strong></td>
<td>13 MW / 4 MWh (2020)</td>
</tr>
<tr>
<td><strong>Annual renewable generation (projected)</strong></td>
<td>about 60 GWh usable</td>
</tr>
<tr>
<td><strong>Renewable penetration rate</strong></td>
<td>Instantaneous up to 85 percent Daily up to 70 percent Year average 50-60 percent expected</td>
</tr>
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### Microgrid objectives and challenges

Gold Fields wanted its microgrid to maximize the use of renewable energy without compromising power quality or reliability. Maintaining the very highest levels of safety and production output are critical for a mining operation. However, the high penetration of renewables presents a significant stability risk to a remote microgrid. Any outage could potentially impact safety and increase the site’s carbon footprint through greater use of diesel fuel. The main objectives for the microgrid project were to:

- Maximize penetration of renewable energy
- Reduce fossil fuel consumption
- Strengthen security of supply
- Provide high reliability in an extremely remote location
- Create a technology blueprint for other mines

From the start, the microgrid integrated 22 MW of wind and solar generation – enough, in theory, to supply 100 percent of the mine’s electricity needs. The target was to achieve, from day one, more than 50 percent renewable penetration. This involved a number of challenges:

- Gas turbines cannot be shut down easily. This forces the system to integrate on a continuous basis some level of fossil fuel generation.
• Gas turbines cannot ramp up and down quickly to compensate fluctuating loads.

• Continuity of supply and power quality are paramount for mines, no breakdown can be tolerated.

• Fast reacting energy storage is needed to prevent any grid disturbances that could be caused by tripping of a generator or sudden changes in wind or solar power generation.

• As a long term target, Gold Fields/EDL are aiming to achieve close to 100 percent usage of renewable energy at the site.

Saft ESS for Agnew microgrid

Saft delivered a fully engineered ESS package. This comprises a Saft Intensium Max+20M ESS in six 20-foot containers, plus a power conversion system (PCS), transformer and medium-voltage (MV) switchgear in three 40-foot containers.

The rugged design of Saft’s ESS technology meant that no modifications were required for the hot, dusty and sandy desert conditions. In addition, Saft is supporting uptime and availability through remote monitoring and annual onsite maintenance. These services are part of a contract that guarantees end of life battery capacity.

Other important factors for EDL were Saft’s technical engagement and its ability to overcome the logistical challenge of delivering the solution to the extremely remote Agnew mine site. The key features of the ESS are:

• 13 MW / 4 MWh energy storage system with power conversion package

• Container insulation and optimized HVAC enable operation in hostile desert climate without excessive energy consumption for cooling

• Factory assembled and tested and delivered in standard shipping containers ready to plug and play

• Commissioned within 8 months of contract signing CEC’s BESS was also commissioned within 8 months of contract signing, and fully integrated and automated on the CEC grid within 14 months.

• 10-year Saft Service for Storage Systems (4S) contract
Operational experience

The ESS has performed reliably since it came online in May 2020 (see Figure 14), with daily renewable penetration regularly in the region of 50 to 60 percent, and as high as 70 percent on days with favorable conditions. The instantaneous penetration rate reaches 85% for shorter time periods under favorable weather conditions. Thus, the ESS plays a vital role in helping EDL to manage short-term variability of wind and solar power and therefore is supporting grid stability, preventing outages and reducing idle running or inefficient ramping up and down of fossil generation.

Figure 15 shows a detailed view of energy production during a single day. The installation is proven to provide a stack of multiple ESS functions at once. These include load following and smoothing, as well as diesel bridging and spinning reserves, which traditionally required keeping a thermal power plant spinning and ready to inject power at short notice. The benefits include:

- Average renewable penetration of 50-60 percent
- Annual saving of 46,400 tonnes of CO2
- Load maintained at about 14 MW, constant
- Gas turbines running at minimum of 2 MW
- Battery provides fast-response, high power discharge, stacking multiple functions:
  - Load following and renewable smoothing
  - Spinning reserves and frequency control
  - Diesel/gas engines bridging

The operational profile for the Agnew site modeled over a one-year period is shown in Figure 16. A projection for the key operational data is illustrated in this table:

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<tr>
<td>Max power</td>
<td>13 MW</td>
</tr>
<tr>
<td>Average cycling DOD</td>
<td>5 percent</td>
</tr>
<tr>
<td>Energy throughput / year</td>
<td>950 MWh Equivalent to 230 full discharges</td>
</tr>
<tr>
<td>Aging</td>
<td>Less than 1 percent/year</td>
</tr>
<tr>
<td>AC roundtrip efficiency</td>
<td>85 percent</td>
</tr>
</tbody>
</table>

The current ESS is ensuring stability and resilience of the system. It also contributes to high renewable penetration and optimized use of gas and diesel generation. Future developments could enable storage of excess wind (mainly during the night) by a bulk energy storage solution. This would enable the complete shut-down of the gas generator.
Functions that address short term variability, including load following, ramp control, spinning reserves and frequency control are critical to enable isolated grids to operate at high renewable penetration. They are the ‘low hanging fruit’ in terms of economics as they require ESS with relatively small storage capacity, but fast reacting, high power and operating with dynamic, high daily energy throughput. Fuel savings are generated by:

- Avoiding the uneconomic running of diesel generators/wasting renewable power
- Running diesel generators at constant power to achieve optimum efficiency
- Enabling high penetration of renewables

In addition to fuel savings, further savings are made in reduced wear and tear and maintenance costs.

The total savings in fuel and maintenance can quickly exceed the purchase and running costs of an ESS.

In all three of the case studies outlined in this white paper, operators envisage the addition of bulk energy storage to harvest the excess renewable energy they produce to achieve daily or even seasonal time-shifting. The business case for this becomes more difficult because they require much higher levels of energy storage capacity. Furthermore, the excess is not equally available every day (in some cases it is available only during the summer season) and cannot be used (turned around) frequently.

An ESS for a remote site must often be suitable for extreme climate conditions, such as withstanding high solar radiation, or low temperatures and snow coverage. High performance container insulation and integrated cooling and heating (that also controls the risk of condensation) must be optimized in order to:

- Prevent excessive energy consumption for heating and cooling, which can impact round-trip efficiency
- Avoid high and/or heterogeneous temperatures for battery modules, which would lead to premature and/or heterogenous aging

Sizing the optimum system, definition of operational strategy and setting parameters is complex. It requires modeling of power flows and battery operation under multiple scenarios and in different use cases. However, when done correctly it can increase battery lifetime by as much as a factor of two.

ESS built from standard building blocks, fully equipped and factory tested prior to shipping is the optimum solution for remote, difficult to access sites. This is because shipping, installation and commissioning can be planned precisely and well in advance. It also eliminates or reduces project risks linked to shipping material from multiple suppliers and origins, local storage, local assembly and testing requiring local manpower, mismatch of component interfaces, missing components etc.

The Covid crisis has also illustrated some additional advantages of this concept. Because, if needed, battery containers can be stored without special precautions upon arrival on site. They can wait for commissioning and this can be executed rapidly, by a few service specialists from Saft and its partners, once travel restrictions are relaxed.
8. Conclusions

In conclusion, building an energy storage solution for an isolated site is a complex exercise involving several external factors linked to the remote character of the site. It requires optimization of the energy mix and power flows from multiple, system-specific generation sources, and the addressing of various challenges during project execution. Highly granular, dynamic simulation of all system components, including battery thermal and aging behavior in the early project phases is therefore critical. This approach has already shown that even a modestly sized storage battery (of less than 1 hour storage capacity), when well-designed and correctly-implemented, can enable renewable generation sources to make the maximum contribution to a remote site as well as offering substantial Opex and CO2 savings.
9. About the authors

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Michael Lippert is currently in charge of product and market strategy for Saft’s Energy Storage Systems (ESS) Business Unit at the company’s headquarters near Paris. He is also Vice-President of the European Association for Storage of Energy (EASE) and Chairman of the Governing Board of “Batteries Europe”, both in Brussels.

Michael is holding a degree in European Business Studies in France and Germany and has been working for more than 20 years in different international sales and marketing positions at Saft for Railway, Traction and Stationary markets. He has played a major role in establishing Saft’s market position in Li-ion battery technology for renewable energy and smart grids since 2010. In parallel he contributed to the development of EASE since its foundation in 2011. In October 2019, he was elected Chairman of the Governing Board of the newly founded European Technology and Innovation Platform (ETIP) for Batteries, which is driving and coordinating R&I activities at EU level.

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Jim McDowall has worked in the battery industry since 1977 and is currently in the position of Senior Technical Advisor with Saft. Involved in the energy storage market since 1998, Jim was a Director of the Energy Storage Association for 14 years and is a past Chair of the organization. Jim is an IEEE Fellow and is Standards Coordinator and Past Chair of the IEEE Energy Storage and Stationary Battery Committee, and Chair of three of its working groups. Jim is a frequent speaker at energy storage conferences and related events.
Appendix - Figures 3 & 4

Figure 3 – Temperature modeling of a battery under high solar load and full charge/discharge cycling.

Figure 4 – Side view of temperature distribution in a high energy ESS container during operation.
Appendix - Figure 12

Figure 12 – Cordova ESS operation during the 2019 Thanksgiving Weekend

Reference: Replacing Diesel in an Alaskan Community: Cordova's New Battery Energy Storage System - Clean Energy States Alliance (cesa.org)
Appendix - Figures 15 & 16

Figure 15 – Agnew energy production on July 22 2020

Reference: Presentation - ACHIEVING >50% RENEWABLES AT AGNEW GOLD MINE, JAMES KOERTING
–ENERGY MANAGER, Energy & Mines Australia, 4 August 2020

Figure 16 - The operational profile for the Agnew ESS modeled over a one-year period.