Large Battery systems to help LNG plants cut their carbon footprint

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Abstract - The Paris Climate Agreement has set the long-term vision for the management of Green House Gases (GHG). For the LNG industry, it means a significant reduction in carbon footprint. The electrical power generation for LNG plant typically has a spinning reserve philosophy of “N+1” Gas Turbine Generators (GTGs). An abatement opportunity is the replacement of part-load GTGs with a Battery Energy Storage System (BESS), allowing the plant to turn off the operating spare power generation unit and operate as (N+BESS). By doing this, the remaining units will operate at higher load and consequently at a higher efficiency.

This paper examines the technical aspects of deploying a large BESS, based on Li-ion batteries, into onshore LNG plants. For an example feed gas constrained plant, the benefits are:

1. GHG and NOx reduction
2. GTG running hours reduction
3. LNG production increase
4. Improved power quality and faster dynamic response

The aspects addressed in the paper are:

1. Will it work? The functionality of the BESS to stabilize the electrical system in case of a trip of the running GTG.

Is it safe? The safety aspects of a large-scale BESS installed on an operating LNG plant.

I. INTRODUCTION

Many LNG plants are in remote locations where the local electrical power grid has insufficient capacity to provide the required operating power, which can be up to hundreds of megawatts, with the necessary availability and reliability. LNG plants, therefore, often generate their own power.

To deal with the planned and unplanned downtime of the power generation unit, an LNG plant has a “spinning reserve” philosophy of at least N+1 operational gas turbine generators so that a trip of one power generation unit does not cause a total power failure. There is often an even higher margin between the operating power generation capacity and the electrical power load demand to enable the power system to recover from a trip of one unit, as the units have limited ramp-up rates and ability to deal with step changes in load. This results in lightly loaded and, hence, less efficient gas turbine generator operation (part-load efficiency can be less than half of full-load efficiency). This configuration provides a highly available power generation system at the expense of cost and greenhouse gas intensity.

An extreme case of the spinning reserve philosophy is shown in Figure 1(a). Two gas turbine generator units are each running (N = 1) at 40% load (the spare unit is offline) so that a trip in one unit will cause the other to ramp up to 80% load while still retaining some margin between its capacity and the plant load. Figure 1(b) shows two offline units and the running unit loaded to 80%. In this case, the spinning reserve is provided by a BESS sized to supply the power for the LNG plant for the period necessary to restart the tripped unit or to start one of the offline units.

Figure: 1(a) N+1 gas turbine generators

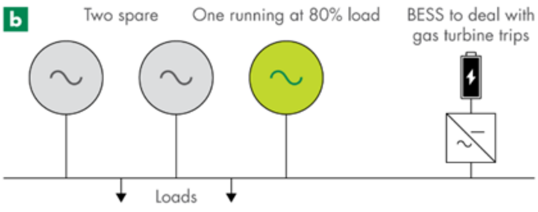

Figure: 1(b) N gas turbine generators + 1 BESS

II. BESS COMPONENTS

Current commercially available BESSs are mostly based on lithium-ion batteries (Figure 2) controlled using a battery management system.

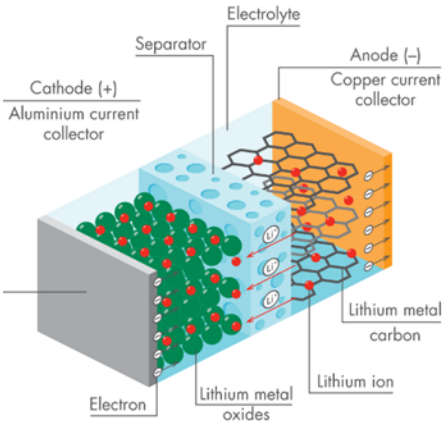

Figure 2: Typical lithium-ion cell construction

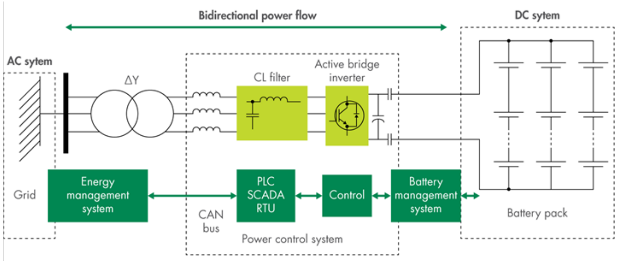

Figure 3: Components of a Battery Energy Storage System

A BESS (Figure 3) has a hierarchical control system. The power management system interfaces with the external power system of the LNG plant (typically 50 or 60 Hz alternating current (AC)) and reacts to commands (i.e., planned events to provide power from the BESS) and to signals (for example, changes in power system voltage and frequency) that indicate a response is necessary to restore control to the power system.

The power control system controls the operation of the inverter, which converts the direct current (DC) from the battery into the AC the LNG plant requires. The AC side of the inverter is connected to the external power system using a step-up transformer to match the voltage. A power system harmonic filter smooths the output voltage waveform for a better sinusoidal output. The power control system also controls the BESS auxiliaries, including other monitoring and cooling systems.

The battery management system controls the lithium-ion cells and modules that form the battery. This system has a high safety integrity level, depending on the type of lithium-ion cell chemistry, and contains a set of redundant measurements and actuators to protect the battery cells against out-of-range voltages, currents and temperatures that could lead to a cell or module thermal runaway. This is a self-sustaining, highly exothermic chemical reaction that can cause extremely high temperatures, produce flammable and toxic gases, and, eventually, result in a fire.

Commercially available BESSs may be highly modular, with each container providing 2–4 MWh of power and including the cells, inverters and auxiliaries for cooling.

III. BESS INTEGRATION INTO LNG PLANTS

When looking at BESS integration into LNG plants, the team considered two basic questions: does a BESS have the functionality to stabilise the electrical system if a power generation unit trips; and is it safe in an operating LNG plant?

A. BESS FUNCTIONALITY

Electrical system studies were carried out to confirm that a BESS could react sufficiently fast to stabilise the electrical system of an LNG plant in case of a trip of a running power generation unit.

When a power generation unit trips in a traditional island power system (see Figure 1a), there is an imbalance between the electrical load and the generated power that causes the frequency of the system to fall. The inertia of the remaining connected units and the rest of the rotating electrical machines (mainly motors) determines the rate at which the frequency falls before the governor control systems of the power generation units act to increase the generated power to restore the frequency. The more spinning reserve there is in the system, the higher the inertia and the smaller the proportional response of each power generation unit.

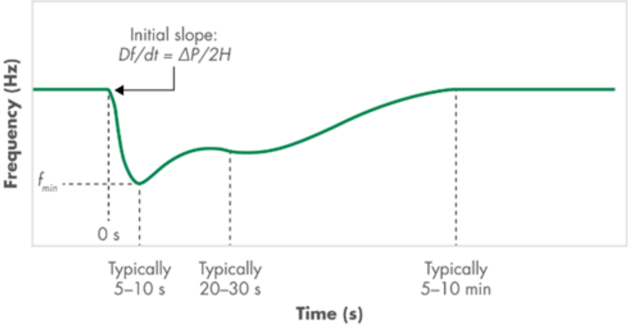

Figure 4: The response of a conventional power generation system after a power generation trip.

Replacing the spinning reserve in part or in whole with a BESS changes the way the electrical system reacts. There is less inertia, which means that the frequency falls faster, but the power electronics and control systems in the BESS can act much faster than those of conventional turbine or engine-driven generators. The BESS response is fast and stabilises the electrical system within a few milliseconds. Figure 4 shows a typical response for conventional power generation system.

Figures 5(a–d) show the system response from a standby BESS when the running gas power generation unit trips. Note that in this configuration, the BESS is operated in parallel with a single GTG, see Figure 1b. After the GTG trips, the BESS is the only active source in the system. The BESS can stabilize the electrical system by generating the voltage and frequency set points as long as the inverters are "grid forming" type. For "grid following" inverters, it is necessary that another power source stays connected to the grid to provide voltage and frequency set points.

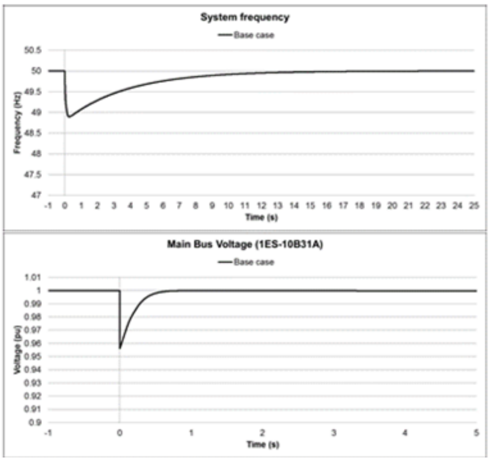

Figure 5: The response of a system with a BESS after a GTG trip: (a) system frequency, (b) main bus voltage

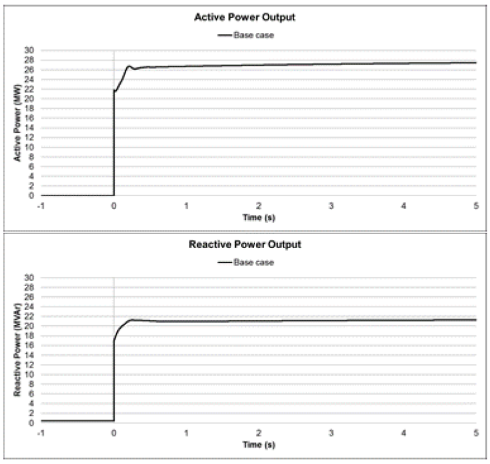

Figure 5: The response of a BESS after a GTG trip: (c) active power output, (d) reactive power output

The BESS delivers active power (megawatts) and reactive power (volts) support to the system more than five times faster than a conventional power generation unit could.

One of the drawbacks of this fast response time is that the BESS effectively acts as an isochronous control unit: it reacts to every load starting or stopping yet still maintains near perfect control of the power system frequency and can have a comparable effect on system voltage. To prevent this from happening, a control system is necessary to provide a suitable deadband so that the BESS only responds to significant events on the power system and does not operate continually. Adequate battery autonomy time is required, for example, 30–60 min, to allow long enough for starting up a second gas turbine generator or restarting the tripped unit.

As an example, at Alinta Energy's Newman gas-fired power station in Australia, a 30-MW BESS successfully took over the complete load after a trip in an external feeder within 10 ms. The power station supplies mining operations.

The main difference between such units and those used in large power grids in North America and elsewhere is the ability to do "grid forming" to control the system frequency and voltage, which is necessary when the BESS is to operate to supply the load on its own.

This capability is currently limited to vendor-supplied models only; a global power industry working group called MIGRATE (www.h2020-migrate.eu) is leading work to study and model what happens to power systems when supplied only by inverter-based power generation systems such as a BESS.

Traditional electrical protection systems based on the detection of the high current that flows during a fault (the principle of operation of a fuse or circuit breaker) are ineffective when considering inverter-based power generation, as the normal load current is not very different from that flowing during a fault. Consequently, different electrical protection philosophies and equipment are needed.

The harmonic content of the system (a measure of how pure the sinusoidal waveform is for the AC voltage) is difficult to estimate during the engineering phase and to control during operation; this requires detailed analysis when the specifics of the equipment are known.

Simple modelling of the inverter-based generation does not adequately address how BESS reacts to events such as the energisation of large transformers. Figure 6 shows typical voltage and current waveforms for the system when a large power transformer is energised. In this situation, the BESS might detect and interpret the current imbalance as an electrical system fault and thus shut down, which would lead to a total power failure; again, more detailed analysis and modelling are required for project deployment.

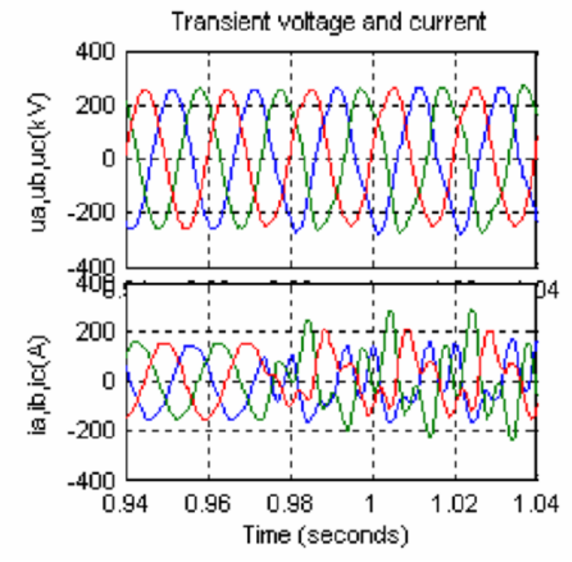

Figure 6: Typical voltage and current waveforms associated with power transformer energisation.

The connection of large numbers of inverters on the same system, for example, a BESS, some solar photovoltaic power generation and variable speed drive units for motor control, could lead to small signal instabilities.

B. BESS SAFETY

Lithium-ion battery technology is the current choice for deployment in utility and industrial systems. Figure 2 shows the structure of a typical lithium-ion cell; the direction of the flow of ions and electrons is shown with the battery discharging.

Lithium-ion battery chemistry offers several advantages over other types of energy storage and battery chemistry for grid and industrial system applications, the main ones being low losses, (relatively) low cost per megawatt-hour and the widespread availability in the sizes (1–50 MWh) being considered.

Lithium-ion batteries have an associated inherent risk of thermal runaway. To evaluate the risks, a coarse hazard identification (HAZID) was undertaken that was initially agnostic to battery chemistry. This identified the following safety risks associated with the use of a large BESS in an LNG plant: thermal runaway, toxicity, flammable gases, electrocution and arc flash. The electrocution and arc flash risks associated with large battery systems are familiar to electrical engineers, as most sites have uninterruptible power supply units connected to large batteries. The major difference is the number of battery cells involved and, therefore, the potential fault current that would flow. There are some industry standards to reflect the phenomena associated with DC arcs and to calculate the arc flash incident energy.

The risk of thermal runaway was analysed by reviewing available test results and literature and by evaluating vendors' protection systems. The conclusion was that the risk associated with a BESS can be mitigated to as low as reasonably practicable. Measures for avoiding thermal runaway and fire include the design of the battery cell, module and rack layout, and the battery management system.

Some scenarios, such as a battery internal short circuit, an external short caused by water or liquid or external heat input, cannot be mitigated by the battery management system. Although such scenarios have a low incident frequency, the battery module design needs to ensure that a thermal runaway in a single cell does not propagate to adjacent cells or modules and subsequently a whole rack or container. The UL 9540A test method and IEC 62619:2017 standard describe methods to test and validate this and should be included in the project specification.

In a thermal runaway situation, flammable and toxic gases are released that could lead to an explosion or fire and/or affect human health.

The risk can be partly mitigated by:

- installing a gas detection system, for example, hydrocarbon gas detection or very sensitive smoke detection system, appropriate to the battery chemistry in co-operation with the vendor or a cell off-gas detection system;
- installing adequate ventilation;
- installing pressure release hatches in the container or housing roof;
- using a firefighting agent to cool down an incipient cell or module fire;
- considering a deluge system to flood the BESS housing with water; however, this might lead to significant quantities of contaminated water and additional short circuits, so controlled burnout might be preferable;
- siting the BESS where fire propagation has limited impact; and
- training firefighters and operations and maintenance staff on recognising and responding to a BESS thermal runaway and fire.

IV. BUSINESS CASE FOR A BESS

Having a BESS will enable a plant to turn off, but not necessarily to eliminate, the operating spare power generation unit and to operate as an N + BESS configuration. With fewer machines operating, the remaining units will run at a higher load and, consequently, higher efficiency. This reduces the total fuel consumption, associated greenhouse gas and nitrogen oxide emissions, machine running hours and operating and maintenance costs. This will also increase LNG production at feed-gas constrained plants.

Screening studies have shown that having a BESS at an operating plant could mean:

- a carbon dioxide emissions reduction of about 20% from the power generation facilities and of 1–3% of the total LNG plant emissions;
- up to a 50% reduction in the gas turbine generator running hours (cumulative) with an associated maintenance cost reduction;
- an LNG production increase;
- a positive net present value or value–investment ratio; and
- improved power system voltage quality and fast dynamic responses to load changes in the electrical distribution system.

V. CONCLUSTION

Battery energy storage has multiple applications in the oil and gas industry, and greenhouse gas abatement by replacing the conventional spinning reserve in power generation is just one. With battery costs continuing to fall, it is hoped that more opportunities for deployment will be identified and progressed.

VI. VITA

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