Case study: Gas turbine generator fleet optimization

G. LA GRANGE, Greenfern Dynamics, Melbourne, Australia; and **D. ALLAN,** Woodside Energy Ltd., Karratha, Australia

Cost reduction has always been an important focus for industrial plants to improve their bottom lines. A well-proven method to achieve and continuously sustain these improvements has been the application of advanced process control (APC) technologies—more specifically, multivariable predictive control (MPC) technology.

In recent years, energy efficiency improvements have seen increased prioritization for sustainable and ongoing operations of these same industrial plants. Although the application of MPC technology has traditionally focused on the main production units, as the penetration of the technology has progressed, industry has been applying this technology increasingly on power generation, boilers and other utility systems.

As operator of the North West Shelf Project, Woodside Energy Ltd. (Woodside) has used MPC technology to optimize its LNG production trains at the Karratha Gas Plant (KGP) in Western Australia for more than two decades (**FIG. 1**). Woodside has collaborated with the author's company, an Australia-based APC and optimization consulting company, to grow the portfolio of MPC applications and execute many revamp projects of older applications at the site over this period.

FIG. 1. The Karratha gas plant in Western Australia.

After an initial investigation into how this technology could be utilized in the power generation area, the author's company was engaged to design, implement and commission a solution that seeks to optimize the fuel efficiency of the entire fleet of gas turbine generators. This case study describes the project applying MPC technology as the solution to this optimization challenge.

Process description. KGP utilizes ten gas turbine generators (GTGs) to supply power to the five-train LNG production complex. An overview of the KGP electrical power system is shown in **FIG. 2.** Six of these are driven by Frame 5 gas turbines, while the other four are driven by General Electric LM6000 gas turbines. The GTGs are arranged to supply the generated power to three distribution networks, with interconnectors to ensure power can be transferred from any network with excess generation capacity to another with a generation shortfall.

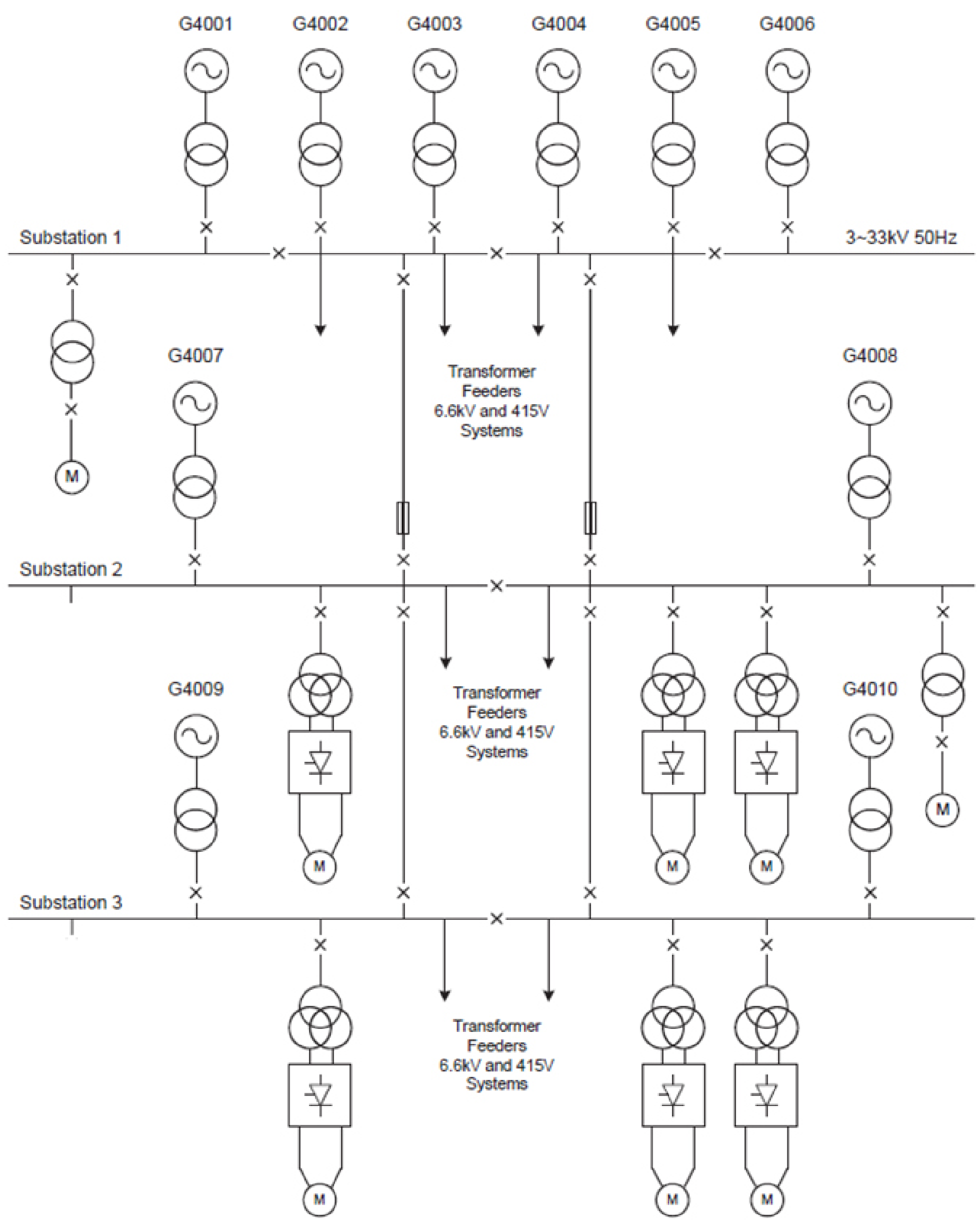

FIG. 2. Overview of the KGP electrical power system.

The maximum power generation capacity of these GTGs is a function of the prevailing ambient conditions, pre-dominantly ambient temperature and wind effects. The maximum power delivered by a gas turbine reduces as the inlet air temperature increases, and this variation can be quite significant in the northwest of Australia, especially in summer.

One key objective for any power generation system is to ensure that sufficient power generation reserves are available in the event of a GTG trip to prevent cascaded trip events. This is typically referred to as "spinning reserve," and is determined by the spare capacity of each GTG. This becomes a moving target for the overall system optimization.

Another complication faced by most power generation systems is managing—or rather, preventing—under-frequency events resulting from excessively large load demands on the online GTGs: this is especially exacerbated when another GTG has tripped. To prevent this, the instantaneous change in load demand is limited to a value (referred to as "load acceptance") that the system can handle while maintaining the system frequency. The result of this approach is that actual (or true) power generation reserve is typically somewhat less than the absolute spinning reserve. This does not necessarily impact the management or control of the power generation system. It is, however, something that should be acknowledged in the design of any automated optimization of the system.

Operational challenges. The location of the processing plant means that significant changes in the ambient conditions not only affect the overall power generation capacity, but also has a significant impact on the power demand from the production process. This is not always a linear or predictable relationship.

The load demand on each LM6000 GTG is set by the panel operator and adjusted on an ongoing basis to manage the varying power demand resulting from changing process conditions and objectives. A power management system (PMS) is used to manage the remainder of the power distribution system by manipulating the load demand on the Frame 5 GTGs. This includes generating the balance of the power demand, subject to the system frequency and voltage.

The LM6000 turbines are more fuel efficient than the Frame 5 turbines and have a greater power-producing capability. The general objective is to maximize the load on the LM6000 GTGs to leverage these improved efficiencies and deliver a net reduction in fuel gas consumption and carbon dioxide (CO_2) emissions across the 10 GTGs operated at KGP.

Unfortunately, optimal operation is not as simple as setting the load demand on each LM6000 GTG at the maximum allowed, or just maximizing the load demand on the LM6000 GTGs. The optimal LM6000 load is a dynamic target that is constrained by a variety of factors, such as:

- Equipment availability
- Power distribution network capability with specific network constraints
- Fuel gas source(s)
- Varying process conditions and objectives.

Technical considerations. The main challenge was to develop a system that can continuously adjust the loads on the LM6000 GTGs to adapt to the continually changing playing field, while honoring the various process and equipment constraints.

The objectives for the system/application were to:

- Maintain sufficient power generation reserves to meet operational objectives
- Maintain substation interconnector loads (between limits)
- Maintain Frame 5 GTGs within the optimal power generation capacity range
- Maintain individual LM6000 load targets above the average load of the Hitachi GTGs
- Honor LM6000 GTG operating conditions (e.g., operating in the preferred firing mode).

Some of the options considered and discussed during the initial design phase of the project were:

- Modifying the existing PMS
- Developing a bespoke application to meet the objectives
- Adding a new power generation controller/optimizer (MPC application).

Existing PMS. One option considered was to add the functionality to the existing PMS, hosted in a high-speed PLC system. Numerous risks were identified that would put the success of the project at risk:

- Offline testing of the changes would be difficult, and making changes to the live PMS posed a real risk of tripping the power system (partial or entirely), which could have impacts on production.
- Ongoing maintenance of the system could be a challenge, as the skill set to maintain the PMS is quite specific.
- It might be difficult to separate the new functionality from the existing functionality, which has been working well and is relied upon quite heavily.

Bespoke solution. Another option briefly considered was to develop a bespoke (or custom) application to interface with the DCS and the existing PMS. This idea was discounted as numerous risks were identified that would put the success of the project at risk:

- Depending on the platform, the interface to the DCS and PMS might require significant engineering effort to develop, prove and ensure robustness [especially if this is done outside the process control network (e.g., cloud-based computing)].
- Ongoing maintenance of the solution could be a challenge, as the skill set to manage the solution could be quite specific and outside the scope of the site-based support engineers.
- The time and effort involved to develop and deliver a solution will most likely exceed that of a standard APC project (the typical benchmark for similar projects at the KGP site).

APC application. It was decided that by *l*everaging Woodside's existing investment, support and acceptance of MPC technology at the KGP site, coupled with the author's company's experience with the specific MPC technology, the proposed solution was to develop an MPC application to optimize the fuel efficiency of the entire fleet of gas turbine generators. This choice of solution was based on:

- An MPC application can find the optimal operating point for any given set of process conditions and prevailing system constraints, as these change during a day.
- The general acceptance of MPC applications as useful and efficient tools for continuous optimization and control of the KGP process, subject to the significant changes in ambient conditions.
- The panel operators' familiarity with the existing technology would mean that the introduction of a new application will be relatively simple in terms of training needs.
- These risks were already mitigated by either the explicit use of the MPC technology or by implementing standards and approaches that resulted in minimal (and acceptable) residual risks.

An important design decision was to retain the existing PMS to manage the load demands on the Frame 5 GTGs, and therefore the system frequency and voltage. The typical execution frequency of an MPC application is not fast enough (typically 15 sec–60 sec) to manage the high frequency demanded by power systems (typically several times a second).

To maximize the LM6000 load demand, an MPC solution was developed that could replicate what KGP operators previously did manually, while continually monitoring and considering the various constraints at a much higher frequency than is realistic for a human. The MPC application also enables this efficiency opportunity to be chased 24/7 in concert with improved operating envelope adherence, as the MPC application does not need to attend to other issues or to take breaks.

Project background. The development of a new power generation MPC application was begun in early 2021 while navigating the various COVID-19 challenges and restrictions. The team was fortunate enough to be able to complete the plant testing and initial commissioning preparations onsite in March 2021.

Although many of the technical steps of the project could be completed remotely, this underlined the intangible benefits of being onsite to discover subtle clues and valuable bits of information that can have a significant impact on the success and outcome of an APC project. Although process control related projects are highly technical, the human interaction with the panel operator (the ultimate customer) should never be underestimated. Being onsite provided valuable opportunities to discuss the solution with the operators, gather more information around the usability features, and start to get them excited about the new tool they were about to receive.

The development of the MPC application was completed following the plant test period, and the application was commissioned onsite in May 2021. Following the initial commissioning period, ad hoc technical support to the site-based engineer and panel operators was provided remotely (due to COVID-19 restrictions).

Project results. The outcome was a robust and well-accepted MPC application that:

- Delivered an overall payback period of less than 3 mos
- Provided an improved mechanism to maximize the power generation demand on the more efficient LM6000 GTG.
- Considered the targeted substation interconnector amps limits, achieving a 70% reduction in the time the prescribed limits were exceeded.
- Resulted in an ~85% reduction in time that the Frame 5 GTG loads operated below the specified low power generation limits

Examples of the results are shown in **FIGS. 3** and **4. HP**

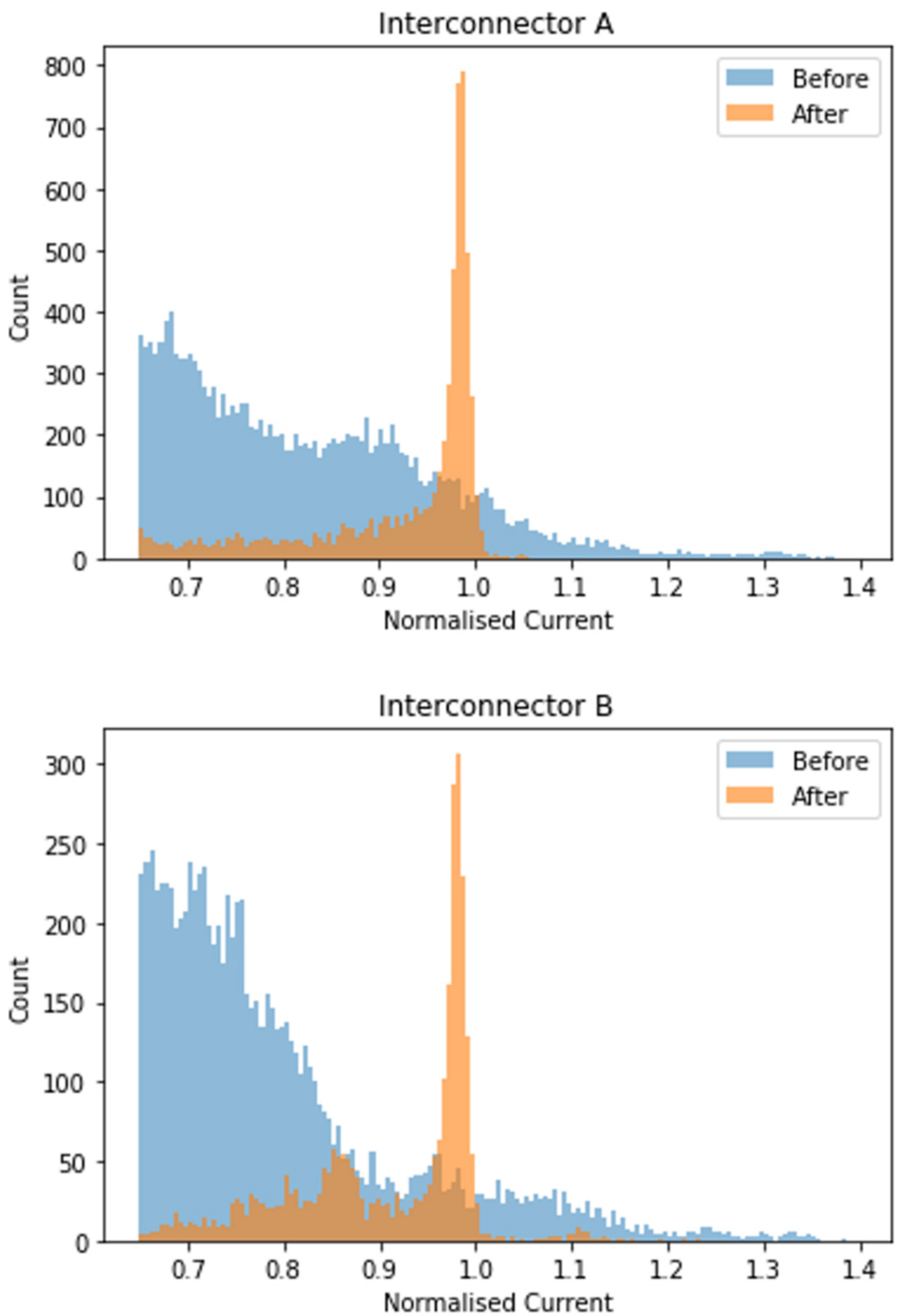

FIG. 3. Distribution of interconnector amps (normalized to MPC high limit).

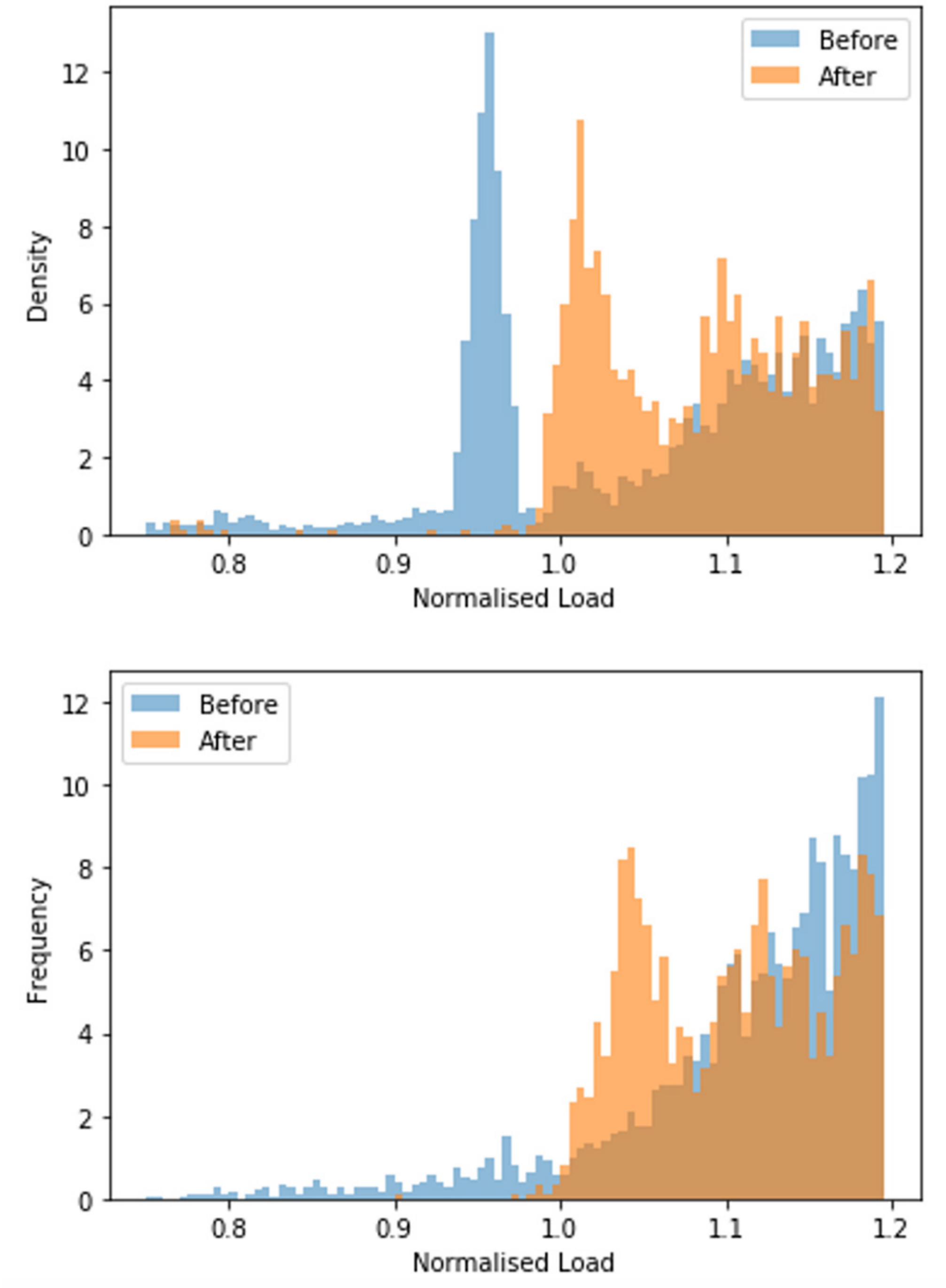

FIG. 4. Distribution of Frame 5 loads (MW, normalized to MPC low limit).

ACKNOWLEDGEMENT

The authors would like to thank the North West Shelf Project joint venture partners for their continued support of APC projects. They would also like to thank Woodside's central control room panel operators for their valuable input, buy-in and support during the development of the APC application.

GEORGE LA GRANGE is a Principal Consultant at Greenfern Dynamics. He has 27 yr of experience with APC in various industries, including oil refining, LNG production, oil and gas, chemical production and minerals processing. He earned a BE degree in chemical engineering from the University of Pretoria and is a chartered professional member of Engineers Australia.

DAVID ALLAN is a Process Control Engineer at Woodside Energy Ltd. He has 10 yr of experience in the oil and gas industry and 3 yr of experience as a process control engineer.

He earned a BE degree in chemical and process engineering from the University of Western Australia.