CONTROL AND PRODUCTIVITY

Saving the day – electric driven gas compressor control

Nowadays, virtually all technical systems rely on automatic control. Not being as tangible as hardware components, its essential role in technical systems is less visible and innovations in the domain of control often go unnoticed. This lies in stark contrast to the popularity of innovative products that would not exist without automatic control: Take quadcopters, autonomous vehicles or industrial robots as examples. In this case, an innovative control system was developed for electric driven gas compressors, where modern control helps to save millions of dollars – where automatic control is literally saving the day.

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Centrifugal gas compressors are widely used in many industrial oil and gas applications covering the whole range from upstream, midstream and downstream processes. The purpose of centrifugal gas compressors is to compress and pump natural gas along pipeline systems from its source to the end consumers. These large rotating machines are typically the largest energy consumers in a processing plant and the most critical equipment, due to the fact that downtimes automatically lead to large economic losses. Therefore, high availability together with dedicated control and safety systems play a key role in their operation.

Large rotating machines can be powered by conventional gas turbines or by electric motors powered by variable-speed drives. Electric driven gas compressors (EDCs) have several advantages compared to gas turbines: Higher efficiencies, faster response times, a wider operating range, decreased maintenance cost and zero local greenhouse emissions count among others.

In this article, EDCs are considered and how the availability and reliability of these machines can be increased by automatic control, using both an advanced process protection system called Dynamic Time to Surge (DT2S), and an advanced drive control system called model predictive torque control (MPTC).

The focus of this work is on electrical grid disturbances, resulting in a fast loss of drive torque, which puts the gas compression process at risk of a harmful phenomenon called surge.

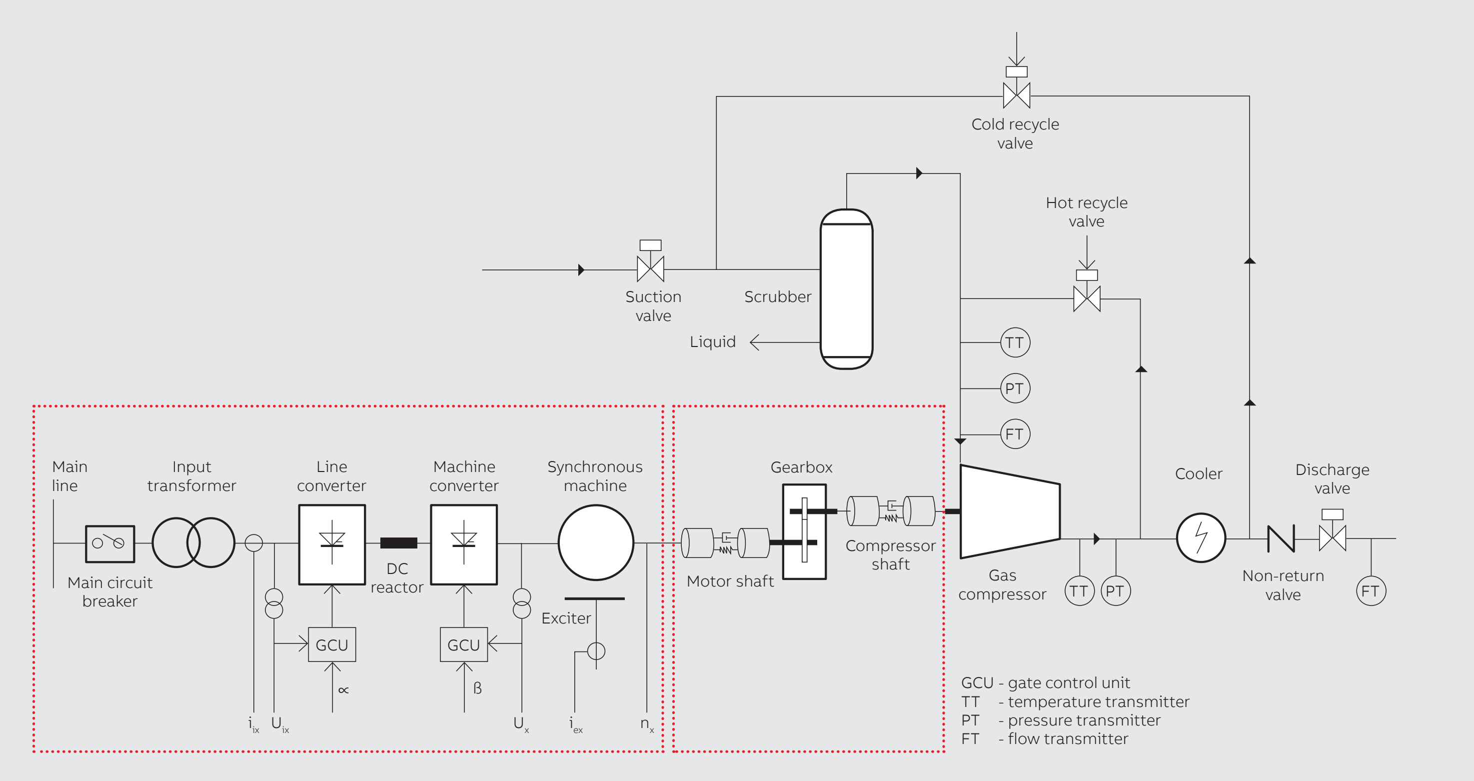
Gas compression process

A typical industrial arrangement of an EDC is depicted in →1. The electrical system consists of an LCI (load commutated inverter) with input transformer, line and machine converters, synchronous motor and excitation system. The electrical system is connected to the gas compressor through a flexible shaft with a gearbox that splits the shaft into a low-speed motor shaft and a high-speed compressor shaft.

Natural gas enters the gas compression process from the suction header, through the suction valve and scrubber to the inlet of the centrifugal compressor. Driven by the electric motor torque, the gas is compressed in the centrifugal compressor

The developed solution provides electric driven compressors with better ride through capabilities at lower risk compared to existing protection schemes.

and discharged through the discharge valve to the discharge header before being cooled in the cooler. Two recycle paths are used to influence the compressor operation by connecting the discharge of the compressor with its suction side. When a recycle valve is opened, it results in a lower resistance, and thus decreases the pressure ratio between suction and discharge, and increases the flow through the compressor. The opening of the cold recycle valve can be changed continuously, albeit rather slowly within the range of seconds, and is



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used to change the operating conditions to protect the compressor from surge conditions. In contrast, the hot recycle valve can only be opened completely, yet within the range of hundreds of milliseconds, and is used to trip the compression process for protection reasons.

The steady-state operation of a centrifugal compressor is often represented by a compressor map, which shows the relationship between compressor head and flow. The compressor head describes the amount of work applied to one unit of gas.

The compressor head is related to the pressure rise between suction and discharge, however the pressure rise produced by a given amount of compressor head varies with the density of the processed gas. As illustrated in →2, several operating constraints need to be met during the operation of the machine. The most important one is the surge limit. During surge, the compressor experiences oscillating process conditions, and increased vibration and temperature levels, which may result in increased wear or even failure of the equipment, and therefore have to be avoided as far as possible.

ABB's Megadrive-LCI

The energy-intensive nature of gas compression naturally leads to the choice of high-power solutions for the variable-speed drives. A typical configuration of the variable-speed drive system comprises a synchronous machine fed by an LCI such as ABB's Megadrive-LCI.

ABB's Megadrive-LCI, depicted in →3, constitutes a decades-long success story in the medium-voltage drive business. The reasons for its continuing market success lie foremost in its proven robustness and efficiency, and its ability to handle very high voltages and powers. Over the years, ABB has produced the Megadrive-LCI in a power range from a few to more than 100 MW.

A sketch of such a variable-speed drive system is shown in the lower left corner of →1. On the line side, the LCI is connected via a transformer to the medium-voltage grid, and on the machine side to the synchronous machine. The LCI itself comprises a line-side converter, an inductive DC link and a machine-side converter, and thus belongs to the class of current source converters. The power part of the Megadrive-LCI is based on thyristor technology, which enables operation in high power applications.

In motoring mode, the fixed-frequency AC power of the medium-voltage grid is first converted to DC power and subsequently to AC power of variable frequency, which enables the efficient operation of the synchronous machine at variable speeds.

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01 EDC industrial arrangement.

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02 Centrifugal compressor map.

Typical challenges
Gas processing plants are usually located at remote locations where grid conditions are prone to electrical disturbances. Weather phenomena such as winter storms, high winds and iced overhead lines occasionally cause short impairments of the power lines, resulting in a sudden reduction of the grid voltage in one or more phases. Typically, the grid voltage is affected over a time of 50 to 150 ms. Even if their duration is brief, the consequences of these voltage dips can be severe.

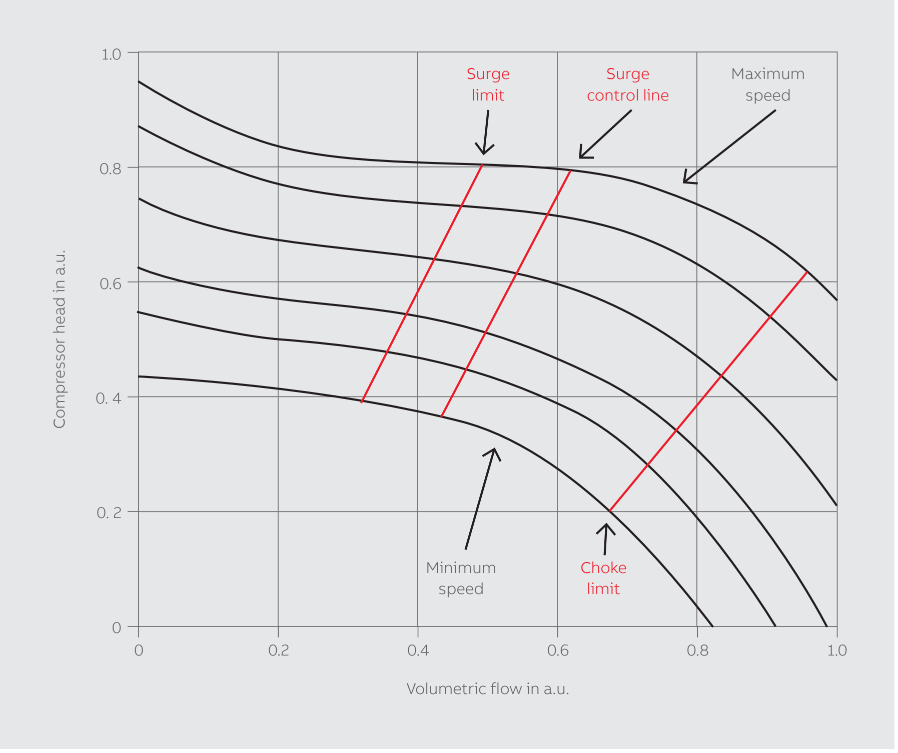
Voltage dips constitute a major challenge to the control system of an LCI. Depending on the ability of the control system to react to these disturbances, the LCI might leave the area of safe operation, which causes the LCI to trip. A common phenomenon is an overcurrent trip due to the inrush current at the return of the grid voltage.

A common industrial solution to these difficulties is to interrupt the operation of the LCI until the grid voltage has returned. For many applications, this is a reasonable approach, however not for electric driven gas compressors: Due to the sudden loss of drive torque, the compressor quickly diverges towards surge. Typically, the compression process is thus tripped in the case of a voltage dip as a precaution to avoid mechanical damage and wear.

In either case, the operation of the gas compressor is stopped and a time-consuming restarting procedure needs to take place.

Deciding about if and when to stop the gas compression process is a delicate question: Stopped too early, the considerable financial consequences due to loss of production might be unnecessary. Stopped too late, the system enters surge, risking mechanical damage to the system.

The decision is even more challenging considering the relatively slow response of the recycle valves. Even the fast response time of the hot recycle valve amounts to a few hundred milliseconds and requires the opening decision to be made early enough. By the same token, a trip decision only becomes effective after a few hundred milliseconds, leaving the compressor system unprotected in the meantime.



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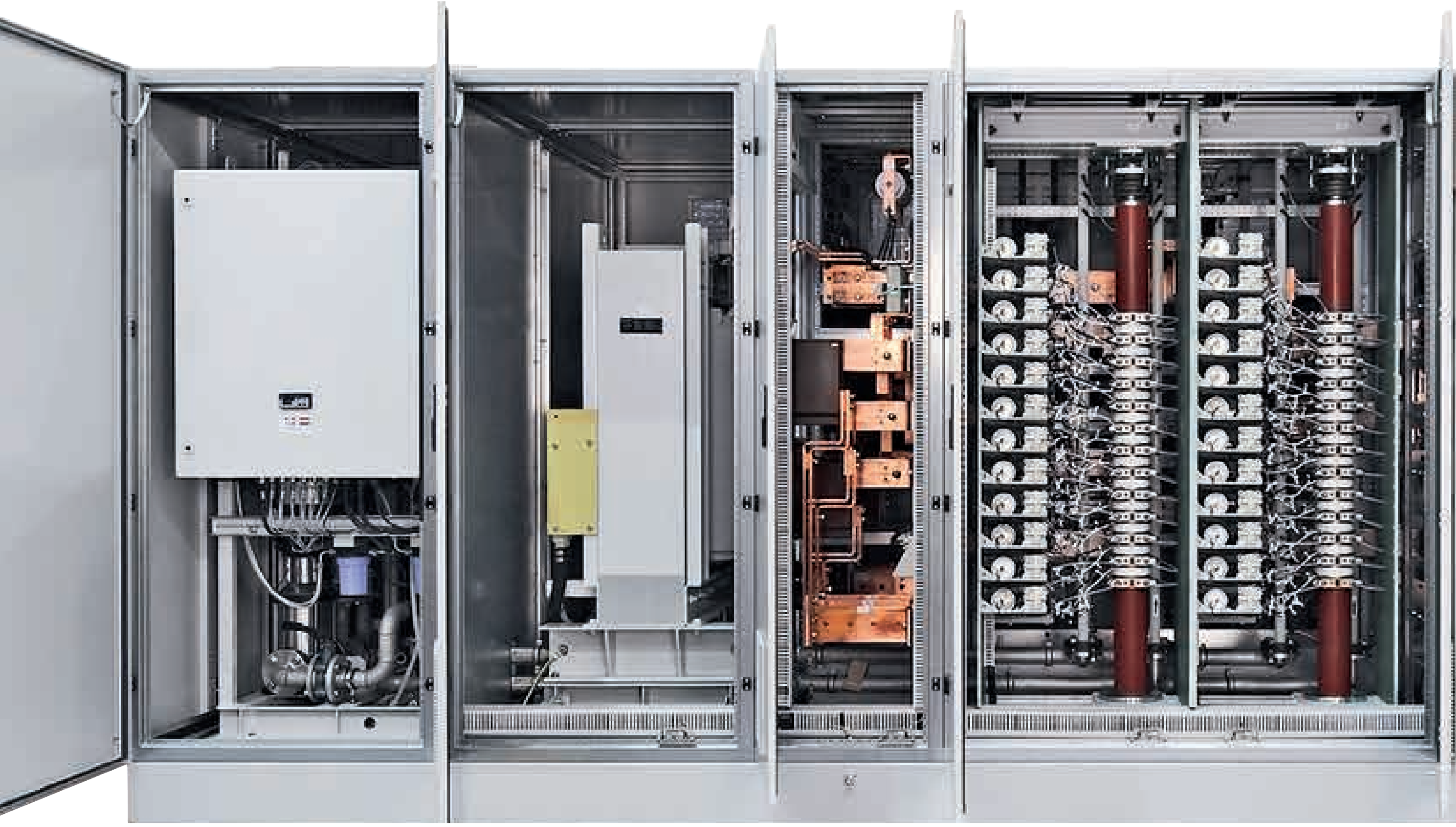

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Automation system architecture
In order to improve the robustness of the gas compression system in undervoltage situations, an automation system was devised, comprising two main ingredients:

- A control solution for ABB's Megadrive-LCI that is capable of riding through voltage dips without tripping the drive.
- A model-based surge protection system for the compression process, which ensures safe operation of the compressor system without unnecessary trips in the case of voltage dips.

The architecture used to support the compressor protection system is illustrated in →4. The compressor protection system is installed on a separate control board, providing the possibility to employ the same system also in other electric drive configurations not containing ABB's Megadrive-LCI. Combining the protection system with ABB's Megadrive-LCI, however, has further advantages, as will be elaborated below.

A prerequisite for the suggested protection scheme is a fast-response estimate of motor speed in order to react precisely during the voltage dips and provide consistent safety margins to surge. This is provided by the LCI controller with a millisecond update rate.

The compressor protection system installed on the separate control board comprises the dynamic time to surge calculation and a monitoring part.

Dynamic time to surge
In the case of voltage dip events, conventional anti-surge control systems are not always able to cope with these very fast disturbances, putting the compression system at potential risk of surge events. On the other hand, the operation should only be shut down when it is strictly necessary from a safety point of view. This gives rise to the question of how to safely ride through voltage dips. It turns out that this question can be answered in a safe and efficient way by integrating the information coming from the electrical system and the gas compression system.

For handling voltage dip disturbances in EDCs, there is no clear state-of-the-art solution. One possible solution could be based on computing a static time to surge in a high-fidelity off-line simulation, reducing the problem to a look-up table in the real-time setting as a function of some process variables. However, this approach does not incorporate varying operating conditions, eg, boundary conditions or changes in system resistance. Moreover, these approaches are typically designed for worst-case conditions resulting in over-conservative solutions causing excessive shutdowns.

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03 ABB's Megadrive-LCI.

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04 Automation system architecture. Example of how the developed automation system for compressor protection can be deployed on site.

In order to solve the problem of operating the EDC safely but also maximizing the ride-through capabilities during voltage dips, a new solution was developed. This new solution is based on combining the electrical system information with the process information and predicting the future evolution of the process trajectory using a process model. Electrical and process measurements are sampled at different sampling rates and fed to an initialization routine. This routine determines the initial process operating point and the expected partial torque during the dip. This information is fed to a model of the gas compression process that is then numerically integrated over a given prediction window. The system trajectories are then used to determine when a crossing with the surge line is taking place within the prediction window.

This value is called the dynamic time to surge (DT2S) and is re-computed in real-time every 5 to 10 ms. The DT2S can then be used as a ride-through or shutdown criterion when compared to a safety margin. The safety margin corresponds to the maximum expected reaction time of the safety system.

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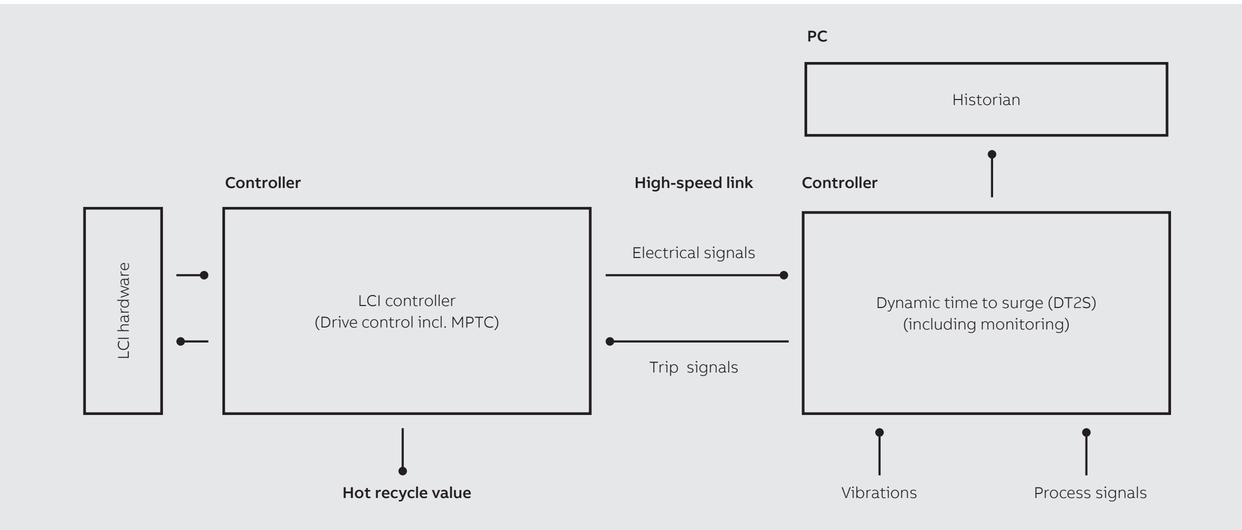
In addition to the protection algorithm, a monitoring system is included in the DT2S solution.

In addition to the protection algorithm, a monitoring system is included in the DT2S solution. A monitoring feature provides exposure of online data and as well as high-resolution snapshots during transient events. All data are stored in a historian that can be used to analyze particular events or developments over time. The monitoring part also includes vibration measurements of compressor and motor.
By using the monitoring data, it is possible to:
- confirm safe operation of the compressor during voltage dips
- support the setting of protection level by eg, evaluating vibrations during voltage dip events
- track possible changes in compressor characteristic that might influence the protection function settings.



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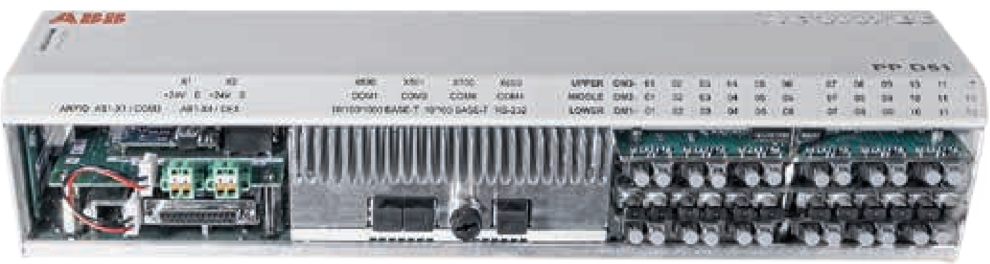
Model predictive torque control
Model predictive torque control (MPTC) is a newly developed control system for ABB's Megadrive-LCI. MPTC uses a control algorithm based on model predictive control (MPC) that ensures the operation of the drive during power and grid disturbances in order to provide the compressor with partial torque, preventing the compressor from going into surge.

MPC is a control algorithm that has its roots in the process industries and that has been in use in chemical plants and oil refineries since the 1980s. In comparison with traditional control techniques, MPC intelligently predicts the future behavior of the system to be controlled via a mathematical model and solves an optimization problem to compute the best control action with respect to given criteria and limits of operations.

The key challenge of controlling the LCI with MPTC stems from the necessity to react quickly to grid voltage changes: A nonlinear optimization problem is formulated, linearized and solved on ABB's AC 800PEC control board every millisecond →5. The entire MPTC algorithm consumes only a minor fraction of the computational resource such that the whole control system can be executed on time.

Apart from the ability to handle limits on operation variables such as the current, and thus avoid overcurrent trips, MPTC decides on the firing of the thyristors in a coordinated way, improving the ability to reject disturbances and thus improving the ability to ride through voltage dips.

More specifically, with MPTC the LCI is capable of riding through voltage dips while providing partial torque to the compression system. How much power can be provided depends on the type and the depth of the voltage dip →6. With partial torque, the divergence into surge might be avoided entirely, or at least it will be delayed, allowing for a longer grace period for the grid voltage to return or for protective measures to be taken. Consequentially, safety and availability of the whole compression system are increased by MPTC.



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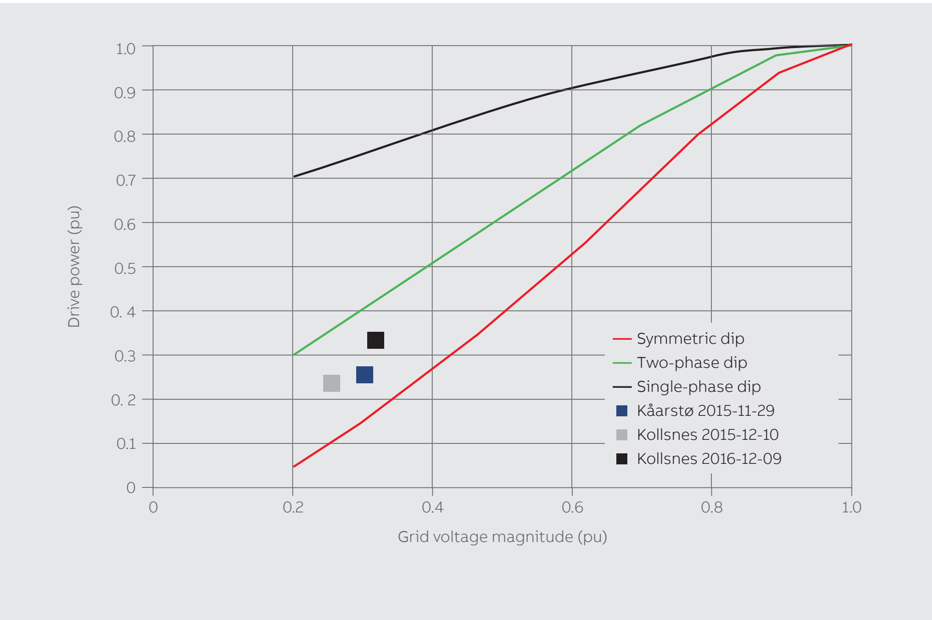

05 ABB's AC 800PEC – the embedded control board used in the Megadrive-LCI.

06 Expected drive power during grid voltage disturbance for single-phase, two-phase and symmetric dips. Measured drive power during some symmetric grid voltage disturbances in Kollsnes and Kårstø.

07 Example of a voltage dip ride through.

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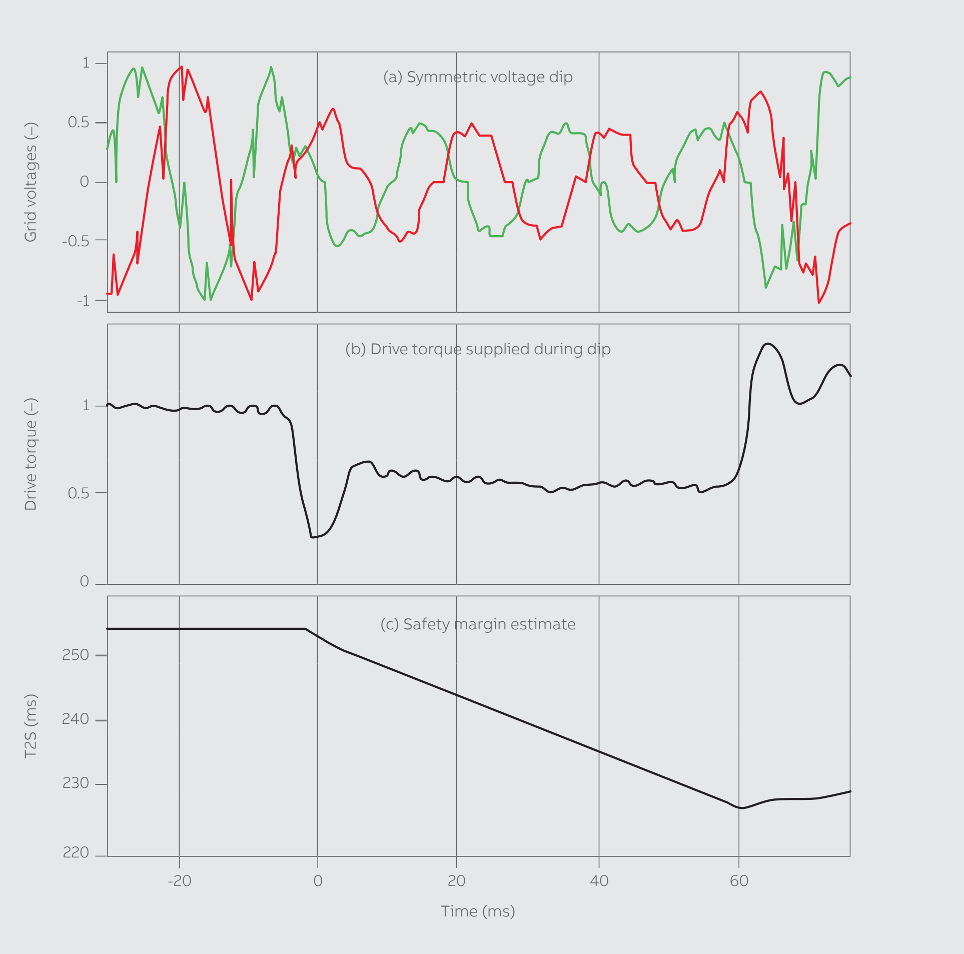

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Pilot installations

The system described here was installed at an electric drive compressor system on Statoil's gas processing and export plant, Kollsnes, in 2016. This included both the MPTC and the DT2S with monitoring. The DT2S system was run in an open loop mode for a period to collect data used for tuning the system and determining the safety limits. The safety limits were set to minimize the risk of damage and to maximize the ride-through capability of the EDC during voltage dips.

After tuning, the system was activated by closing the control loop, meaning the system was protecting the 41.2 MW electric driven gas compressor system in case of a grid voltage dip.

After activation, the system was successfully riding through voltage dips. The recording of an event is shown in →7. The symmetrical voltage dip lasts for approximately 60 ms. The LCI manages to supply torque during the dip, making movement towards a surge condition slower. At the same time, the DT2S evaluates the situation as safe with no need to trip the compressor system. After voltage recovers, the compressor is again accelerating and increasing the distance to the surge line.

Business aspects

Electric drives constitute an important part of ABB's portfolio for the oil and gas industry. There is an ongoing trend to replace gas turbines with electric drives, due to both lower maintenance costs and emission regulations. Other advantages include larger operating range, increased efficiency and more dynamic torque changes. Consequently, electric drives have become the de facto standard for onshore facilities.

A few large players dominate the market for large medium-voltage drives. Price, obviously, is an important factor for customers, but also that the product can deliver high availability. The amount of gas exported is directly related to availability, and thus, the financial cost related to downtime is significant. ●

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