



Power Management Systems

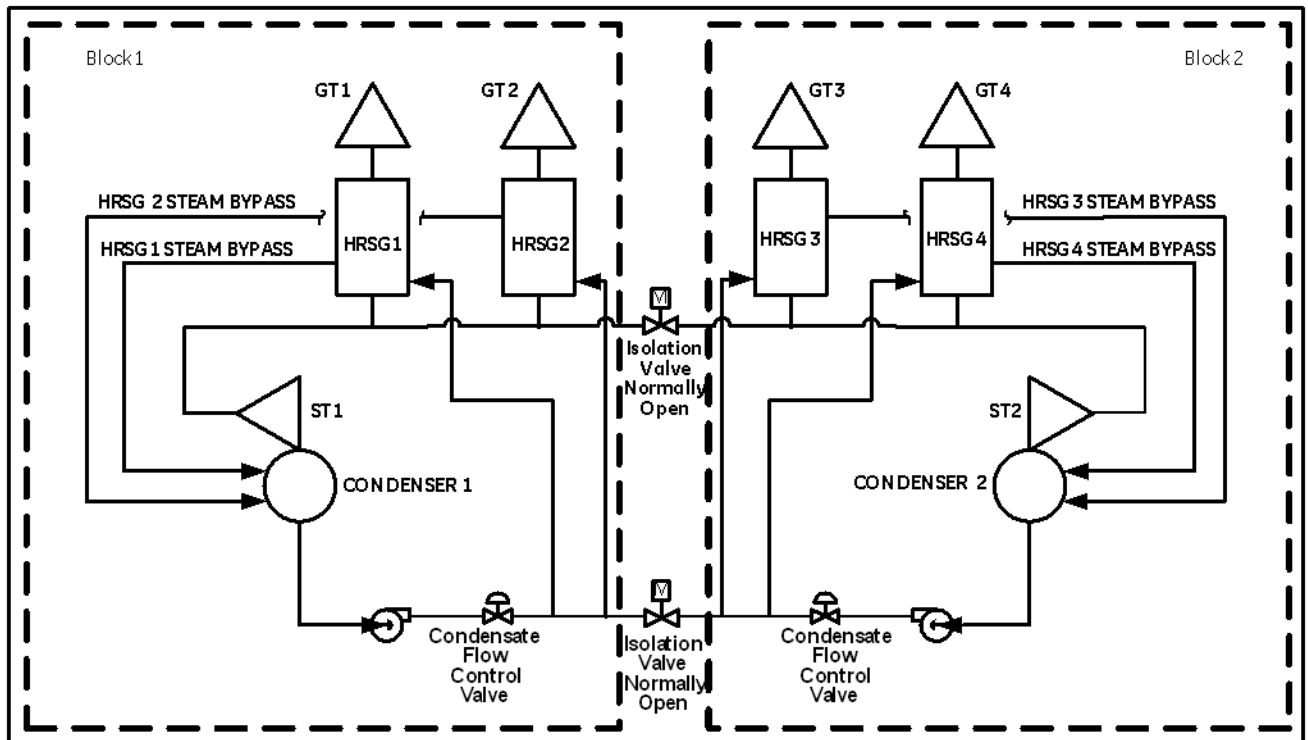
White Paper

Aluminum smelter plants require large amounts of reliable electricity. Loss of power can have a tremendous financial and scheduler impact on the facility. A power management system (PMS) can add a layer of protection to the supply of critical power to the aluminum smelter.

This document describes the PMS used at the power generation facility associated with Qatalum’s Aluminium Smelter plant in Mesaieed Industrial City, Qatar. Qatalum is a joint venture partnership between Qatar Petroleum and Hydro Aluminium of Norway.

The Qatalum facility has a capacity of 585,000 metric tons of aluminium production per year. The associated power plant supplies 1015 MW to the aluminum smelter to supply power for the 2 x 480 MW per pot line, plus 55 MW auxiliary loads. Qatalum’s complex facilities include an aluminium smelter plant, port and storage facilities, as well as a captive power plant. The Aluminium Smelter facility requires a large quantity of power to be continuously available. If this does not happen (for example, if the power supply is interrupted for as little as 2–4 hours), the smelter pots will be damaged and will have to be repaired, resulting in significant cost as well as lost production. The function of the PMS is to reduce any disturbances of power availability at the Qatalum facility.

The Qatalum power plant configuration consist of four Frame 9FA gas turbines (GT) with inlet evaporative coolers, four two-pressure heat recovery steam generators (HRSGs) with duct burners, and two C7 steam turbines (ST) (refer to the following figure). The plant includes HRSG bypass stacks with GT exhaust gas diverter dampers for GT simple cycle operation and for operation in contingency situations.



Power Block Overview

The two STs receive steam from a common steam header connected to all HRSGs. The condensate extraction pump discharge from each condenser hotwell is connected to a common condensate header, which supplies all HRSGs. Each HRSG has two bypass valves (one per pressure level) to divert steam to the condenser.

The plant expectation is to supply 1015 MW to an aluminum smelter, which has 2 x 480 MW potlines plus 55 MW auxiliary loads. Normal smelter operation is at full load continuously with the power plant tied to the grid.

The PMS is configured to respond to plant disturbances such as a gas and steam turbine trip or a smelter potline trip. The PMS will rebalance load as quickly as possible while maintaining plant stability.

Normally, the plant is connected to the power grid; however, power exchange between the power plant and the grid is limited requiring extremely rigid control of power import and export. To overcome this restriction, the plant may also operate in Island mode (disconnected from the grid). Other operational modes include the N-1 configuration (3GTs/HRSGs feeding 2 STs, 3 x 2 operations), with one GT/HRSG train not operating as it may be undergoing maintenance or on standby to be started in a contingency. Another possible operating mode is N operation (4 x 2), such as 4GTs/HRSG feeding 2ST's, or N-2 operation, such as 2GTs/HRSG feeding 2ST's.

Plant Operational Concerns

Smelting is the process of extracting aluminum metal from aluminum oxide (alumina) through electrolytic reduction. The fundamental component of a smelting operation is the electrolytic cell or *pot* where this reaction takes place. The smelting process is energy intensive and continuous where power must be available without interruption. A power disruption could result in several weeks of lost production, which can translate into millions of dollars of lost revenue. If generating supply is lost and not restored within a few hours, it is possible that the liquid metal could solidify, requiring that pots be repaired at a significant cost.

The purpose and functionality of the PMS is to prevent power loss to the smelter by managing the operation, loading and load shedding of the gas and steam turbines, as well as managing the load shedding and tripping of the smelter potlines.

The GE Solution

The PMS is based upon the Mark* VIe control system currently used throughout the power industry today. Visualization of all plant controls, including the PMS control, is presented to the plant operators on a common Human-machine Interface (HMI) arrangement, which integrates plant controls in a single interface. The HMI is based on GE's CIMPLICITY* software and implemented on a Windows XP® based computer platform.

The modular architecture of the Mark VIe control system provides the flexibility to customize the PMS to virtually any configuration. To achieve the required reliability, availability, and stability of energy supply for energy intensive industries, such as the Qatalum Aluminium Smelter plant, redundancy is built into the PMS equipment in the following areas:

- Network communication
- Controller processor and memory modules
- Power supply for I/O and controller modules
- Communication with remote I/Os

The power management, GT, ST, Balance of Plant (BOP) controllers, and HMIs are then arranged with two redundant data highway systems; one for control and one for plant interface functions. These data highways are Ethernet-based and provide flexible capabilities for interfacing with many different devices and systems.

The power management, turbine, and BOP controllers are networked together to form one control system allowing all operating data, alarm monitoring, and control references to be collected into a common interface. This networking results in improved system control performance and reliability because it removes the external communications data links that are required in traditional distributed control systems to pass data and commands between the unit controllers, operator stations, and plant automation systems.

Mark VIe Control System

The dual MarkVIe controllers are configured to provide a redundant control platform that allows the secondary controller to take over from the primary controller without interruption. Each of the process controllers independently receives the input data through multiple network paths. The controller can act on the inputs from the second network if there is a failure on the first network.

As the control processor executes the application software, the output state data is sent from each controller on its network. A state table of internal variables for such calculations as integrators, counters, or timers is transferred from the designated controller to the secondary controller. Thus at the start of the next application code scan, the same set of internal variables is used by both controllers. The two controllers remain synchronized. The output modules can use the outputs from the second controller immediately. Therefore, if either controller is shut off or fails, the process continues to operate without interruption.

Scan times of the PMS control processors are set at the following maximum values:

- Analog I/O scan time: 40 ms
- Digital I/O scan time: 40 ms
- Discreet logic: 40 ms
- SOE inputs: 1 ms

Benefits

Using a common hardware and software platform across the power plant provides:

- Unified plant control, monitoring, and data collection
- Reduction in number of spare parts required
- Reduced hardwired signals saving installation costs
- Common engineering and diagnostic tool across power management, turbine, and BOP controls
- Improved operation and reduced training expenses
- Built-in Sequence of Events (SOE) recorder on every digital input improving plant troubleshooting, and analysis of system upsets and trips
- Tighter integration of plant systems, improving equipment control and protection and overall asset management

PMS Software

The PMS control strategy is to balance power demand and supply between the smelter and the power plant. When power is balanced, it reduces power plant frequency fluctuation when islanded and maintains power export or import with the grid within prescribed limits. As a result of this balanced power, the GTs operate at a stable operating condition and/or remain connected to the grid.

Some sub-functions within the PMS from a GT control perspective are:

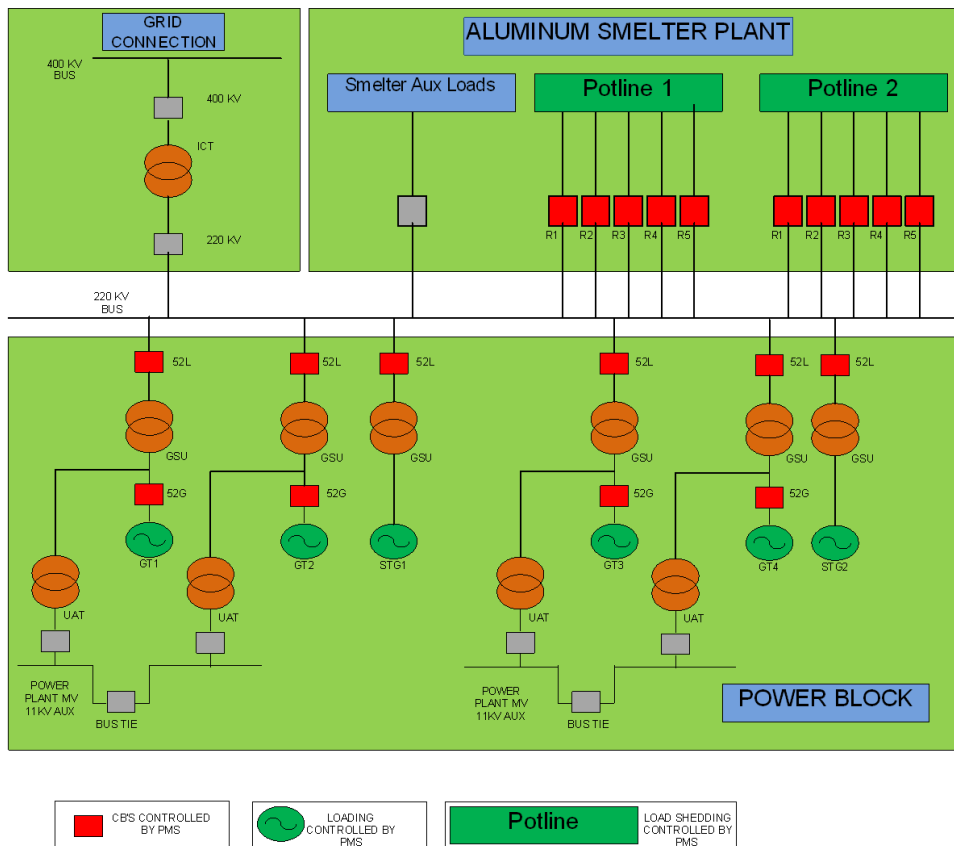
- Calculate various threshold values (in MW) for stable GT operation (stable combustion) as a function of ambient temperature
- Distribute MW setpoints among running GTs to avoid operation in the combustion transfer zones
- Distribute MW setpoints among running GTs to avoid combustion transfer in case large load changes
- Ensure no GTs operate below the minimum power limit to keep them in stable combustion modes
- Prompt alarms to the operator to configure GTs and duct burners to the recommended MW setpoints and modes
- Control generator operation point (generated power and combustion mode) in accordance with MW setpoint and initiation given by the operator

The PMS software continuously calculates the spinning reserve, as well as the turndown capability of the running GTs in real time. The spinning reserve of a GT is calculated as baseload output minus current output. Turndown capability is the amount by which GT output can be reduced while above ~100 MW.

The PMS also continuously calculates the required increase or reduction in GT output to maintain frequency and power export or import with the grid within prescribed limits in case of a contingency.

The PMS takes action based on these calculations in case of a contingency. If the required increase or reduction in GT output is less than the minimum of a pre-determined threshold and the available spinning reserve or turndown, then no other action is taken; for example, no other generator or potline is tripped. The GTs will reduce or increase load to match smelter demand in this situation.

If the required increase or reduction in GT output is beyond the capability of the GTs, then the PMS response is to load shed the potlines or trip a potline and/or another generator. It is important to match plant output with smelter load as closely as possible to reduce frequency fluctuation and the probability of tripping other generators in the transient.



PMS Interface

Plant Load Control

The plant load controls function is to manage the loading and unloading of the GTs to provide the power needs of the aluminum plant. The total power (MW) generated by all gas and steam turbines is combined to meet the aluminum smelter plant power demand. The total load demand (MW) of the aluminum plant consists of the load of potline 1, potline 2, and plant auxiliaries. The PMS load control software automatically tracks the smelter total power demand, making this the master load setpoint for the power block. The duct burners are modulated based on an operator configurable ST MW setpoint, and are fired when GT's approach baseload conditions and additional power is required. After duct burner firing is started the operator can increase the duct burner MW setpoint. Increasing the duct burners firing rate will increase HRSG steam production, which in turn increases MW production of the ST generators.

GT Modes of Operation

When the power plant is connected to the grid, the GTs operate in droop speed control mode. When the power plant is disconnected from the grid (island mode), the GTs operate in isochronous load sharing control mode with GT loads balanced and maintaining island frequency. During operation, if the grid connection opens unexpectedly leading to island operation, the GTs automatically go into isochronous load sharing control mode. While in isochronous load sharing control mode, the GTs respond to frequency variation driven by smelter load changes; loads are equal between GTs.

PMS Responses to Contingencies

GT Trip (Island Mode)

- a. If the MW generation lost from the GT trip is within limits to be compensated by the remaining online GTs spinning reserve, then the PMS does nothing further and allows the online GTs to increase load to respond to the MW deficiency.
- b. If the MW generation lost from the GT trip is beyond the limits to be compensated by the remaining online GTs spinning reserve, then Instantaneous Load Shedding (ILS) on the smelter command is initiated to re-balance the load.
- c. Conversely, if the MW generation lost from the GT trip is beyond limits to be compensated by either the online GTs spinning reserve or the ILS, then the potline closest in load to the tripped GT is tripped.
- d. After the potline is tripped, if the total MW generation is less than current smelter load, then ILS is issued to the remaining potline; or, if the total MW generation is more than the total smelter load, then a ST is tripped.

ST Trip (Island Mode)

- a. If the MW generation lost from the ST trip is within the limits to be compensated by the remaining online GTs spinning reserve, then the PMS does nothing further and allows the online GTs to increase load to respond to the MW deficiency.
- b. If the MW generation lost from the ST trip is beyond the limits to be compensated by the remaining online GTs spinning reserve, then the ILS command on the smelter is initiated.
- c. If the MW generation just lost from the ST trip is beyond the limits to be compensated by ILS, then the potline closest in load to the losing MW generation is tripped.
- d. After the potline is tripped, if the total MW generation is less than current smelter load, then ILS is issued to the remaining potline. Otherwise, if the total MW generation is more than the total smelter load, then the second ST is tripped.

Potline Trip (Island Mode)

- a. If the MW load just lost from the potline trip is within the limits to be compensated by reducing the online GT's loads, then the PMS does nothing further. If the generation just lost from the potline trip is beyond limits to be compensated by reducing online GT's load, then the ST closest in load to the tripped potline load is tripped.
- b. After the ST is tripped, if the total MW generation is less than remaining potline load, then ILS command is issued to the remaining potline. Otherwise, if the total MW generation is more than the total potline load, then the second ST is tripped.

GT or ST Trip (Grid Connected)

- a. If the MW generation lost from the GT or ST trip is within limits to be compensated by grid import, then the PMS does nothing further.
- b. If the MW generation lost from the GT trip is beyond limits to be compensated by grid import, then the PMS issues an ILS command to the smelter.
- c. After the ILS is issued, if load reduction is still required, the PMS will continue to runback the smelter until the import limit is reset below the setpoint.

Potline Trip (Grid Connected)

- a. If the MW demand lost from the potline trip is within limits for grid export, then the PMS will not trip any units but will unload the GT to rebalance load demand.
- b. If the MW demand lost from the potline trip is beyond limits to be accepted by grid export, then the PMS trips the ST closest in load to the tripped potline.
- c. If the ST trip is insufficient to balance load demand, then the PMS checks for GT turndown capacity. If GT turndown is insufficient, then the PMS trips the second ST.

Grid Connection Opens

If the grid tie opens while power is being imported from the grid, the PMS performs the following actions:

- a. PMS takes a snapshot of power import value.
- b. If the MW lost from the interconnect transformer (ICT) trip is within limits to be compensated by the remaining online GTs' spinning reserve, then the PMS does nothing further and allows the online GTs to increase load to respond to the MW deficiency.
- c. If the MW loss from the ICT trip is beyond the limits to be compensated by the remaining online GTs spinning reserve, then ILS on the smelter command is initiated to re-balance the load.
- d. Or, if PMS determines that ILS will be insufficient to balance the load, the PMS will instead trip the potline closest to MW import lost.
- e. If the trip of the potline results in an excess of power supply compared to smelter load, and the remaining online GTs do not have the turndown capability to shed the excess MW, the PMS trips the ST closest in load to the tripped potline.
- f. If the ST trip is insufficient to balance load demand, then the PMS checks for GT turndown capability. If GT turndown is insufficient, then the PMS trips the second ST.

If the grid tie opens while power is being exported to the grid, the PMS performs the following actions:

- a. PMS takes a snapshot of power export value.
- b. If online GTs are within turndown capability to shed excess power generation, then no units are tripped and GTs will unload through load control.
- c. Or, if GTs lack turndown capacity, then the ST closest to the export MW value is tripped.
- d. If the resultant ST trip causes a load deficit, then the PMS checks for GT spinning reserve to make up the deficiency. If spinning reserve is unavailable, then the PMS will issue an initial load shed command to the potlines.

Plant Frequency Back-stop Protection

To prevent a power block blackout, the PMS incorporates a frequency back-stop protection scheme in instances where there are multiple contingencies (such as in the case of more than one generator or potline trip, as an overall backstop protection). The intent is to isolate and protect GT's from tripping to allow for the most rapid repowering of the smelter.

The PMS will perform the following actions during extreme frequency fluctuations:

- a. Frequency low: generates an operator alarm
- b. Frequency low-low: initiates smelter load shed (both potlines)
- c. Frequency 3-low: trips smelter plant, trips the ST, and sets GT's to house load (opening of 52L)
- d. Frequency high: generates operator alarm
- e. Frequency high-high: generates operator alarm
- f. Frequency 3-high: trips smelter plant, trips the ST, and sets GTs to house load (opening of 52L)

Smelter Trip

A smelter trip will trip all online generators and place GT 1 and GT 3 in house load mode to allow for a faster restart.

Conclusion

Based on tested results, the PMS provides rapid response and load shedding protection to achieve stable energy supply to the aluminum smelter plant. In actual operation, the PMS has responded as expected and required. This is due in part to the holistic approach used in integrating the power plant and aluminum smelter. Taking a systems-level approach that spans the power plant and aluminum smelter allows identification and resolution of potential issues before a PMS is dispatched. The PMS needs to work with the software in the Distributed Control System, the SCADA controls, and the aluminum smelter process control and protection. The capability to simulate generating unit dynamics was valuable in assuring system performance and examining 'what if' scenarios.

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