Energy is vital for industries to operate. Many of ABB's energy-intensive customers require a reliable and stable energy supply for the motors that drive compressors, pumps, fans and machines. Some operate in areas where the public electricity supply is unreliable or non existent meaning they must rely heavily on their own generation capabilities. An unscheduled trip in, for example, a refinery or a liquefied natural gas (LNG) plant due to a total loss of power could result in several days of lost production. When translated, this represents a value exceeding $10 million.

Because of this dependence on electricity and the volatility of energy costs, combined with a growing environmental consciousness and more stringent legislation, efficient energy management is becoming ever more important.

ABB's Industrial^{IT} Power Management System (PMS) is a family of unique solutions that ensure reliable and stable energy supply for energy-intensive industries. The PMS balances energy demands with the available energy supply, thus preventing disturbances or even blackouts in operations. Furthermore, it enables a company to control its energy costs, to enhance safety, and to mitigate environmental and health impacts.

Not on my watch

How ABB's Power Management System prevents multi million dollar shutdowns

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Network Determination

The *Network Determination* function is an important supporting function for the Power Control, Load Shedding and Synchronization functions.

By checking the open/close positions of critical circuit breakers in the electrical network and using its internal "knowledge" of the electrical network topology, the Network Determination function can determine network contingencies.

The PMS uses sophisticated matrix calculations to determine electrical network contingencies. Network contingencies must be calculated in a matter of milliseconds after a circuit breaker position has changed and are therefore determined by complex logics. To give an idea of the complexity and size of the necessary logic, an electrical network with one grid connection and eight generators has $2^{(1+8)} - 1$ possible network contingencies.

The electrical network matrix is a square matrix with same number of columns and rows. Each column and row represents a (main) bus bar in the electrical network. The cells in the matrix represent circuit breaker positions which are the connections between the (main) bus bars.

The Network Determination function calculates the electrical network contingencies from this matrix - it calculates a "reduced" network matrix. The number of rows in this reduced network matrix is equal to the number of sub networks (or network islands) in the electrical network. The reduced network matrix is used by: Power Control to calculate imported and generated power and balance loads in sub networks; Load Shedding to calculate imbalances between available and required power; Synchronization to check which power sources (grid and generators) are available to achieve synchronization.

The situation in nearly any black-out is almost always the same: one part of a system fails forcing nearby equipment to absorb its load. This equipment is then pushed into an overload mode causing it in turn to fail. These multiple failures snowball and a large area ends up in the dark with potential dire consequences including potential loss of life, loss of production and damaged equipment.

It is imperative that process upsets and shutdowns are avoided as they will have a negative effect on the financial, environmental and social performance of a company. Power supply reliability and power quality affect both throughput and safety; therefore avoiding black-outs and power disturbances are of substantial value to any process plant. Equipment must be monitored continuously to ensure optimal performance and stability over time. The extremely fast dynamic properties of the electrical process require quick response times – of the order milliseconds – to prevent protection relays from issuing trip commands leading to a domino effect in terms of equipment overload.

Inefficiency isn't just costly in terms of excessive fuel consumption; high emissions can rack up the cost still further. Solutions that help lower operating costs while reducing environmental impact are sorely needed by industry.

One such solution, ABB's Industrial^{IT} Power Management System (PMS), helps achieve stable operation whereby the electrical plant as a whole can withstand larger disturbances from within or from outside the plant. This application package contains not only the traditional SCADA functionality but also a full complement of electrical solutions including Power Control and Load Shedding, two major functions that are described in details in this article.

A common platform for process control, safety, power generation and utility control

The PMS is based on ABB's Industrial IT Extended Automation System 800xA [1, 2], which is designed to monitor, control and protect all sections of a process plant. This common Industrial IT platform provides control functions, and a flexible and well organized single-window interface that allows operators to work efficiently. In addition, advanced functions such as intelligent alarm filtering, consistency analysis and operator guidance help reduce the need for operator intervention and, more importantly, these functions can prevent incorrect interventions.

The importance of systematic operator training in a realistic setting is increasingly acknowledged as a prerequisite to reach operational best in class targets. The Industrial IT Training simulator can be integrated with a multitude of process and electrical simulators. Because it runs on the Industrial IT platform, the PMS can be conveniently deployed in the integrated Training Simulator, where control strategies – such as load shedding priorities – and "what-if" simulations can be tested prior to deployment 1.

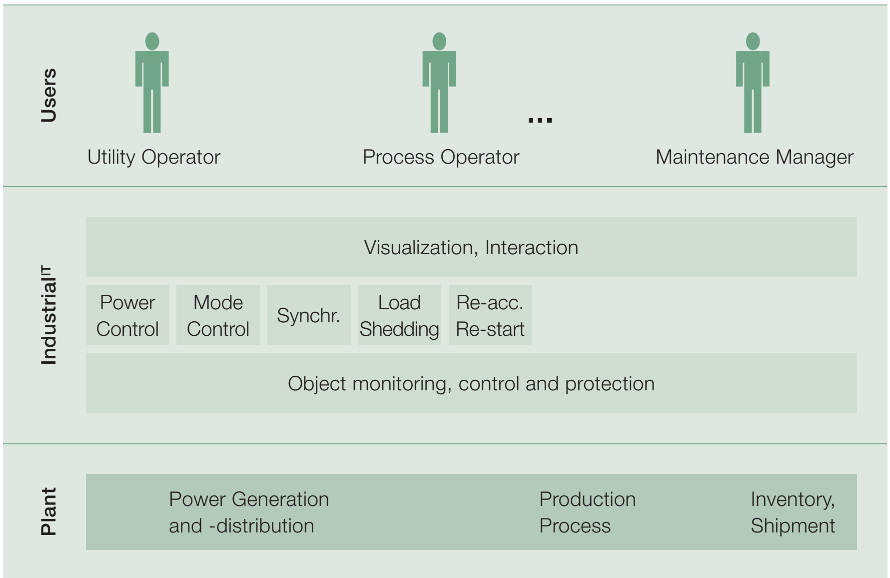
PMS main functions

The PMS provides an integrated set of control, supervision and management functions for power generation, distribution and supply in industrial plants. Such broad functionality is partially represented by modules commonly used by the industry under different names[1)].

In addition to the traditional functions of supervisory control and data acquisition (SCADA), the system offers:

- SCADA electrical functions:
  - *Generator control* including integration with the governor and excitation controller.
  - *Circuit breaker control* including integration with protection relays, event monitoring, time synchronization with 1ms resolution. Synchronization between two electrical islands must be performed and checked by the PMS before a circuit breaker is closed. The generators used for synchronization can be selected manually or automatically. This is performed by the *synchronization* function.
  - *Transformer and tapchanger control:* the mode control function changes the control mode of tap-changers, governors and excitation systems according to the status of the electrical network 2.

1 What is needed for an efficiently operating plant.



– *Motor control* including integration with motor control centers, time synchronization, automatic sequential re-start and re-acceleration release after load shedding or under-voltage.
- *Network Determination:* This and the mode control function are important supporting functions for the Power Control, Load Shedding and Synchronization features. See textbox on page 32.
- *Power control* including tie-line control, peak shaving and load sharing.
- *Load shedding* including both fast, slow and frequency based.

Both Power Control and Load Shedding are described in greater detail in the following paragraphs.

Power Control
The objective of the Power Control function is to maintain stable operation. It does this by sharing active and reactive power demand among different generators and tie-lines in such a way that the working points of the generator sets are as far as possible from the border of the individual PQ-capability diagrams so the plant can withstand bigger disturbances 3.

In the following paragraphs, the control strategies contained within the overall Power Control package are described.

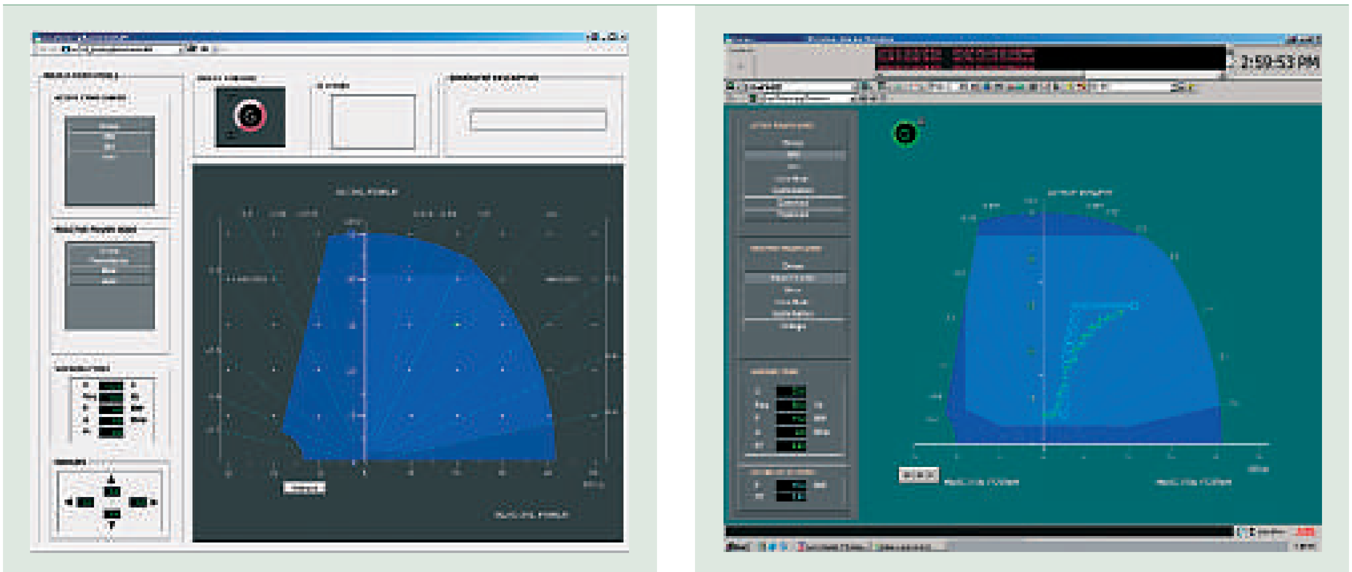
Tie-line control
The Tie-line control function, which is part of Power Control, optimizes the power exchange with the Public Power Company (PPC) to an adjustable setpoint based on contractual obligations, such as the maximum 15 minutes peak value used in Europe.

The importance of systematic operator training in a realistic setting is increasingly acknowledged as a prerequisite to reach operational best in class targets.

It works as follows: the PMS measures the imported (or exported) power, or the transmitted power between different locations, by counting pulses from energy meters. From these measurements, a sliding 15 minutes power demand forecast is calculated. When power demand tends to exceed contracted electricity import limits or a setpoint specified by an operator, the PMS will initially try to increase in-plant generation to avoid exceeding the contractual obligations. If this is not possible, the Tie-line control function will interface with the Load shedding function (see Peak Shaving below) to shed sufficient non-critical loads.

Active Power Control
As part of Power Control, the Active Power Control module performs frequency control and active power flow control at an exchange point with the grid. It monitors the actual network configuration and sends an active power setpoint to the participating generators to:

2 Generator Capability diagram with working point and mode selections.



- Maintain the bus bar frequency at a pre-defined value if that particular network is isolated.
- Or maintain an active power flow between a particular network connected to the grid.

Active Power Control Aspect decides if frequency control or power flow control is applicable. This decision depends on the actual network configuration. This means no operator interaction is required after a network configuration change.

The active power setpoints are sent to the participating generators, ie, the generators that act in Governor Auto-mode.

Power mismatch

In the case of frequency/voltage control, the working point, taken from the bus bar, is subtracted from the setpoint. In case of active power control, the difference in [Hz] is converted into an active power unit [MW].

In case of power flow control, the power working point at the exchange point is subtracted from the power setpoint.

PI control

The input to the PI control element is power mismatch. The output of the control element increases/decreases as long as there is a mismatch at the input of the PI control element.

Participating factor

The operator can assign a participating factor to each generator. This determines to what extent the generator will participate in power control. To decide on the most suitable participating factor, the operator can look to calculated factors based on the available control margins. There are participating factors for active power control and reactive power control.

Power setpoint per generator

A power setpoint can be set to keep the generator at a desired spot in the generator capability curve without affecting the frequency/voltage or active/reactive power flow control.

Reactive power control

The Reactive Power Control module is the Object Control Aspect for voltage control and reactive power flow control at an exchange point with the grid. It monitors the actual network configuration and sends an reactive power setpoint to the participation generators and/or transformer to:

- Maintain the bus bar voltage at a pre-defined value. Maintain a reactive power flow between a particular network and the grid, or another network.
- Maintain the powerfactor at the exchange point.

The Reactive Power Control Aspect decides if voltage control or reactive power flow control is applicable depending on the actual network configuration. This means that no operator interaction is required after a network configuration change.

The reactive power setpoints are sent to the participating generators and transformer.

Also a reactive power setpoint can be set to keep the generator at a desired spot in the generator capability curve without affecting the voltage and/or reactive power flow control.

Reactive power control in cooperation with transformer control

A transformer is used for main control when it participates in voltage control or reactive power flow control. Transformer control maintains the voltage or reactive power flow at a desired setpoint and the remaining mismatch between setpoint and working point (measured value) is minimized by the AVR control of the participating generators. Control parameters as gain and time integration are adjusted in such a way that the transformer control prevails.

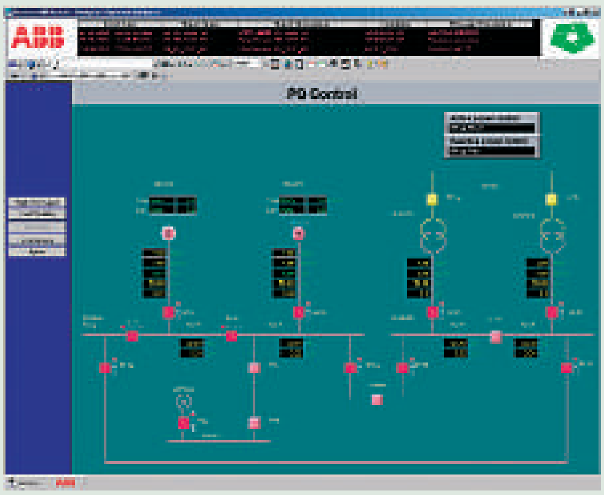
Load Shedding

The PMS Load Shedding function ensures the availability of electrical power to all critical and essential loads in the plant at all times. Load shedding is achieved by switching off non-essential loads when there is a shortage of power generation capacity in the electrical network of the plant.

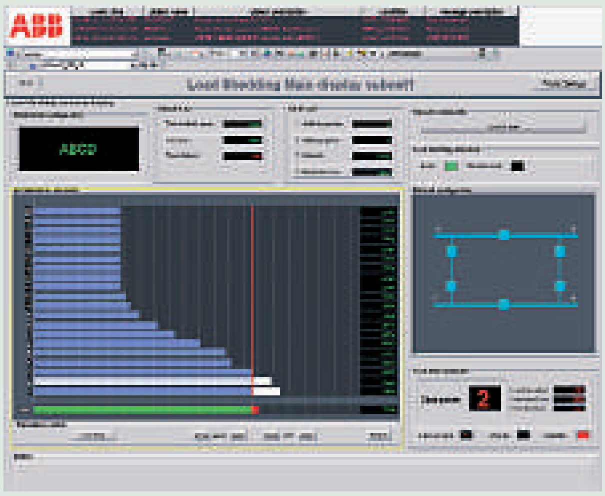
There are four different types of load shedding:

- *Fast Load Shedding* is based on electrical energy balance calculations. As soon as one or more electrical islands are detected (using network determination software), the system calculates if there is enough electrical power available in every individual island to power

3 Single Line Diagram indicating that four motors have been shed after a generator trip.



4 Graphical presentation of the accumulated effect of shedding the loads assigned to the 20 load shedding priorities.



the loads. If not, any existing demand surplus is shed. The shedding process is dictated by priority tables, which are based on the operational conditions of the process.

- *Frequency Load Shedding* (or back-up load shedding) uses a frequency drop as an input to activate load shedding. Activation of an actual shed command can be based on a frequency decay or by passing a frequency threshold. Frequency Load Shedding is usually used as an independent back-up system for fast load shedding
- *Slow Load Shedding* is used when an overload has occurred. For example if a transformer is loaded at 120%, switching off some loads to bring the transformer back to its nominal load is by far the best solution. The system advises the operator which non-critical loads he can switch off. This manual effort must be done within a specified period of time otherwise the system will do it automatically.
  – Peak Shaving is another type of slow load shedding and occurs when the following situation arises: if in-house generation is maximized but it seems highly probable the 15 minutes sliding maximum power demand will exceed the contracted maximum value, then some of the low priority loads are shed. *Manual Load Shedding* is mainly used when one of the afore-mentioned conditions for Slow Load Shedding occurred but operations did not allow the system to shed automatically.

How much to shed?

The ABB system is fast because it doesn't wait for a decrease in frequency before it starts to shed loads. Instead, its decision to shed – as well as how much should be shed – depends on the balance between the amount of power generated and consumed in every island. To execute load shedding within 100–250 ms of a disturbance, however, many calculations must be done in advance.

Deciding how much power should be shed depends on the number of priorities used, the size, in MW, of the load shed groups, and the availability of system measurements.

ABB's load shedding set-up is very flexible because an operator can adapt (online) the priority of the various plant loads to the process operating conditions and the electrical network 4. Also at the moment the system determines the shedding order, it considers how much spinning reserve is available. To utilize this reserve, the system can, and will if necessary, change the operating mode of a generator.

The coordination between load shedding and re-acceleration is also important. Re-acceleration is disabled when a load shedding action is required, and is immediately restarted once the conditions for load shedding have vanished.

In certain industries energy costs represent approximately 30 percent to 50 percent of the total production cost.

Summary

The PMS benefits are clearly visible during:

- *The plant definition phase:* the improved system stability allows tighter dimensioning and thus reduced costs.
- *Plant start up:* the PMS will ensure the power system capacity is not violated at any time by holding load start commands until the system can provide the power required to start a particular load. This helps get the plant safely on stream as quickly as possible.
- *All phases of plant operation:* the PMS will control generators and transformer tap-changers to ensure stable power system operation, as well as monitoring and controlling active and reactive power exchange with the public grid. The general workload and number of interventions from the operators are reduced.
- *Maintenance planning:* comprehensive data are recorded and aggregated on the condition of the electrical assets. The appropriate ABB Industrial IT Asset Monitors can monitor this data automatically, and the responsible people are notified when actions must be taken. The ABB Industrial IT Asset Optimizer workplace provides the overview of equipment health and the base information needed to plan maintenance campaigns.

The PMS can also be part of a broader electrical system delivery from ABB. In certain industries such as chemical, petrochemical, cement and steel, energy costs represent approximately 30% to 50% of the total production cost. ABB's PMS can pay for itself in a short space of time just by ensuring greater efficiency of power generation, import and usage under varying operating conditions.

The investment can easily be justified in both green and brown field plants, and several examples of recent installations exist around the globe. The same system is used for both electrical and process control allowing cost reduction in training, spare parts and maintenance.

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References

[1] Taft, Mike W., "Industrial^{IT} System 800xA, Extending the reach of automation to achieve continuous productivity improvements", ABB Review Issue 1/2004, pp 32–37.
[2] www.abb.com/automation

Footnote

– Electrical Control System (ECS).
– Electrical Integrated Control System (ELICS).
– Integrated Protection and Control System (IPCS).
– Power Distribution Control System (PDCS).
– Load Management System (LMS).
– Electrical Network Monitoring & Control System (ENMCS).