Optimizing Substation Automation
by Using IED Data in an Intelligent Gateway

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Abstract

This presentation will discuss the use of automation functions (PLC functions) in a substation data concentrator/gateway. It will focus on the economical advantages, the technical challenges and will be concluded with a case study.

As more and more substations are using IEDs for protection and measurement functions and the standard RTUs are becoming obsolete, intelligent data concentrators/gateways are entering the substation to be the link between the IEDs and the control center. This opens the possibility to completely replace the RTUs by placing the needed automation functions in the gateway.

Based on the already ongoing replacement of the RTUs with the IED/gateway combination this presentation will discuss the economical advantages and technical challenges.

Economical advantages:

1. No additional hardware needed; as all elements are already being placed.
2. No additional wiring needed, only communication wiring between the IED and the gateway.

Technical challenges:

1. Response times
2. Exception handling
3. Redundant gateways

Economical advantages explored

The main advantage is quite obvious. Because the hardware is already in place and completely wired, no additional hardware investments are needed. However, we must not forget the indirect advantages. Less hardware also means fewer spare units to buy and maintain, which leads to less administration and less overhead costs such as training.

As the automation functions in the gateway will interact with the field through the existing IEDs no additional wiring is needed. Again it is not only the direct advantage but rather the indirect advantages of fewer construction diagrams to maintain and so less administration overhead.

Technical challenges explored:

Because of the additional communication the response times are longer. This issue can be reduced with high-performance protocols.
Because of the distributed architecture, some additional exception handling must be added; especially in the case of invalid input data from the IEDs and error sending commands to the IED.

As the intelligent gateway is a central part of the substation architecture it might be used in a redundant mode. To make sure that there are no execution problems during a failover special care needs to be taken when programming the logic.

**Case study: Emergency load restoration**

For the CSPC refinery, an automation solution was needed so that in case of a total plant black-out the substation’s outgoing feeders are opened, emergency generators started and the feeders re-closed on a priority basis. All feeders are controlled by individual IEDs, the emergency generators have their own controller and the intelligent gateway handles overall automation and control.

With more and more substations using IEDs for protection and measurement functions, intelligent gateways and data concentrators are replacing the traditional RTU as the link between the devices and the control center. Most of these new devices provide the capability of processing data in order to implement automation functions.

The direct benefits of this approach are quite obvious – since the hardware is already in place, and completely wired, the automation functions can be implemented with no additional hardware investment. This will reduce both the engineering and installation time. However, let's not forget the indirect benefits – less hardware also means fewer spare units to buy and maintain, which leads to lower administrative and overhead costs for training.

Furthermore, since the automation functions in the gateway will interact with the field through the existing IEDs, no additional wiring is needed. Again, it is not only the direct benefits that must be considered, but also the indirect benefits of a simplified architecture, with less construction diagrams to maintain and less administrative overhead.

The following real-world case study will be examined: emergency power management and load restoration after a complete plant blackout.
Introduction

Traditionally, RTUs were used in substations to act as the link between the switchgear and the control center. Some of these RTUs had some intelligence such as interlocking functions, but no substation- or region-wide automation was available.

Now that more and more RTUs are being replaced or complemented with specialized IEDs capable of multiple protections and measurements, intelligent gateways and data concentrators have also arrived in the substation. These gateways replace the RTUs as the link with the control center, and may even incorporate inter-substation links.

Most of the new intelligent gateways have enough processing power to provide the capability of processing and analyzing data in order to implement small- to large-scale automation functions.

This combination of IEDs with powerful intelligent gateways opens a completely new possibility to optimize substation data utilization at both the substation level and the regional level, without any additional hardware required.
IED Data Availability

Because of the distributed data collected by the IEDs, data concentrators or gateways were brought into the substation to create the link between the devices and the control center. These data concentrators now have access to all the data available in the IEDs. Moreover, from the control center, only 1 communication link is needed to access the substation's data.

Since IEDs have much more processing power to perform tasks such as bay automation, interlocking and local computing of power, angle and other variables, there is far more data in the substation than a single RTU could supply.

Architectural Optimization

Because data concentrators can interact with any of the available protection devices on the market, utilities can now select the optimum price/performance protection relays without being dependent on a single manufacturer. This freedom of choice can lead to optimized substation architecture. This, in turn, leads to fewer simplified construction diagrams being drawn and maintained, as long as no additional hardware is required.

Hardware Optimization

The immediate benefit of having automation logic functions embedded in the central intelligent gateway are, of course, the freedom from PLCs or other automation devices, along with all their wiring and administrative overhead costs.

In the long run, the indirect cost reductions are even more important - less hardware means fewer spare units to manage and maintain, and less training for the engineers.

Challenges and Their Solutions

Implementing automation functions in the gateway creates several technical challenges. In this section, we will look at the following challenges with their possible solutions.

1) Response times

2) Exception handling

3) Redundant gateways
1) Response Times

Because of the way communication gateways obtain the real-time information, there are always additional delays involved. These delays are not only on the reporting side (from the IED to the gateway), but also on the command side (from the gateway to the IED).

The reporting response time can be optimized by using intelligent protocols that support unsolicited reporting, such as DNP3, IEC60870-5-101, IEC60870-5-104 or IEC61850. Demonstration tests have shown that IEC61850 messages can be faster than hardwired solutions.

Command time can be optimized by giving commands the highest priority in the gateway; this ensures that the gateway sends the command immediately to the IED. Of course, the IED must also optimize its side of the command handling, so that the final switchgear is operated as quickly as possible.

Given the intelligence of the IEDs, the response time in case of a fault is already highly optimized (as this is the main function of the IED). Since the IED operates the breaker in case of a fault; it should not be the function of an intelligent gateway to incorporate, for example, overcurrent protection schemes with a response time of less than 10ms.

2) Exception Handling

As the gateway depends on the communication with the IEDs for the incoming data and the outgoing commands, additional care needs to be taken for the exception handling regarding the communication.

There are 2 special cases that require exception handling: invalid or no input data from the IED, and problems sending commands to the IED. All other exception and error handling is pretty much the same as when using automation logic in an RTU or in a separate PLC.

The solution for handling invalid incoming data by the automation program should be based on the quality of the data. The data quality can be based on the indications from the IED (on a per-point basis) or on the status of the communication between the IED and the gateway within the gateway (assuming that the gateway monitors the communication status with the IEDs). The latter normally operates on all incoming data, as a block.

To ensure that a command is executed correctly, the automation program in the gateway should check the command result messages combined with the verification that the corresponding indications (breaker open/close) are changed within a certain time. The latter should be a standard automation programming habit.

3) Redundant Gateways

As the gateway is central to the substation architecture, it is highly preferable to have it in a redundant configuration to ensure minimal downtime. When the gateway is in a
redundant configuration, special attention should be given to failover behavior during the execution of the automation functions. To ensure a correct execution in all situations, the data between the redundant gateways must be synchronized, as well as the internal variables of the program itself. The redundant gateway software should support the synchronization of the embedded automation programs. However, it is up to the engineer to create the logic such that in case of a failover, no dangerous situations arise and that the execution follows its normal way. The logic to handle failover situations can be based on the internal program indications or on signal conditions from the external devices.

**Future Developments**

The emergence of the IEC61850 communication standard with inter-protection messages has made it possible for the gateway to actively participate in the substation protection schemes, to do so the automation functions should be able to send IEC61850 GOOSE messages based on the internal logic.

With the ever improving and expanding communication paths between the substations and the control centers, the installation of gateways in multiple substations makes it possible to use the combined intelligence of the individual gateways to provide full region-wide automation.

**Case Study: Emergency Power Management and Load Restoration**

At the new refinery of the CNOOC-Shell joint venture in Nanhai China, the intelligent gateway-IED architecture is used to re-establish the most important loads in case of a complete plant blackout. For example, the system restores emergency power to chemical cooling equipment.

An overview of the substation can be seen in Figure 1. A total plant blackout is defined as an undervoltage trip on both incomer lines.
Figure 1: Substation single-line diagram overview
The substation architecture is shown in Figure 2. Here we see the redundant control centers, redundant gateways, emergency diesel generator breaker IEDs, incomer undervoltage PLCs, emergency diesel generator control unit, and feeder IEDs.

![Figure 2: Substation architecture](image)

The following logic is handled by the intelligent gateway:

1. The two circuit breakers on corresponding incomer lines are tripped open by the undervoltage relays.

2. On receiving the two undervoltage trip signals, the master controller of the emergency generator starts the running up sequences of the three emergency diesel generators.

3. On receiving the two undervoltage trip signals, which are hardwired from 2x 6KV incomers, the automation function starts to trip all seventeen transformer, and the bus tie breaker is closed by the EDG MCP.

4. When all outgoing feeders are open and the load on the 6kV emergency bus is less then 1 MW, the automation function sets the “Permissive to syn and close EDG’s CB” signal to 1.

5. If the “Permissive to syn and close EDG’s CB” does not reach the EDG MCP due to faults on the gateway, automation function or MODBUS RTU link, the EDG MCP closes EDG CBs after an x-second delay.
6. Whichever emergency generator runs up first has its corresponding breaker closed on the dead bus.

7. When the second generator runs up, its corresponding breaker is closed via auto-synchronization.

8. Similarly, when the third emergency generator runs up, its corresponding breaker is closed via auto-synchronization.

9. The central automation function receives the breaker closed status from any available emergency generator breaker from the associated IEDs. The automation function then initiates the closing of the transformer feeders’ circuit breakers based on priority (set by the operator at the control center) and available generation. The available power generated is computed based on the number of emergency generator breakers that are in a closed position.

The solution is a straightforward state machine program that follows the logic, as depicted in Figure 3. Remarks:

A) If all feeders were open, the state machine bypasses the “Wait for feeders to open” state. This is done so that in case of a failover, the feeders are not reopened again.

B) Power is calculated on the simple formula that each generator supplies 2 MW. The whole system is designed such that only 2 generators are needed for the complete supply.

C) The action “Determine next feeder” selects the next feeder to close based on priority. However, for operational safety, feeders that were open at the start of the state machine will not be closed. The idea is that those feeders were open for a reason, so the automation function should not close them.

D) There is no immediate check if a feeder closed immediately; rather there is a general retry mechanism for all feeders that did not close due to whatever error (communication problem, no power on the close coil, etc.). This is done to reduce the total restoration time.

E) When the incomer lines are restored, the automation program can get into “IDLE” state without closing the remaining feeders. It is up to the operators to handle this.

The whole system was commissioned in November 2005 to the complete satisfaction of CNOOC-Shell. Under normal conditions, it takes less than 1 minute to execute the complete cycle.
Figure 3: State machine