

# Applications and Benefits of a New Generation of Combined Protection and Control Devices

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*Presently, more than 15 years of experience with numerical protection relays and substation control systems led to a new generation of bay level devices. Based on a common hardware for protection and control this generation of modern multi-functional relays allows convincing economic and technical solutions for substation protection and automation. Especially combined protection and control devices build basic bricks for the automation of substations. The integration of protection expertise, sophisticated control with high security, measurement, programmable logic, local human machine interface and open communication make those devices – often named as One-Box Solutions - ideal for new and refurbished substations.*

## 1 APPLICATIONS AND REQUIREMENTS

It has always been a tradition in the power industry to consider the market demand and the culminated solution as a two way street. The sharply rising market demand is prospecting for a state-of-the-art-technology and cost efficient solution. Traditionally it is mostly first the utility who takes the step with their perception of modernizing their power system taking into account the technological advances and the economical aspects. Once it is set up there then this is just a paradigm for the industries to utilize and take advantage of the prevailing solution.

Power system operators determined that the most cost-effective approach to replacing the antiquated units was to develop a comprehensive platform that emulates and transparently replaces their complete secondary system by a single device as one box i.e. all the protection, control, monitoring, metering, oscillography and communication features are provided within one chassis.

The emerging technology of numerical processors is widely exploited to revolutionize the power industry. The microprocessor, which allows manufacturers to develop products that are smaller, cheaper and smarter, is the most powerful tool for developing an intelligent electronic device (IED) for a seamless integration into a power automation system. The integration of microprocessors in protection, measurement and control hardware was the most significant technological development that has impacted the utility field.

The development of high speed digital communications has been a great technology enabler. The trend in this sector seems to continue as the developer, the manufacturers seeking desperately the solution for a unified communications protocol.

The sharply rising market demand is prospecting for a state-of-the art technology and cost efficient solution. This was the case in 60's till mid 70's with electromechanical relays, till late 80's with the static analog devices and from then onwards with the numerical devices for protection and control.

The user is prone more and more to the devices with reduced sizes, increased functionalities, with high degree of operational flexibility and finally, because of the cost pressure on secondary devices in MV substations, the indispensable improved Performance / Cost ratio, which will have an impact on his overall expenditures for setting up a substation. System integration in the utility enterprise has entered a new era. Utilities, in achieving improved operations, competitive advantage and operational efficiencies are biased to consider the economic aspects and the principles of design of an advanced protection, control and monitoring system in one box.

Utility deregulation promises customers lower costs and enhanced services. As the wheels of deregulation move forward, most utilities focus on reducing costs. Utilities achieve this goal by slashing the overall component cost. Electric utilities have transformed their business to take full advantage of technology.

When the first product came into market 1995 the users were reluctant and apprehended because of the immature technological advancement. It was then a momentary set back for the solution provider because of the declining interest of the users. However, it has now taken up a dramatic paradigm shift and the demand for one box solution (OBS) is increasingly growing and this trend seems to be continued for the next decades to come. To sum up the survey of the current market situation the following is stipulated:

### **Market needs**

#### **What are these?**

- State-of-the-art technology
- Uniformity of the design
- Higher degree of flexibility
- Also work as a stand-alone autonomous device
- Shall be able to interface with the existing systems
- Reduced cost with increased functionalities ( increased functionality to cost ratio )

#### **Why are these?**

- Convergence of technological, political and economical forces
- Keep track on the technological advancement
- Modernize the power system
- Cost pressure on secondary devices in MV substations
- Era of deregulated electricity market



**Figure 1: Application of One-Boxes in 20kV Substation**

Thus the scenario was set out for initiating the development of a revolutionary device. Reciprocating the above market requirements which were posing a challenge to the protection industry ALSTOM has reacted promptly with taking up this challenge and launched a combined protection and control device as a one box solution in 1998 within a very short span of development by very usefully exploiting the gained knowledge and utilizing the prevailing offshelf hardware and library of the software.

The culminated solution resulted in improved functionality and reduced maintenance costs, space and interdevice wiring with getting rid of the comprehensive and time consuming documentation. Increased functionality to cost ratio for MV/HV networks users, due to integration, where a multitude of protection functions is integrated in one box (Figure 1) for even the lesser costs as was in the past. Functional and discipline integration go hand-in-hand with cost savings as hardware cost is saved. Multitude of protection functions and two disciplines i.e. protection and control are integrated in one box. Hardware cost saving by the user e.g. CT & VT are required only once. The control and monitoring information are directly connected to the OBS without any interposing relays which allows an optimized wiring and less documentation (Figure 2).

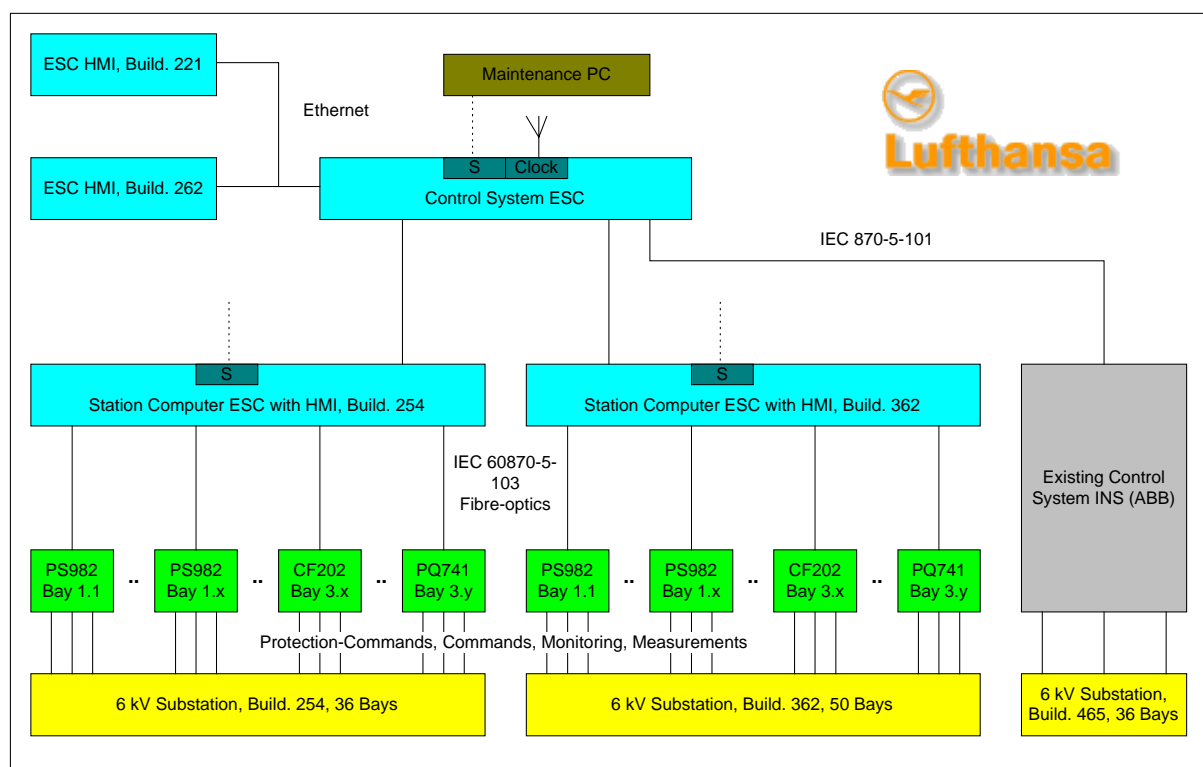


**Figure 2: Reduced Wiring inside MV Cubicle**

- Only one device replacing all the secondary equipment, reduces device interwiring and comprehensive documentation
- Quick customization at site without hardwiring and the pertaining documentation
- Lower time scale for the evolution of the new device (reduced development and manufacturing phases)
- Reduced training and commissioning duration
- Increased functionality and high degree of flexibility
- Astronomical amount of system information available by the optimized information management (LCD Panel)

Thus there is a growing demand in this era of deregulated electricity market of such a cost effective solution and the power generation operators world-wide are making ever increasing efforts to cut every excessive cost. From numerous existing solutions, one of these is illustrated as in Figure 3, showing the application of such devices in a most comprehensive and sophisticated system:

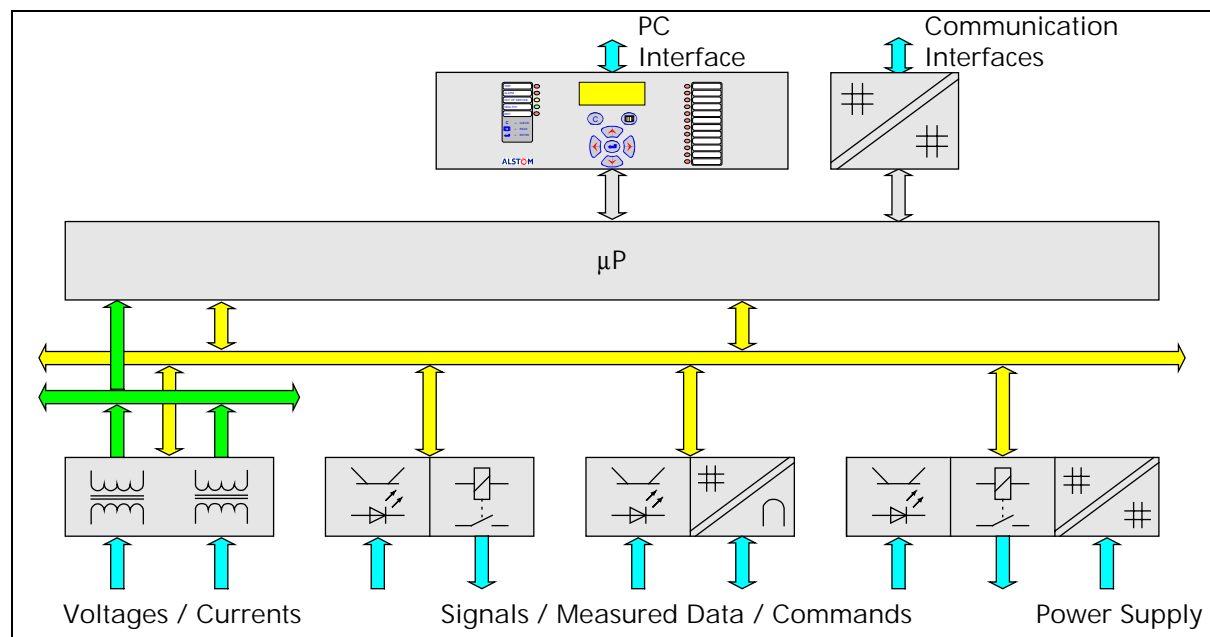
- At Lufthansa Maintenance Center, Hamburg, Germany, both refurbishment and extension of the distribution network is being carried out seamlessly
- The specification was to provide protection and control functions for 84 different MV bays of a 6 kV distribution network, replacing older secondary devices by one device
- 72 OBS ( PS 982) are employed, providing overcurrent protection and the control
- 12 bay controller (CF202) are integrated in the bays in combination with existing distance and line differential protection devices
- Via IEC 60870-5-103 all bays are then integrated into substation control system ESC from ALSTOM
- Via IEC 870-5-101 additional 36 bay were incorporated in an existing substation control system



**Figure 3: Application of One-Box Solutions for Refurbishment / Extension**

## 2 HARDWARE CONCEPT

The OBS devices are developed on a state-of-the-art hardware platform [ 1 ] for MiCOM Px3x protection devices. Besides the overcurrent and distance OBS, this platform presently is covering distance protection devices for MV, HV and EHV applications, feeder and motor protection devices, transformer differential protection and bay computers.



**Figure 4: General Structure of Hardware**

The overall structure is shown in Figure 4. The most remarkable items are:

- Modular hardware system using standardized boards providing highest level of reliability and EMC
- Single processor system for all protection and control functions
- Controllers with serial interfaces to the main processor for dedicated purposes:
  - Human machine interface (HMI) board, including full-graphical display and local PC interface. The HMI can be mounted separately from the device case for ergonomical local handling
  - Communication board with up to 2 serial interfaces for substation control and remote access
  - Special board for determining the direction of ground faults in compensated or isolated power systems by evaluation of the transient signals
- Universal I/O boards:
  - All contacts are rated for tripping purposes. Wide-range binary inputs (24...250 VDC) with nonlinear characteristics to provide high interference suppression. Analogue I/O board for transducer connections
- Universal analogue input board (rated nominal frequency 50/60 Hz settable):
  - Dual-rated CT inputs (1 A/ 5 A); VT input range between 50V and 130 V
- Wide-range power supply board (48...250 VDC, 100...230 VAC)
- Compact case size: 4U height, 40TE width with standard screw-clamping pin terminals

### 2.1 PLUG AND PROTECT

The basic information of each board (e.g. board type, production number) are stored in an EEPROM on the board itself. During power-up procedure, this information is read from the processor and compared with the permissible assembling. Thus the system checks the hardware integrity. Parameters (like I/O configuration) and functions (like check synchronising) are only made visible to the user if the required boards are fitted.

## 2.2 CT / VT CALIBRATION BY SOFTWARE

Measuring deviations resulting from the CT's and VT's as well as from the A/D converter are automatically determined by the OBS during a calibration procedure. The necessary correction factors are stored in EEPROM on ct/vt board and processor board separately, to allow easy replacement of defective boards. This calibration procedure is the first step of the final factory test of the device. If the deviations exceed permissible limits, the device is refused. Statistics as shown in Figure 5 allow continuous supervision of the production quality.

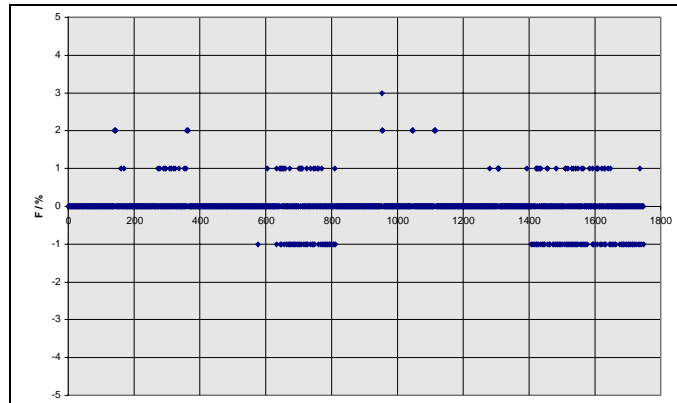


Figure 5: Relative Error F of VT's at  $V = 0,75 V_{nom}$

## 3 SOFTWARE CONCEPT

The software concept takes care for the relevant needs of the application process:

- Highest priority for protection tasks with shortest tripping times (instantaneous elements)
- Permanent access to the control functions at any state of the power system and the OBS device
- Continuous self-supervision of the hardware and software
- Incorporating further requirements on an open software system which allows future functional extensions and a „re-use“ of type-tested protection and control routines

The basic work of the processor is to control A/D conversion and to pre-process the new samples (numerical filtering, data organization ...). This is done in a non-maskable interrupt (NMI) procedure which is run 20 times per cycle, e.g. every 1 ms in a 50 Hz power system. The remaining time is available for the protection, control and communication tasks, as given by functional groups (e.g. DIST = distance protection) in Figure 6.

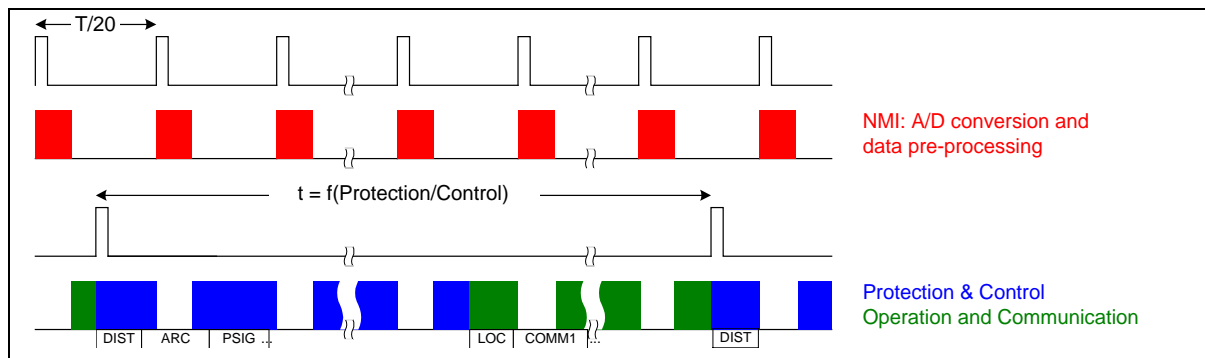


Figure 6: Chaining of SW tasks

The processing time for each task is depending on the status of the OBS device as well as on the power system. E.g. during short-circuit conditions the protection tasks obtain more processing time, after fault-clearance communication may get more time to transmit the fault data to the substation control system. In any case each task has to be processed once per processing cycle to prove correct operation of the device. The overall turn-around time of the process is typically 15 ms, maximum 25 ms.

## 4 FUNCTIONALITY

The functionality of modern numerical protection and control devices has a modular structure. This allows both the common use of basic functions which are available with all devices of the same range, and the use of the same module in different devices. The functionality of OBS devices is splitted into the following 3 sections:

- **Configuration** = physical and functional accommodation of the device to the application:
  - Assignment of binary inputs, output contacts, LED's
  - Configuration of measured data inputs and outputs
  - Local human machine interface (HMI) and communication interfaces
  - Activation of required protective and control functions
  - Selection of the bay type:  
The OBS fixed logic already includes over 200 different bay templates (including mimic diagram, I/O and COMM configuration, interlocking logic etc.). Using these templates renders any engineering superfluous. In addition, one customized bay template can be set up and downloaded to the OBS by the customer himself.
- **Global Functions** = general services:
  - Management of alternative setting groups (selection via HMI, serial links and binary inputs)
  - Self-monitoring
  - Cyclic measurands (V, I, f, P, Q,  $\cos \phi$ , energy) as per unit and primary values
  - Data acquisition and recording during normal operation/ operation under overload/ operation under earth-fault in compensated systems/ short-circuit
- **Main Functions** = specific protection and control functions:
  - Protective functions with fixed logic like distance protection, including signaling scheme logic, switch on to fault protection; autoreclosing logic; measuring-circuit supervision and back-up overcurrent; definite time and IDMT overcurrent; thermal overload; etc.
  - Limit value monitoring for indications (alarms) that permissible operating limits (like overcurrent or undervoltage) are exceeded
  - Flexible programmable scheme logic using boolean logic and timers to set up specific protection schemes
  - Control functions for control of up to 10 switching devices, including interlocking, etc

### 4.1 HUMAN MACHINE INTERFACE

Special care has been taken to the local HMI (Figure 7). A graphical LCD (Figure 8) is used to clearly show the mimic diagram of the bay and the status of all switching devices. By use of only 3 buttons any switching device can be selected and operated. Beside this bay control capabilities the HMI allows easy access to the measurements and the event log. The selection of measurands is user-configurable. According to the actual state of the power system - normal operation/ operation under overload/ operation under earth-fault in compensated systems/ short-circuit - the measurand tables are automatically updated. Only the fault measurands are kept until reset by the operator or update due to consecutive faults, as they are of transient nature.

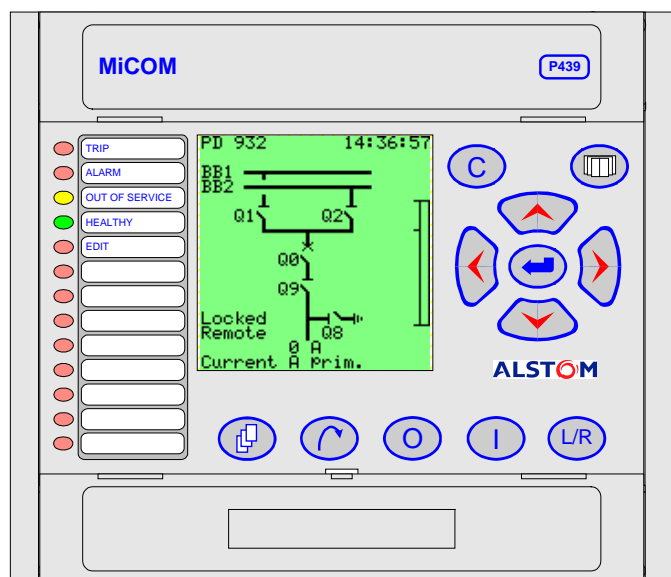


Figure 7: Local HMI



Last but not least the HMI allows access to all settings (identification and configuration settings, function parameters, etc.), operating data (cyclic measurands, logical and physical state signals, test functions, etc.) and recording data (from self-supervision, fault records, etc.). Due to the large number of parameters and information of multifunctional devices, the organization of the data must be done carefully within the menu tree. It is a must that they are presented at the local HMI in the same way as by PC operating software and documentation. This consistency is obtained by using a common data model which is set up by using a central data base.

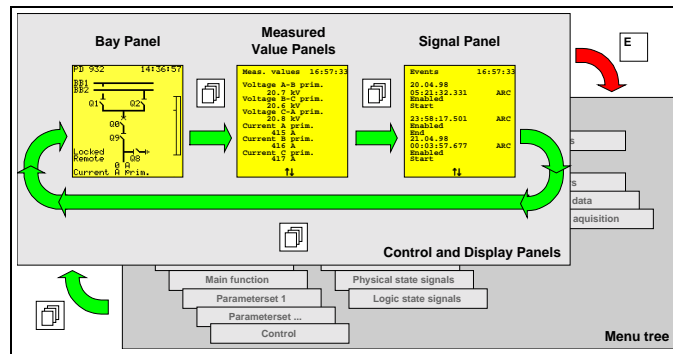


Figure 8: Selection of LCD Panels

## 4.2 CONFIGURATION AND PARAMETER SETTINGS OF CONTROL FUNCTIONS

In the past the application of control functions was often strongly linked with customer dependant schemes and modes of operation. This led to a time overhead during engineering, commissioning and documentation. Those overheads could be avoided using One-Box Solutions due to implemented, pre-defined and type-tested schemes. Control functions in this sense are related to switchgear control, monitoring and interlocking, while auto-reclose and breaker failure are treated as protection functions. The configuration and setting of both functional sections is done with the same tool and follows the same philosophy. This is based on a model of functional groups as explained. These functional groups are modeling internal functions and the of external primary devices like breaker or disconnectors. A device-specific model is containing information about the physical interface, operating time constraints, modes of operation and applicable schemes of a primary device. The information related to a single external device is grouped together in a single functional group. The model of a bay or zone is build up on the complete set of functional groups of external devices. To support an easy configuration of the One-Box a catalogue of predefined types of bays was defined. Presently more than 200 types of bays including different methods of device operations are implemented in the database of the One-Boxes. This database is containing information on the external devices itself – as described above -, the related mimic diagram, applicable interlocking equations and basic communication structures.

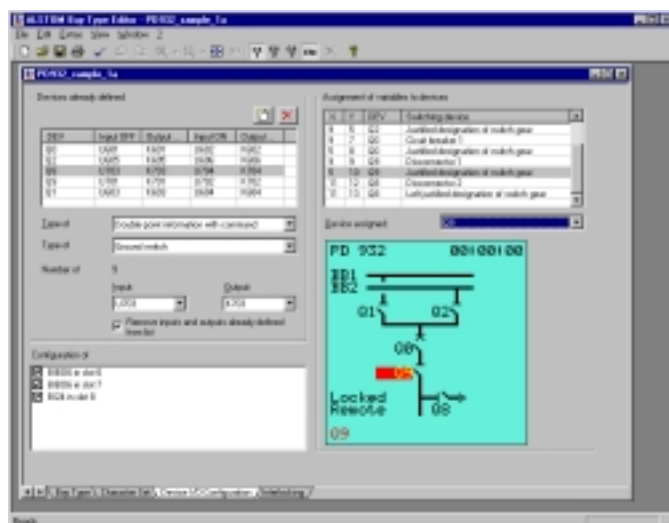


Figure 9: Bay template configuration

The basic engineering is the choice of the applicable bay type. By using a given reference number this bay can be configured by a single setting of this reference number of the bay. Nevertheless application specific requirements could be implemented by changing each single information object (e.g. operation time) by the user. If a pre-defined bay is not applicable, a user-specific type could be designed with a specific module inside the setting software MiCOM S1 (Figure 9). This configuration again consists of the physical I/O, the HMI configuration and the interlocking equations. The created file could be downloaded to the One-Box. The setting itself is based on the selection of one of the already implemented or downloaded files with possible modifications of settings.

### **4.3 OPEN COMMUNICATION FOR SUBSTATION AUTOMATION**

Open communication is starting to be a key factor for digital equipment inside substations. The reliable and quick information exchange between digital equipment inside the substation and network control centers builds the backbone of a cost effective network management. In addition to the information related to telecontrol the remote access for protection and control engineers to a single device is reducing reaction time in the case of network faults or equipment failures. Modern communication links provided by the digital equipment are offering those features and are allowing to integrate them into digital substation control systems (DCS). Especially for One-Box Solutions, an integration into third-party systems is requiring an open interface. Due to historical reasons different national, international and industrial standards had been developed around the world, mainly dealing with the protective information. To be able to cover the different requirements, One-Box Solutions as the stand-alone protection or control devices are supporting multiple protocols. They could be selecting out of a list of protocols: IEC 60870-5-103, IEC 870-5-101, MODBUS, DNP3.0 and K-BUS/Courier. Control information is implemented in the "private" range of the mentioned protocols, but the implementation is open. Presently, in addition to the integration into ALSTOM Control Systems, independent vendors of RTU's and DCS's are supporting this implementation. Beside these widely used protocols, ALSTOM is supporting standardization activities and pilot projects [ 2 ] on substation communication inside IEC. Main focus is given to IEC 61850, which is going to cover EPRI's UCA.2 and the IEC approach in a single standard.

Three independent interfaces are provided: on the front one local interface to a PC with the setting software, one the rear one for a remote access via modem and one for the serial link to a DCS or RTU. The latter link could also be used for time synchronization. Depending on the accuracy of the master, the accuracy will be within 10ms to any other device in the communication network with a resolution of 1ms. Another source for time synchronization could be a clock impulse or an IRIG-B signal.

## **5 CONCLUSION**

The application of modern technology in secondary equipment in substations allows highly available, cost effective solutions for refurbishment, extensions or new substations in deregulated energy markets. The "Total Cost of Ownership", that is the costs for purchasing, training and maintenance, could be decreased dramatically due to use of products with same properties for different applications. Applying One-Boxes of the ALSTOM MiCOM range is leading to additional cost reductions due to easier wiring schemes, minimized commissioning times and simplified documentation. Open interfaces are allowing the integration into substation control systems or RTU's. This ensures quick access to relevant information processed by the secondary equipment. Modern solutions on communications are providing access not only locally but also remotely from the SCADA system or a PC of the protection engineer. This will cause additional savings in network operation.

## **6 REFERENCES**

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- [ 2 ] Schubert, H.; Haude, J.; Janz, A.; Rudolph, T.; Schäffler, T.: A Pilot Project for Testing The Standard Drafts For Open Communication in Substations; CIGRÉ, 2000