Inter and Intra Substation Communications:

Requirements and Solutions

by

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Abstract
As the substation communication world searches for the "Promised LAN", it would be helpful to have a roadmap to give direction to the search. Many are the expectations of a LAN flowing with data and able to connect with any Intelligent Electronic Device (IED) that was ever made. Such expectations must be tempered with the cost and complexity of achieving them. This paper presents an outline of the communication requirements of the myriad of IED's in existence in the substation today as well as the expectations of what second generation microprocessor based devices might be able to do. Requirements will focus on language issues, system capabilities, performance requirements, external interfaces, environmental, and quality issues. Some attention will also be given to the architecture of a solution and some guidelines as to how this structure might be built.

Introduction
From the introduction of processor based devices, we have had the ability to communicate with these devices. The ability to communicate gives added value to the IED and as such, has hastened their implementation. As time has gone on, we have watched communities of these devices sprout up in the substation - typically with no concerted attempt to inter-communicate much less interoperate. As a result, a veritable "Tower of Babble" has arisen inside the substation. Attempts to date to achieve some semblance of common communication have focused around "Rosetta Stone" solutions whereby a translation module of software is located between the IED and host computer. Although this technique achieves today's goals, translation hardware is usually required and creation of the translation module can be costly and time consuming. Another aspect is that revisions and generations of new IED's have become a frequent occurrence demanding constant "stone cutting" and "chipping" of translation communication software. Newer IED designs implement faster communication rates, have more data to communicate, and are capable of performing some programmable logic functions.

In view of future capabilities and a continuing proliferation of IED's in the substation, a cry has come from the utility community to create a framework for not only common communication but an architecture that will provide for interoperation. Interoperation implies the ability to "plug and play" and also to be able to "share" data and functions. As an example, a protective relay may be required to provide a "check synchronism" function which requires the magnitude and phase angle comparison of two voltages. The relay performing the function may have intrinsic access to only one voltage. The other voltage may be available from another device in the substation . An interoperable system could then negotiate for access to the other voltage and as such, avoid all the overhead involved in direct wiring.

Integration Benefits
As substation integration becomes a reality, there are numerous benefits that can be realized. With data sharing, wiring between devices can now be minimized. Distributed data acquisition now becomes the foundation of substation integration. Traditional hardware devices such as the Remote Terminal Unit and the Digital Fault Recorder now become primarily functional entities that draw on other IED's for their data. Interoperation permits distributed functionality, that is, the data and/or the decisions needed for a particular function may reside among multiple IEDs.

Such changes in the substation design paradigm can be measured both quantitatively as well as qualitatively. Quantitatively speaking, substation integration has the potential for the following savings [1]:

- Elimination of the station fault recorder & wiring
- Elimination of the station Sequence of Events recorder & wiring
- Minimization of RTU wiring

- Minimization of Breaker Wiring

Qualitatively, the integrated system brings with it:

- Reduced O&M through "Real Time" condition monitoring
- 100% redundancy in fault recording
- Rapid fault location
- Integrated Protection & Control

and many others.

Requirements Document Creation
Through the funding of EPRI and in conjunction with numerous IEEE Working Groups and the MMS Forum, work has begun on a top down design to define the requirements for an integrated Protection, Control, and Data Acquisition communication system. The requirements document (open to the public for review and comment) is intended to be the foundation of an open protocol definition that will focus on peer to peer communication in the substation and is expected to have extensions to other areas of power system communication.

The software architecture is based on the International Standards Organization (ISO) seven layer Open System Interconnect (OSI) model for communication protocols [2]. This model breaks a protocol down into 7 independent functional entities that can be linked together (depending on the functional requirements) to create a protocol definition. In the substation environment, there are three layers that are applicable and only the bottom one is of interest to the utility. Figure 1 illustrates this shortened stack of protocol agreements. The bottom layer is know as the "Physical" layer and defines how one connects into the system. For example, do I connect a fiber optic cable or a pair of copper wires. The middle layer in this Substation stack is the Data Link Layer which defines how the data is packaged.

The top layer of this model is known as the Application layer. It is at this level at which the user or user's program interfaces with the communication protocol and ultimately other IED's. It is also at this level where the greatest challenge lies as the development of a common language is required here in order to interoperate among the various IED's. The challenge here can be equated to communication through the spoken language. As a simple model, the basic building blocks of most languages are nouns and verbs. Combinations of these nouns and verbs express requests, issue commands, and exchange information. The reason we can communicate together is because we have all learned the same nouns and verbs in the same language and can turn to a dictionary to describe the words we do not understand.

The requirements definition process mandated some technique whereby the various information items and functions of the IED's could be described and where that description could be shared by all. A device description technique known as Object Oriented Methodology (OOM) has been adopted as a fundamental requirement in the overall design process. OOM provides a tool whereby the "nouns" and "verbs" that describe an IED and its functions can be created or "abstracted". The "nouns" or the information contained within the IED are known as the "attributes" of the object and the "verbs" or what the IED can do to the data are known as the "methods". For example, a relay will make measurements of voltage and current and compute watts and vars. The attributes for this one aspect of a relay would be: Volts, Amps, Watts, and Vars. Subsequently, one of the methods would then be "Compute".

In establishing the groundwork for abstracting the numerous attributes and methods of the substation IED's, a model of the model or a "meta" model was created. This "meta" model defines data that would be present in any type of IED. There is a standard diagram that is used to construct the object model which is illustrated in Figure 2 via the "meta" model for an IED.

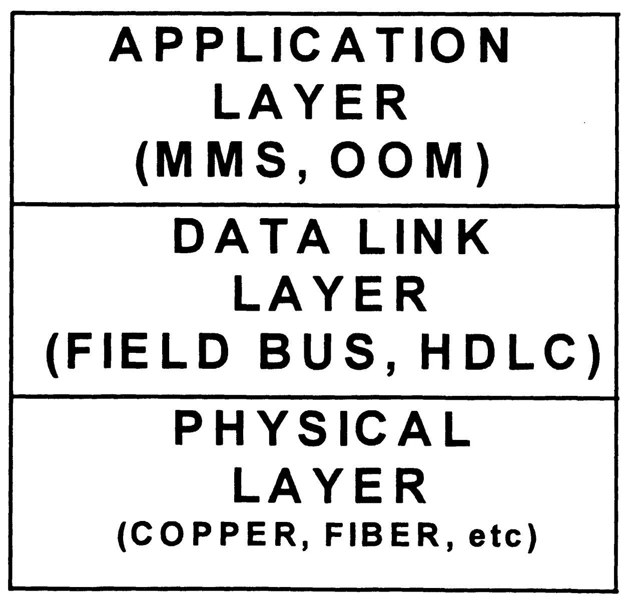

Figure 1
3 Layer Protocol Stack

The top line is the name of the object being described which in this case is a Virtual Device object. The middle section is the "attribute" list and the bottom section is the "methods" list. Clearly, there are more attributes and methods needed to describe, for example, a relay object. The beauty of the object modeling approach, however, is that various attributes can be grouped in classes and then linked back to the base model. This technique allows the addition of new attributes without having to re-do the definitions and assignments of the previously defined attributes.

Work is now in progress in the MMS Forum and the IEEE Power System Relay and Substation Committees to define standard or public object definitions. Common items such as Voltage, Current, Watts, Vars, etc. can very readily be agreed upon as far as a standard definition goes. It is inevitable, however, that each manufacturer's IED will have attributes that are new or unique to that IED. These "vendor specific" attributes, being otherwise unknown to anything else in the system, need a mechanism to define what they are.

As such, the concept of "self defining data" was included in the requirements document. In response to the standard query "who are you?", an IED would be required to download its object definition, complete with a data dictionary, to define any "vendor specific" attributes. In this manner, an RTU function could automatically query all IED's in the substation and compile a standard list of the information it is required to obtain.

System Requirements

System functionality was based on application requirements of existing relaying schemes such as breaker failure, reclosing, fault recording, metering, and sequence of events recording. In so basing the thinking, system capabilities, performance requirements, facility, environmental, and external interfaces were specified to meet these application requirements. The various elements fall out as follows:

System Capabilities

Addressing - each data source and receiver need to be identified by and respond to a unique address. One issue to be resolved is whether all IED are assigned a unique address in the universe similar to the addressing done on Ethernet boards.

Broadcast - the ability of a pre-specified group of receivers to respond to a common address. This feature is useful for re-triggering multiple IED's when one IED is triggered for a data capture. Broadcast transfers can reduce the total traffic loading on the communication system, however, broadcast messages cannot be acknowledged and thus cannot be used when confirmation of a message is required.

Multicast - a variation of Broadcast whereby multiple addresses can be specified to receive a message.

Directory Services - automatically creates and maintains a map of all network resources. This function is critical for automatically configuring the network.

Negotiation - the ability to query the availability of required system data elements and methods. For example, the IED doing check synchronism may need to negotiate for the availability of the voltages on the network.

File Access, Transfer, and Management - the transparent transfer of data files between IED's as part of the data management function of the various IED. As processor power increases, the number and size of these data files will increase in kind.

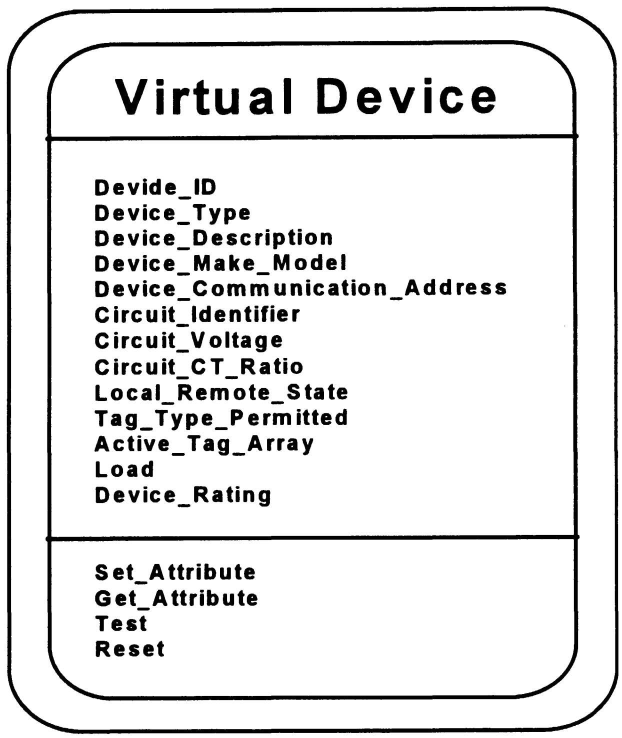

Figure 2
Standard Object Model

Network Access - this is how an IED obtains its ability to respond to a query or to offer and unsolicited message. There are two primary access methods for consideration:

> **Peer to Peer** - wherein any IED in the substation can communicate with any other IED. Peer to peer can take place either through controlled access (such as a token-passing scheme) or via random access (such as the listen before you talk access of Ethernet). A variation of either of these access methods is the ability to permit "priority access", that is, the ability to interrupt a message transfer with a higher priority message.
>
> **Master / Slave** - wherein IED's in the system only responds to requests from a master device. A variation of this occurs where there are multiple masters - each capable of peer to peer communication.

Network Management - this shall provide the network manager up to the minute information on the network size, operating conditions, alarms, system loading, and error statistics. This function shall also be used to add new devices to the network.

System Performance Requirements
To implement the various functions that are envisioned for implementation on a substation LAN, the following performance requirements have been defined:

Time Synchronization - Two levels of time synchronization have been identified in the substation. For general purpose synchronizing, a time accuracy of 1ms ±0.1ms was selected. For higher accuracy data, such as phasor measurement and data sharing, an accuracy of 1μsec ±0.5μsec has been chosen.

Timing Constraints - data transfers intervals were divided into three categories, namely, "High Speed" for data transfer requirements less than 10ms, "Medium Speed" for transfer requirements greater than 10ms and less than 1sec, and "Low Speed" involving data transfer rates greater that 1 sec. Note: At this time, the requirement for the exchange of High Speed sample data was not a priority and as such was not addressed by this document.

Delivery Times - the time allowed to transfer any routinely updated data element from a sending to a receiving IED must be less than the average update interval.

System Quality Requirements
The following elements deal with the question of "how well" the system performs its tasks not only today but also tomorrow.

Scalability - the protocol profile chosen should be robust enough for operation today and should have a clear migration path to increased performance in the future.

Reliability - the system shall provide error free data transmission, shall possess "fail soft" recovery from link congestion, and shall provide support for link and/or equipment redundancy.

Transportability - the system software shall be migratable to multiple hardware, software , and network operating environments and support the object management structure chosen as well as its expansion.

Flexibility and Expandability - the system shall have adequate address space for today and moving into the future. It shall easily detect and add on new devices hooked into the LAN. It shall support on-line network and IED system upgrades.

Security and Integrity - provisions shall be available to prevent unauthorized access, provide management of user authorization, support for encryption, and automated virus detection.

The Number of the Beast
As the requirements lead to a proposed solution, one of the questions that arises is "how big" or "how fast" is the size of the animal that is being defined? Taking a stab at some numbers for two different system requirements, the results roll up as follows:

For a "Medium Speed" system that is addressing 32 IED's once every second and transferring up to 256 bytes each second, an aggregate throughput of about 65kbps would be required.

For a "High Speed" system also addressing 32 IEDs on a Token Passing network but with a smaller data packet of 64 bytes and a response time of 4ms (including any turn-around time), an aggregate system throughput of about 4Mbps would be required. The benefit of "Priority Access" can be seen here in that similar response time can be achieved with a lower data rate.

Implementation

The current institutional efforts to define structure for the new digital universe must be accompanied by the rapid development of implementation vehicles if the industry is to advantage, rather than succumb to the new technology. If the current standards work is to have more than historical value it must be accelerated to synchronize with the pace of technological change, be viewed as a real time consensus definition of best practice, and be connected to an implementation path embraced by the utility industry.

Utilities are driven by the need for increased productivity in the emerging competitive environment, while at the same time are undergoing personnel reductions which weaken their ability to define and implement integrated automation systems to improve productivity. Functionally fragmented institutional structures are evolving to support these integrated system goals, but the trauma of such major changes further inhibits internal solutions.

Figure 3 illustrates the principal elements of substation integration and automation systems. The integration function has, in today's environment, typically moved outside of the utility box. The Integrator's challenge is to define best fit / best value solutions tailored to the specific utility's goals. In this consulting role the Integrator is expected to develop specifications for open systems with maximum flexibility for growth. His role can be expanded to identify the supplier of products and services, layout the program, manage the program, or take turnkey responsibility, as well as providing ongoing support and services.

The IED suppliers provide protection or monitoring based intelligent digital devices which are performance / cost optimized in a rapidly changing competitive market. The IED's also provide the data acquisition and control interface with the power system at the substation.

The Software suppliers provide custom software interfacing, drivers and control functions to integrate the IED's and provide the required system functions. The Integration Equipment includes the substation control and interfacing equipment such as Programmable Logic Controllers (PLC's) Personal Computers (PC's), Remote Terminal Units (RTU's), and associated communication equipment.

The value to the utility of being able to implement open systems which meet current and future requirements with interoperable elements is obvious. The alternative of a single supplier providing all elements integrated into a closed system has generally not been acceptable to the utility industry. Several other approaches are emerging which include:

- Combinations of the Software supplier and the Integrator
- The IED supplier with the Software supplier
- The integration Equipment supplier with the Integrator

and so on. In the absence of at least an appropriate de facto standard embraced by all the often competing elements, the solutions will continue to be somewhat cumbersome, inflexible and costly.

The two essential aspects of realizing the benefits of the application of digital technology to substation and power system automation are: First; a fast track commitment by the utilities to sponsor and support the definition of open standards for integration; and Second; the development and utilization of Integrators who effectively implement these emerging standards.

One example of the possible ways in which this could be accomplished would be the utilization of existing utility organizations such as EPRI to establish system integrators which, because of their utility sponsorship, would implement the preferred standards, represent the utilities, and strongly influence the support of the related hardware and software suppliers. Various other proactive utility initiatives would appear to be worth considering. The screens for such initiatives might include:

- support by a significant number of utilities
- a possible equity position by the sponsoring utilities
- a strong linkage with the continuing "standards" activity
- a strategy that allows customizing for individual utilities
- operational control at the Integrator with an advisory board representing the sponsoring utilities
- the assignment of key utility personnel to the Integrator during a project.

The alternative of waiting to see what becomes available does not look very attractive for the utility.

Conclusions

The search for a common communication platform in the utility industry is becoming acute being driven by the proliferation of communicating Intelligent Electronic Devices. A "top down" approach to solving the communication problem has been sponsored by EPRI. This effort has resulted in the creation of a requirements document that is open to the public for review. A summary of the basic requirements is presented. The heart of the requirements document is the use of Object Oriented Methodology as the tool to create a common IED communication language. This effort will only be effective if there is a concerted effort between the various industry players to quickly bring this technology to practice.

References

1. "The Integration of Protection, Control, and Monitoring is a High Voltage Substation", M. Adamiak, E. Weintraub, J. Schnegg, J. Burger, Proceedings of the 46th Annual Texas A&M Conference for Protective Relay Engineers, April 12-14, 1993.

2. ISO 7498 - OSI Basic Reference Model

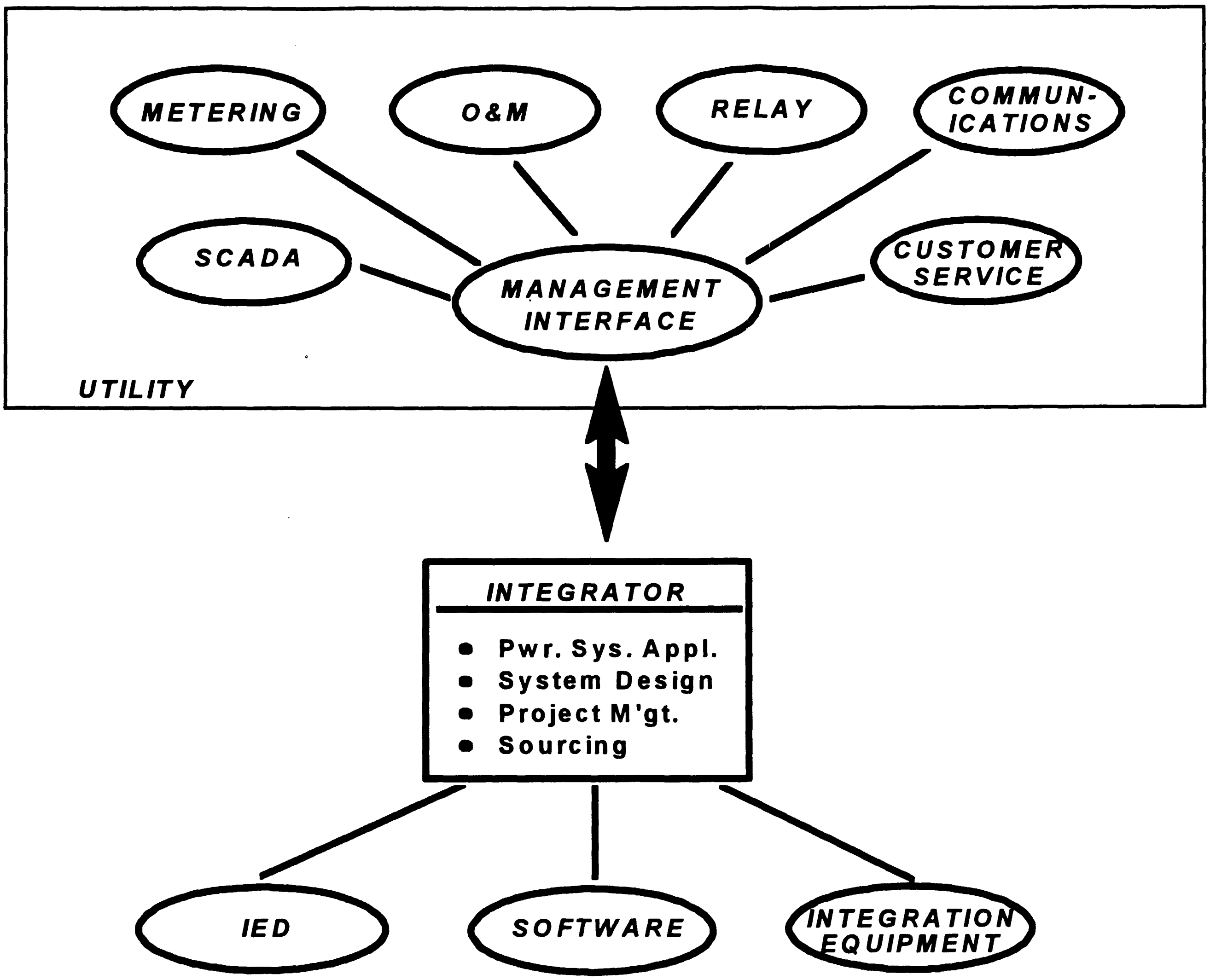

Figure 3
Principal Elements of Substation Integration and Automation Systems