NONCONVENTIONAL SYSTEM DESIGN FOR FLEXIBLE DATA RETRIEVAL AND USE

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APPROPRIATE INFORMATION VIEWS

Instrumentation and Control (I&C) System Engineers often begin the control system design process by identifying the variety of inputs and outputs (I/O) and defining the processes and programs needed to produce output data. In the substation portion of SCADA systems, these I/O connections were traditionally in Remote Terminal Units (RTUs). Recently, less traditional systems have used Intelligent Electronic Devices (IEDs) for some or all of the I/O connections.

However, to properly address the system requirements, the system designer needs to examine what the system needs to do before jumping to the details of how to accomplish the needed tasks. To determine the required functionality of instrumentation or control systems to address the system needs, one useful approach is to examine the power system and apparatus and determine what you want to really know about each component. The purpose of the instrumentation aspect of the system is to provide information about the state or history of the "real world" of the power system. The purpose of the instrumentation aspect of the system is not to merely provide information about the level of the raw digital inputs, digital outputs, analog inputs, or analog outputs and not about the tradeoff issues of 5 Amp or 1 Amp cts, 67 Volt pts, 4-20 mA versus 0-1 mA, or DNP V3.0 Level 2 versus UCA protocol.

This apparatus centric view poses the question: What do you truly want to know regarding a breaker, line, transformer, capacitor bank, or bus? Some examples are:

For a breaker, the issues include:

- What is the breaker's present state?
- Should I trip the breaker? If yes, do so.
- Should I close the breaker (is it safe to close it)? If yes, do so.
- Did the breaker operate correctly? If not, what remedial action should be taken?
- When will I need to maintain, replace, or upgrade the breaker?

For a transmission line or distribution line, the issues include:

- Is it energized? If so, what is transmission line loading?
- Do I need to trip it or energize the line?
- Was there a fault? If yes, where is the latest fault location so I can fix it?
- What is the safe loading margin?

For a transformer, the issues include:

- Is it energized? If so, what is the loading of the transformer?
- Do I need to trip or energize the transformer or change a tap?
- When will I need to maintain, replace, or upgrade the transformer?
- What is the safe loading margin?
- What local conditions predict single contingency loading?
- What is the voltage regulation?

For a station battery, the issues include:

- Is the battery system functioning correctly during quiescent times and times of station operations?
- When do I need to maintain, replace, or upgrade the battery?

In summary, to consider the best approach to answer these underlying questions, first examine the underlying requirements independent from the solution mechanism. Then, in defining subsequent levels of processing, view the data desired to meet the needs of each user of data. The user may be a human or may be a process or calculation requiring the information as input variables. Finally, evaluate the appropriate communications method for each data acquisition and dispersion function. The keys to an optimal solution are to determine what information is important to each person or process, and to identify the best method to provide only the refined data needed for each use.

NONTRADITIONAL DATA COLLECTION FROM TRADITIONAL SOURCES

Apply the guidelines of an apparatus centric dataview, realizing that each intelligent node of a network can sense raw data. The appropriate raw data to sense are those that can be used by a decentralized node local to the apparatus to calculate the refined data. This local node can feasibly sense more raw data inputs at a lower cost than a centralized data collection system. A decentralized expert module can collect more information to make a better decision and pass on only the refined results. This yields a benefit by reducing the volume of data transferred and adds value to transferred data.

Traditionally it was often not feasible to collect these data. Economic constraints in the substation include the costs of wiring, documentation, installation, and the database and I/O capacity of RTUs. Another local constraint is the risk to safety; running copper I/O wiring from the yard to a central RTU increases the risk of injury to personnel and equipment damage. Remote economic constraints include channel bandwidth, memory, or software I/O point capacity, and processing and communication performance degradation stemming from the need to transfer large amounts of centralized data.

In addition, often the value of data was not clear or not recognized. In some cases, these raw data meant nothing to an RTU centric view but could be valuable to a local intelligent node to make a rapid, informed decision and provide the refined result. The unconventional use of the traditionally collected data and new data available through decentralized collection nodes opens the door to performance driven control and maintenance strategies. The dynamic real-time performance characteristics of an apparatus and its environment can be used as feedback to better control it. When these data are forwarded to the correct user, it is the basis for improving maintenance schedules and reducing physical inspection and manual data recording.

Local transformer control is an example of creating a more sophisticated control strategy, by using this newly recognized data. Gather the traditional dynamic transformer operational information, e.g., internal "spot" temperatures, real-time load currents, cooling fan status, load tap changer positions, and high- and low-side voltages. As the transformer ages and mechanically degrades, it deviates from the factory supplied loss characteristics and thermal damage curve of the "as-shipped" transformer. Real-time collection of these dynamic data becomes essential to accurately monitor operation of the transformer. The communication processor acquires this real-time data from relays, smart transducers, digital contacts, etc. Newly available data such as ambient air temperature, wind speed and direction, and precipitation is easily collected from inexpensive weather stations. The communications processor then concisely disperses this data, collected from many sources, to an expert node which will more accurately evaluate the true operational thresholds. Contrast this with the assumption that every day is the hottest day of the year, and that today the transformer performs the same as the day it shipped from the factory.

Better maintenance scheduling is afforded through the evaluation of the performance of the apparatus and its time of use rather than its time in service. Archived performance data are used to trend deterioration or improper configuration of the apparatus. Time-of-use data, including the frequency and duration of operations of the apparatus, are used to develop appropriate interval maintenance schedules. Contrast this with absent or manually collected historic data used to predict periodic maintenance schedules.

Expert Nodes and Systems Use Traditional and Nontraditional Data

Refinement of input data or control is best realized through algorithms and intelligent processes. These algorithms or processes are best developed by experts that understand the underlying system apparatus and needs. These same experts then implement the algorithms in nodes or software. Contrast this with the path you might take with the traditional view of the I&C System, where all too often an expert in programming is called upon to solve a problem that is really in the domain of an apparatus expert.

In the past it was necessary to choose from generic programmable devices, such as RTUs or PLCs, and program custom nodes for each application. Today, it is still useful to rely on these custom nodes to provide automation solutions not readily available, however, ever increasing numbers of IEDs are offering off the shelf expert solutions.

Beyond the generic class of IEDs, it is important to recognize that there are many "expert" nodes that should be provided by the appropriate experts. These nodes perform various amounts of raw data collection and processing appropriate to their intended purpose. Often, this intended purpose is a specific automation task and not to function as a protocol library. Each developer is faced with the tradeoff decisions of where to best allocate precious processing time, memory, and development resources. The tradeoffs include using the resources to enhance expert functions versus using those resources for multiple communications functions or adding additional resources and costs. It is obvious, from the dissension of several industry groups tasked with finding a single, all purpose protocol, that a single protocol cannot satisfy all users. In the event that one protocol was decided upon, it would soon be rendered obsolete as technology and system needs change.

These expert nodes and custom nodes, connected in a communications processor star configuration, perform as an expert system. These expert systems, instead of or parallel to stand-alone nodes, can be connected to create larger coordinated expert systems and so on until the needs of the entire utility or other enterprise are addressed. The selection of expert nodes is nonvendor specific. Protocol and transmission media for each master communications path between communications processors are chosen for individual merit rather than system-wide constraints.

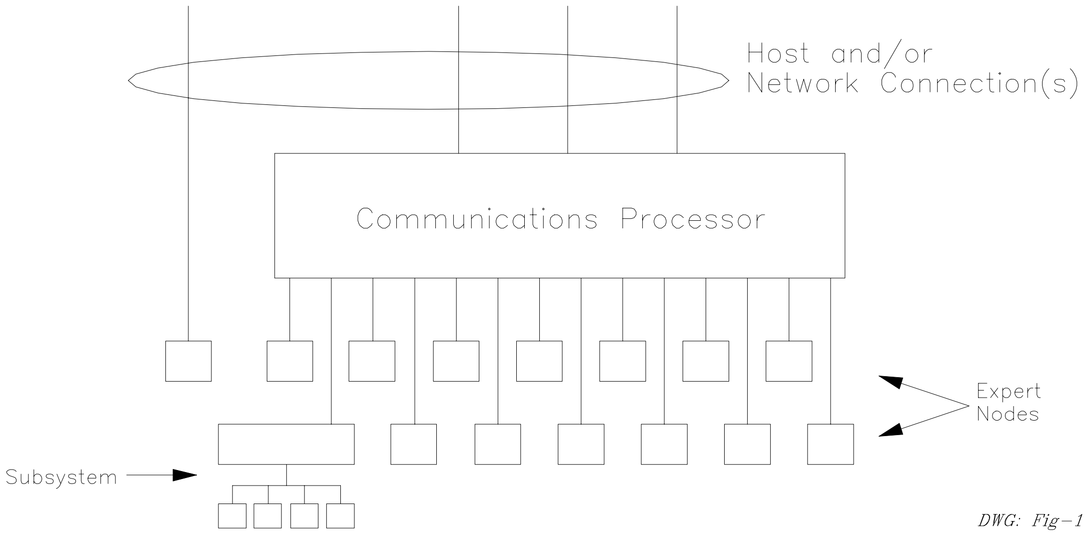

Figure 1: Communications Processor Star Network Expert System

One example of using this new information to improve traditional systems is to use the output of modern protective relaying expert nodes or subsystems as inputs or blocking contacts in a traditional electromechanical relay subsystem. In this way, improved fault location, system topology, or condition data refined by the new system can improve the performance or reduce misoperations by the older subsystem. This is accomplished through forwarding this data via serial communications or physical telemetry outputs or through supervision or control of the subsystem.

Distribution automation also provides a dramatic example of a function greatly enhanced through a system of appropriately located expert nodes. The application guide *Providing Automated Primary/ Alternate Source on Distribution Feeders* describes an expert system created entirely of protective relays and communications processors as nodes. The decentralized expert nodes are placed within the substation and on the pole top. This system provides protection first and foremost. The expert nodes support fast binary transfer of the essential periodically collected information interleaved with ASCII transmission of the other information. This link, as would be the case using other vendors' expert nodes, requires no expensive development of the most recent standard protocol. The same connections that provide the communications processors with fault location, breaker status, overcurrent conditions, etc., provide this data to each node for the other nodes in the system. This connection also allows remote operations of these nodes and settings changes. Using groups of settings stored within the expert node, unique algorithms can be selected based on values collected from the other system nodes. Each substation belongs to a different utility, therefore, two communications processors were used when one would have sufficed to accomplish the automation. Each utility had a desire for a separate communications processor to assure autonomous substation automation and host connections.

The distribution automation function of this installation is exhibited in the following drawing.

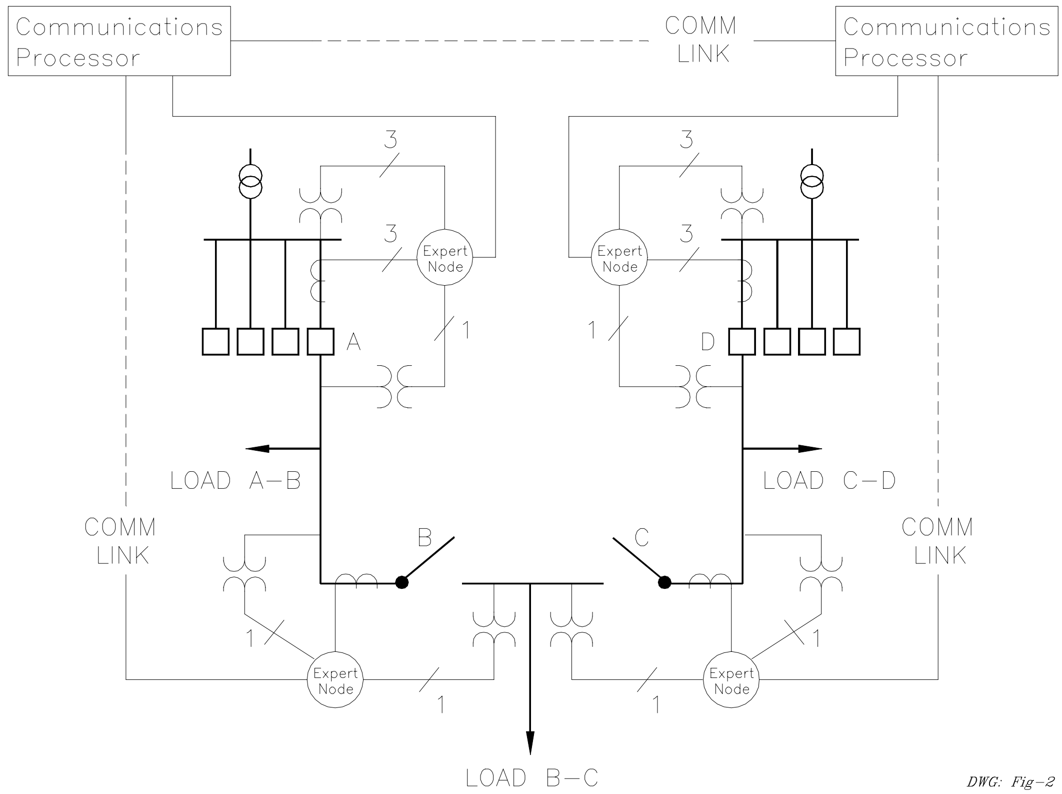

Figure 2: Communications Processor Star Network Distribution Automation Expert System

By using protective relays rather than the traditional RTU approach, the expertise of line protection engineers is applied to the task rather than the expertise of RTU software programmers. The stand-alone system performs protection, sectionalization, and restoration while also dispersing measured and refined information to other applications. The expert system's faster intelligent reclosing reduces system shock, customer voltage disturbances, and breaker operation. This system replaces the "process of elimination" method of multiple trips and reclosures traditionally used to find the faulted line section in part through sharing information among the substation and line switch relays via remote communications and the communications processor.

The system is further enhanced by choosing where to disperse what information. Persons or systems responsible for action want a concise event summary report immediately while a forensic analysis application requires the full event report but not immediately. Thus, it is appropriate to consider different communication paths and protocols to transmit the summary report to one user and the full event report to another.

The resultant expert system has many advantages over its predecessor, including the following:

- Expert system node operations are not diluted by elaborate communication protocol overhead.
- The expert nodes provide autonomous protection in the event they lose communication with the collective expert system.
- The system operates faster; the local automation does not rely on commands from a remote host.
- Boolean control equations provide traditional and custom control schemes.
- Equipment procurement and installation costs are reduced.
- Coordinated, automatic settings groups change as the system configuration changes.
- Multilevel underfrequency protection at each switch or breaker provides distributed and coordinated underfrequency load shedding and restoration.
- Fault locating, IRIG-B time synchronization, sequential event recorder (SER), and digital fault recorder (DFR) features greatly enhance the forensic analysis of local or system-wide disturbances.
- Advanced metering allows the expert system to record and disperse revenue-class accurate meter values.
- Multiple host interfaces support simultaneous data acquisition and control via several SCADA, EMS, and AM/FM/GIS systems.
- Fault records are automatically retrieved and archived.
- The expert system components support multiple uses. The same communications processor can simultaneously support several distribution automation systems, automate the substation, and disperse information to several remote applications as well as support expansion needs that arise in the future.

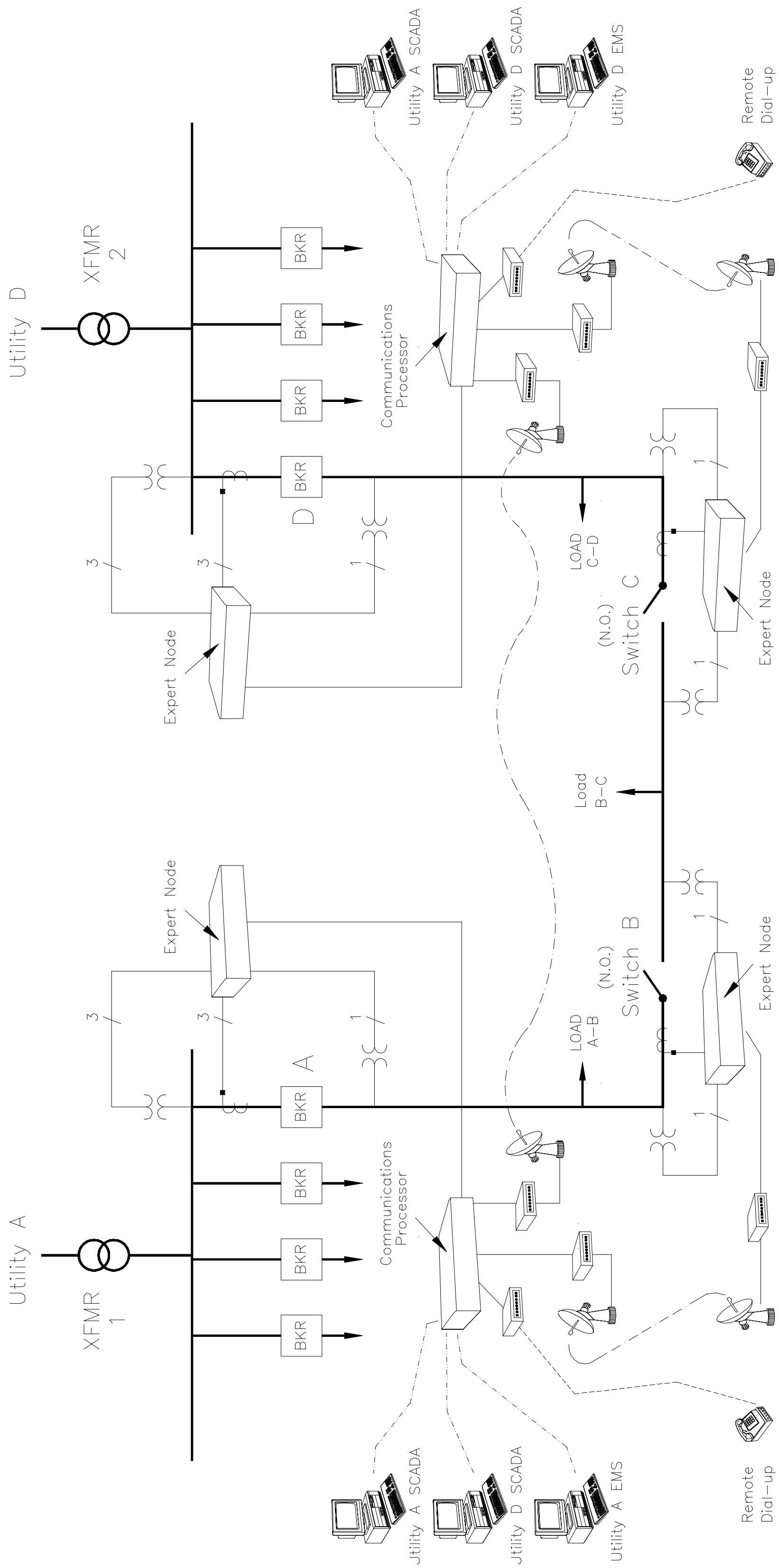

Figure 3: Expert Nodes Replace RTUs in Distribution Automation

The Real World Changes and so Must the I&C System

The I&C System exists to refine data sensed from the real system for the purpose of monitoring and controlling a real system. These systems grow and change. The I&C System also needs to grow and change with the real system as new expert nodes are developed that economically or more expertly perform, old nodes cease to be productive, or new real system needs are realized. The people responsible for this growth should not be shackled by slow moving standardization on quickly obsoleted nodes or built-in communications products with restrictive protocols.

Once the subsystem or node is in operation, it should be used as long as it is accomplishing its tasks properly. Therefore, the age of nodes in the substation and the rate that you change equipment or subsystems will vary, influenced in part by equipment life, changes in needs, and advancements in expert solutions. Human Machine Interface (HMI) and other hosts also have changing needs which should be accommodated by the ability to connect many legacy and future nodes without discarding appropriate nodes in place.

Innovative Integration Merges New and Legacy Technology and Migrates Data, Not Protocols

When choosing the best new and in-service nodes to create a successful I&C System, you will not only select from multiple vendors but also multiple vintages or generations of products. Many of these nodes and systems employ proprietary communications and interfaces. Communications processors collect and reuse the measured and refined data from all of these nodes by directly soliciting data or by sharing communication links. Again, rather than forcing several, or all, "standard" protocols into the expert nodes, its resources should be used to increase performance. Communications processors allow the system designer to choose the node(s) best able to automate a function and choose which protocols are appropriate at each level. The system can also retain and enhance operational nodes and islanded systems that are still performing their tasks. Expert systems no longer have to be replaced as the control system or communication backbone is upgraded at an asynchronous pace.

The ease with which new nodes can be incorporated, using a communications processor star configuration, ushers in a new era of portable automation system elements. Mobile test and monitoring units can be used at appropriate times and places where permanent installations are cost prohibitive. An example is a mobile test set for periodically evaluating transformer operation and subsequently updating the guaranteed loss characteristics and thermal damage curve. Units like this can be purchased, or leased, and moved around the system on a periodic or demand basis.

Solicit Data With Protocol Subset Dialogue

The most direct way to retrieve the data of interest is to solicit it directly from the nodes. To do this, it is not necessary to develop a vendor specific protocol driver for each version of protocol installed, but rather to use the pertinent subset of messages of these protocols. Consider communicating with people who speak another language. It is not always convenient to learn the form and syntax of this language but is easy to learn and use key words and phrases to get what you want.

As an example, the MV90 protocol consists of messages to configure meters, verify configuration, perform diagnostics, send data to the meters, and acquire real time and archived meter data. A communications processor sending MV90 format data acquisition messages to the meters can capture, parse, and store the meter response. This dialogue, performed by sending a subset of the MV90 protocol request messages without developing a protocol driver, can be commanded periodically, by time of day, based on data received from one or several sources or as a result of a logical calculation. The values in the response can be acted upon, condensed, and forwarded to other destinations via other protocols.

Other nodes may dictate that the communications processor not only solicit data, but also send data and control messages to the node. These messages can be commanded in the same manner as acquisition messages or as a result of a message received by the communications processor from multiple hosts. The communications processor can check the status of remote control of the node before control messages are sent.

Using this technique with a legacy system is beneficial. No longer do you need to abandon a functional system because its protocol is abandoned. Nor do you need to use system procurement dollars to develop a legacy protocol interface into your new data acquisition system. Instead, by utilizing commanded dialogue, data can be retrieved into the communications processor. Another consideration is the need to send data to these nodes and systems in their legacy format. A decade ago GOES systems were popular and sent time stamping information to synchronized nodes. Today, as these systems are replaced with GPS systems, the legacy nodes rely on receiving time stamping in the legacy format. The communications processor can acquire this information through the new system and transmit it in the legacy format. The nodes continue to function as designed, oblivious of the fact that the time stamp technology changed, and will likely change again before they outlive their usefulness.

"Eavesdropping" for Reactive Data Capture

Proprietary data links, often employing proprietary interfaces, are used in closed systems partly because of their efficiency in communicating data to other nodes within the closed system. The closed system data is readily seen to be valuable to a more comprehensive open system as well. Though not designed to be part of a larger system database, these values can be acquired by sharing data links. The communications processor can listen to the conversation between two nodes in this closed system and capture, parse, and store the data.

The MV90 protocol is used as an example of solicited dialogue and is also a good example for eavesdropped dialogue due to its common use in closed expert systems. An example of such a system is an MV90 meter data acquisition system. This closed system was installed for the limited purpose of providing meter data to a revenue system. The destination of this data is a host available only to the revenue department. It is obvious, however, that reuse of the data measured by the meters would be valuable to local automation, Energy Management Systems (EMS), regulatory compliance, or maintenance purposes. Add an "eavesdropping" connection between the closed loop and the communications processor so that the processor can monitor the dialogue. When it recognizes a predefined message within the request and response exchange, the communications processor captures, parses, and stores the resultant data response message. Thus, the communications processor can extract data from the dialogue without influencing it. Again, the values in the response can be acted upon, condensed, and forwarded to other destinations via other protocols.

Proprietary data links and interfaces exist in older legacy systems due to past limitations in protocol selection. Though the implemented protocol in these systems may have been designed to be "open," the task of developing a legacy protocol driver in a new expert system is often formidable. Soliciting data directly into the communications processor by using elements of this legacy protocol is one solution previously discussed. If, however, the existing hardware does not allow additional communications connections, sharing of the system data links can migrate data from this legacy system to the new expert system. Once captured, parsed, and stored into the communications processor, this data can be used locally, eliminating the need for redundant measurement paths, and forwarded to several nodes and applications. This data can enhance the expert system, support nodes, and applications that were not previously feasible or satisfy needs that were not considered at the time of installation.

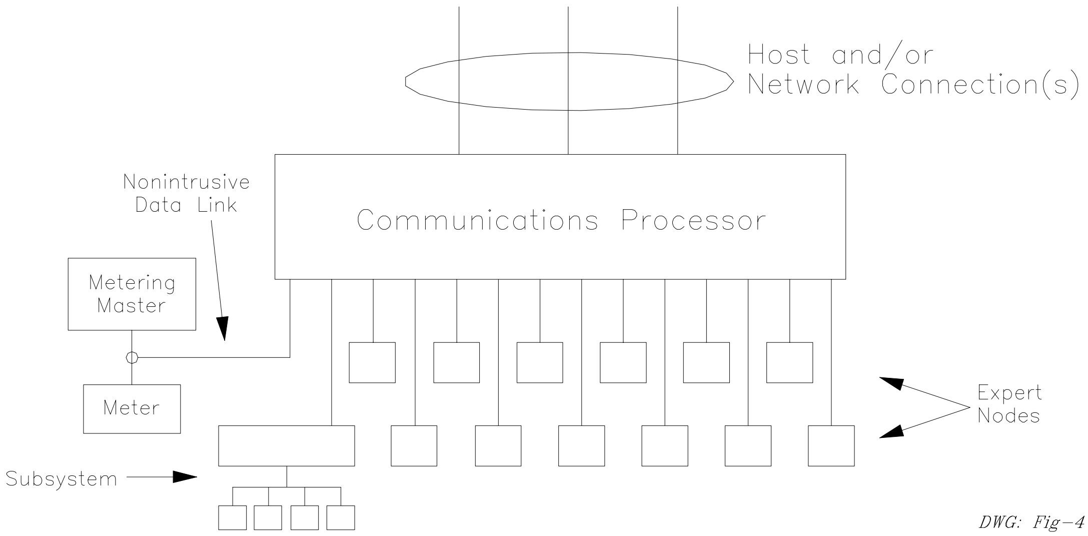

Figure 4: "Eavesdrop" for Reactive Data Capture

EXPERT SYSTEMS REFINE, FILTER, AND FORWARD DATA

These new collection techniques can acquire much more data both locally and remotely from the node and provide it to the expert system. This system uses this newfound wealth of data to make rapid, informed decisions allowing it to perform better automated strategies and forward fewer, more valuable refined filtered data to the overall system, or enterprise. Thus, the enterprise information needs are addressed at the lowest tier possible and only the essential data are propagated across the various communications paths. Also, reactions to the results of these processes can be executed by the local expert system. A call-out, land line or cellular, or page for remedial action is performed by the communications processor immediately. Contrast this with waiting for the data to travel all the way to an enterprise repository, be forwarded to a host and resulting in a flashing symbol on a crowded operator console.

The communication processor becomes the source of responses for data acquisition requests, it does not merely convert messages from one protocol to another and pass them on. When information is needed from several nodes, the concentration capabilities of the communication processor significantly simplify the system and reduce the elapsed time to move data packets and control commands.

The nature of the data may also not warrant that it automatically be sent anywhere. Reduce system communications overhead by leaving noncritical data in a communications processor or subsystem until it is needed. Casual or infrequent purposes can be met by the user contacting the system when and however appropriate. Consider a user accessing the communications processor via the enterprise internet/intranet connections.

SELECT THE APPROPRIATE COMMUNICATIONS CONFIGURATION AT EACH TIER RATHER THAN RIGID SYSTEM NETWORK

A distributed system is more than many nodes which gather data. Part of its value comes from dispensing the processing to nodes or subsystems. This often reduces the volume of forwarded raw data. The net result is that the demands on the communications path vary throughout the network hierarchy. At the level that data are sent to a centralized control system, a high throughput addressable channel may be appropriate. At the fundamental node level, fewer data items are transferred and a simple, slower protocol is appropriate. At the distributed node level, star network topologies are often appropriate due to the use of the data and the advantages of low cost point-to-point optical fiber links. At a higher level in the block diagram, a multidrop communications topology may be appropriate. If system designers apply the constraints that all nodes throughout the station share the same protocol and the same network, they will calculate a need for very high performance communications system. However, using the appropriate paths to communicate between the nodes nets higher performance while reducing cost and channel demands.

RETRIEVE IMPORTANT SYSTEM DATA FROM OUTSIDE THE SUBSTATION

Substation data gathered from a remote location are valuable nontraditional information. The performance of the nodes within a substation can be further evaluated with the new perspective from the outside looking in. Appropriate data collecting by one system is easily forwarded to neighboring systems. In the same manner, relevant remotely collected data can be incorporated into automation schemes. In much the same way that nodes exchanged data in the previous distribution automation example, entire systems can exchange valuable information about themselves and each other. Also, all information gathered in a completely different way such as satellite photography or lightening detection services can be dispersed to the appropriate expert nodes or systems.

One obvious example is expert systems collecting power quality information and making it available to multiple users on demand. Power quality groups will need this information occasionally to address concerns about voltage irregularity. Different operating regions or neighboring utilities access this information and/or provide it to your system. When available on demand, this information helps speed the response to customer complaints.

Another great example is line fault analysis enhancement using data from remote sources. In the event that a case ground problem on an electromechanical relay prevents the substation equipment from recording a fault, fault records from neighboring systems help verify the fault’s occurrence and location boundaries. Also, data from a lightning stroke detection system will not only corroborate the fault source but also pinpoint its location.

CONCLUSIONS

- It is important to understand the use of information to best determine the paths it should follow in route to the appropriate destinations.
- As the underlying "real world" system changes and grows, the instrumentation and control system needs to adapt to changes without replacing most of the I&C System.
- Some information is useful only as inputs to local expert nodes, which operate on multiple I/O points or many samples over time.
- If two nodes require information from each other as inputs to their expert functions, and the information does not have other users, then the data path can and often should be independent of a centralized data path.
- Experts on the underlying systems or apparatus should encapsulate their expertise in expert nodes.
- Common networks or hierarchies are appropriate for transferring information needed by many nodes in the substation or gathering data needed by people or processes concentrated at one or more remote locations.
- Protocol standardization has an appropriate role to allow interoperability at a level where data needs to flow between multiple nodes or towards centralized data sites. This does **not** mean that every node in the site should directly communicate in the same protocol; it means that there needs to be a point somewhere in the network structure where the appropriate refined data are available through the appropriate protocol and path.
- Do not jeopardize the performance of expertly crafted automation solutions by insisting that every node within the enterprise contain some or all standard protocols. This insistence can add to the cost of each node and accelerates their obsolescence as technology advances. Instead, build an expert system by choosing nodes and communication paths based on their individual merit for each specific task. Today's technology is yesterday's innovation and tomorrow's legacy.
- Deregulation is forcing utilities to provide ever increasing degrees of automated support for operations. Expert automation systems are the path to meet this demand.
- It is almost inevitable that today's networks and protocols will be legacy subsystems of future systems since there usually will not be justification to replace entire systems or subsystems.

Biographical Sketches

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Gary W. Scheer received his BSEE from Montana State University in 1977. He worked for the Montana Power Company before joining Schweitzer Engineering Laboratories, Inc. in 1990 as a development engineer. He now serves as vice president of research and development. He holds one patent and has another pending. He is a registered professional engineer and is a member of the IEEE.

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