Intelligent Substations: Costs and Benefits.

Andrew McRae

Megadata Pty Ltd.
2/37 Waterloo Rd
North Ryde, NSW

This paper presents a case study of a joint project between Prospect Electricity (PE) and Megadata to develop and install intelligent transmission and distribution substations throughout the electrical distribution network controlled by PE in Western Sydney. A key focus of the paper will a detailed examination of the costs and benefits of substation automation, and how these have influenced the evolution of the PE Substation Automation system.

Introduction.

This paper discusses a number of issues of substation automation and management (SA/M), with a particular focus on the costs and benefits to regional authorities.

Initially, the motivation behind SA/M is examined, and why this area is becoming increasingly important to utilities and supply authorities. The costs and benefits of various solutions are compared, and how the various architectures directly relate to the viability of an effective SA/M strategy.

A case study is presented, showing how new applications can be developed that bring immediate direct and indirect returns and benefits, both from the operational and cost viewpoints. Megadata's Substation Management System (SMS) is used as the basis in this case study, the result of ten years of joint development between Prospect Electricity and Megadata.

Distribution automation (DA) is becoming an important issue, and the role of SA/M as a basis for DA is discussed.

Example applications are discussed, highlighting the need for a technically sound architectural foundation for developing new customer applications, and how these applications lead to new benefits for the user.

Why Substation Management is Important.

The traditional model of electricity supply is centred around the bulk transmission of power to distribution substations, which then provide power to consumer sites. Growth and load management focussed on new generation and transmission facilities, and an increase in the number of distribution points.

This model is changing, and several forces are driving this change:

- The cost of new generation and/or transmission facilities is becoming prohibitive; changing community attitudes are also reducing the options available for these facilities.
- With the advent of corporatisation of many authorities, and an ever increasing demand for accountability and profitability, the whole cost structure of electricity supply is changing. This is being helped along by government deregulation.
- Customers are desiring more flexible options in the supply of electricity, such as accepting lower tariffs for placing certain loads under management by the supplier.
- There is a growth in the use of alternate generation facilities, such as wind generators, solar power, small hydro etc. Often this generation of power is obtained from a customer site, using some power

sharing arrangement.

- The advent of government initiatives to drive towards a national grid allows traditionally separate authorities to bid for supply.

A factor in this change is that the traditional demand curve is trending towards greater peaks at times when the system is at greatest stress, such as the growth in the use of air conditioning in summer (figure 1).

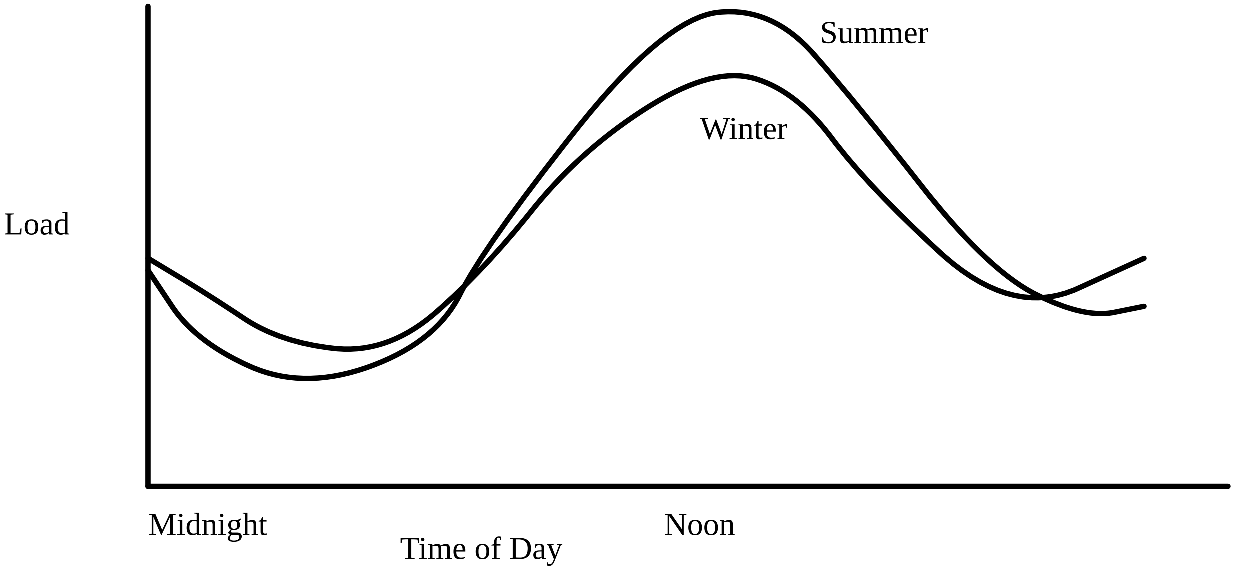

Figure 1: New load curve

Authorities are realising that if the load can be effectively managed, large direct and indirect cost savings may be instigated, such as:

- Operationally, equipment can be run at more optimal ratings, lengthening effective lifetimes, reducing maintenance costs, and providing lower losses.
- Higher reliability of supply will result if the distribution network is not placed under stress (or at least the load is managed so that unnecessary stresses are minimised).
- Since the peak cost of electricity is high, reducing peak load has greater benefits than reducing base load.
- Finer grained control over the network allows the authority to ‘tune’ the network to operate optimally under the various load scenarios experienced within the distribution system.

Since the focus of managing electricity supply is shifting towards the distribution side, the use of SA/M is a key element in the strategy of authorities learning the cope with these changes.

Moreover, SA/M provides authorities with a degree of control hitherto unthought of, presenting new opportunities and benefits arising from better control of their distribution networks. Coupled with greater demands from the customer base, SA/M must be considered a foundation strategy that must be planned and executed with care, so that the authority may remain competitive in an ever-changing environment.

Benefits of Substation Management.

Depending on the particular architecture and method of SA/M in use, many benefits can result. Apart from the obvious benefit of SA/M as remote telemetry, there is a hidden cost in *not* providing an effective SA/M strategy, including the following:

- More and more vendors of substation plant equipment are providing sophisticated control interconnection for their products (e.g solid state protection relays). Traditional control methods such as pulsed relay outputs or clean contacts do not take advantage of the new capabilities of this equipment, such as faster response, programmability, and self testing.

- Operationally, there is no integrated or common interface to the field staff, so that operations personnel need different procedures or training for each different site.
- By not providing optimal control of the network, the cost of maintenance is higher, and power losses are higher.
- By not keeping abreast with new technology, applications or control infrastructure, the authority will rapidly fall behind in cost effectiveness and efficiency.

Depending on the SA/M architecture selected, different levels of cost/benefits can result. It is vital that the architecture provides an effective and flexible base for current and future SA/M applications. Some of the goals that should be considered for a successful architecture are:

- Reliability, considered both in terms of the inherent nature of the architecture (i.e distributed, redundant, duplicated, no single point of failure etc.), and of the known track record of the particular implementation of the architecture.
- Cost effectiveness, so that deployment of SA/M can take place at all levels of the distribution network.
- Flexible communications, so that the SA/M system can interoperate with a wide range of other items or systems, such as intelligent plant equipment, remote field devices (sectionalisers, reclosers etc.), other substations, different vendor RTUs and master stations etc.
- Scalable, so that large substations, or clusters or substations in a localised area (such as a central business district) can be managed as easily as a distribution substation.
- Extendable application foundation, so that the user could develop new algorithms or applications as required.
- Highly configurable, so that the user can tailor the SA/M system to their own local situation, and also adapt the system to a wide range of operational conditions and requirements.
- Easily maintained, so that as plant equipment is changed or upgraded, the SA/M system can be readily reconfigured to reflect the changes.
- Easily installed; since a substantial cost of SA/M is the physical marshalling of cabling, providing a method of easy installation can reduce significantly the cost (and man hours) involved in the installation of the SA/M system.
- Integration with an enterprise wide Information Technology strategy, that may involve GIS, AM/FM, SCADA, Energy Management etc.

Different architectures meet the above goals with varying degrees of success.

Over the last 10 years, Prospect Electricity and Megadata have developed and tested 4 distinct generations of substation management hardware and software architectures, each of which has attempted to meet some or all of the stated goals.

From this experience, it can be seen that certain architectures provide a better foundation for SA/M than others. A comparison of these architectures is useful in understanding the costs/benefits of each.

Hardwired Mimic

Figure 2 show a typical substation with hardwired control back to a mimic panel that contains measurement hardware and control operation with physical switches and relay logic.

This architecture is common in older substations, and suffers from the problem of the high cost of physical equipment and installation, as well as often presenting operators with a nonstandard control situation. Little information concerning substation events is known, and fault conditions are often not reported.

An extension to this system is to place a dumb RTU in the substation so that remote supervision and control can take place. Local operations can still be made through the mimic panel (though usually hardware interlocked with the remote control).

Centralised Unit

Figure 3 shows a centralised control unit that has the plant interface marshalled to a central cabinet; the addition of an intelligent control unit allows specialised Local Control Routines (LCRs) to operate on

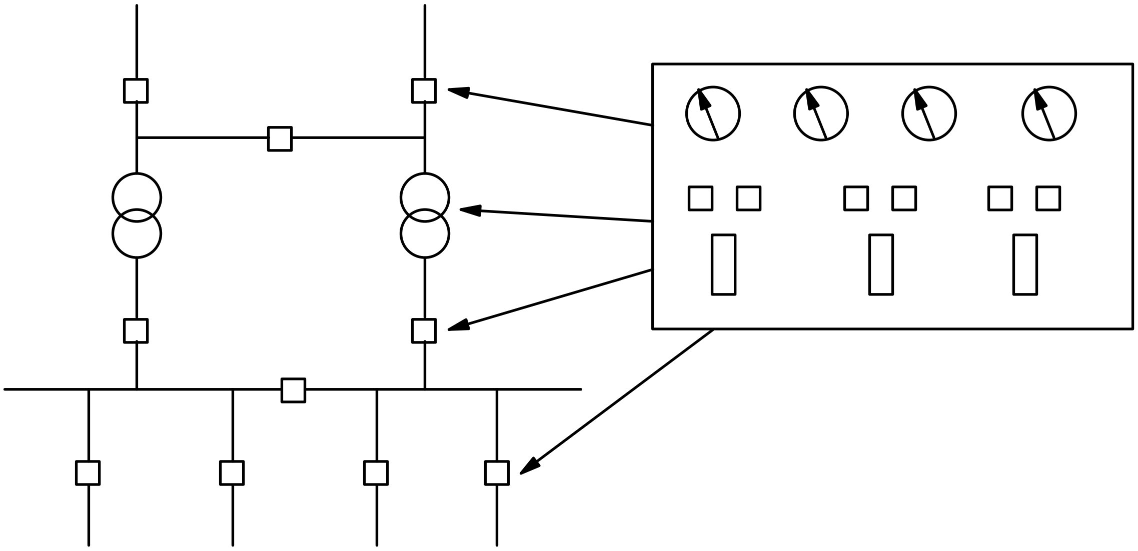

Figure 2: Hardwire Mimic

the plant. An operator MMI may exist to provide a common user interface, and allow access to event lists, and provide local operator control. Disadvantages of this system include the high cost of installation due to the physical marshalling of the cabling (though often the cabling already exists due to an existing mimic control panel), the lack of redundancy, and a single point of failure.

This architecture does not scale well, and often has performance problems. Expansion is limited, and connecting new items of plant can be difficult due to the cabling problems. Also problems are faced such as the requirement for good isolation, and the possibility of damage to the central unit if there is a fault in the switchyard. This architecture is useful in existing substation sites, especially when an existing mimic control panel exists that can be paralled with the telemetry I/O.

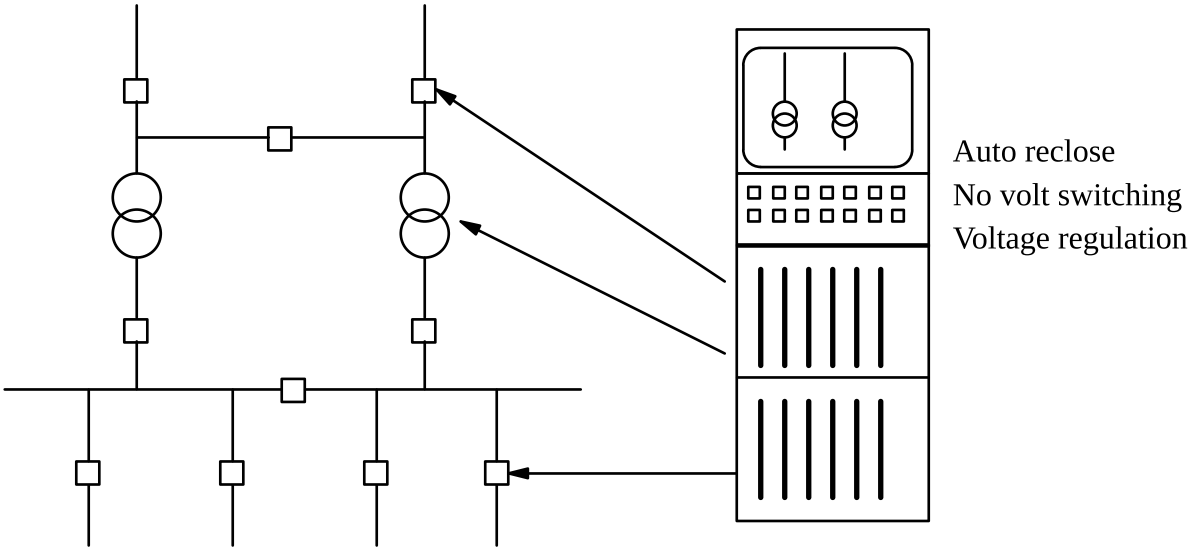

Figure 3: Centralised Unit

Distributed Telemetry

The next architecture to examine is the most commonly available solution, which is a centralised MMI and control unit interfacing to the plant via smaller nodes performing the telemetry I/O, physically mounted on or near the equipment. The acquisition nodes often perform time stamping, and interface to the central unit via a low or medium speed point to point or multidrop communications bus. No other

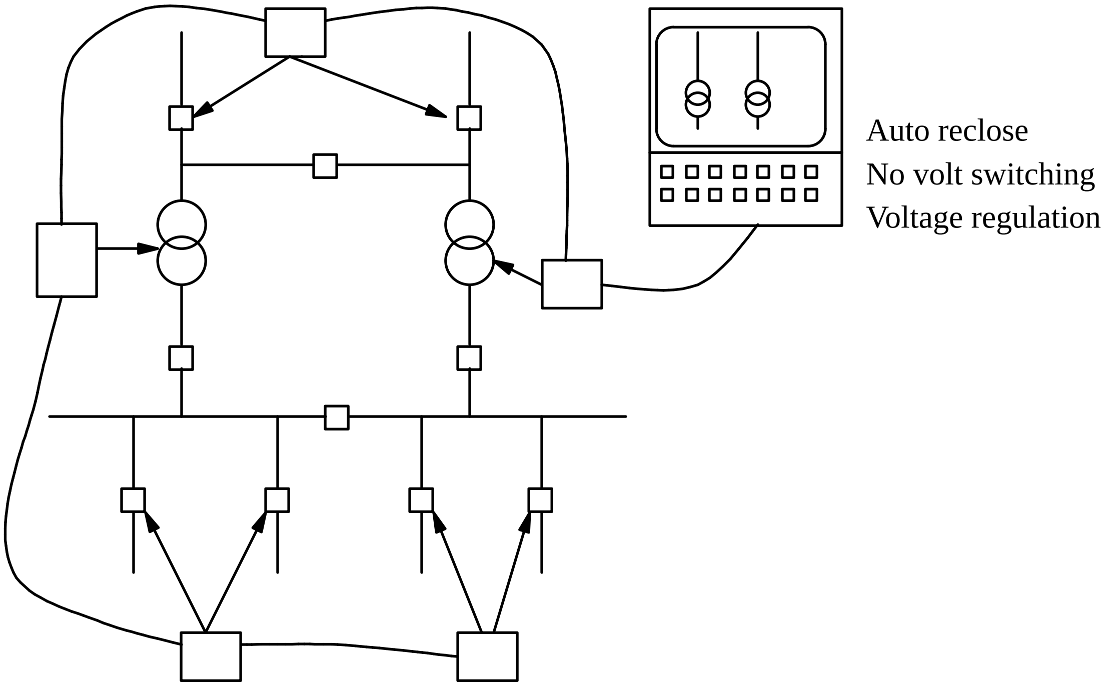

Figure 4: Distributed Telemetry

processing occurs on the acquisition node. The central unit performs all local control of the plant, and performs the communication functions of data gathering and event processing etc.

This architecture is an attractive solution to eliminate the cable marshalling problem, as instead of the (usually more bulky) telemetry cabling and control cabling, a fibre optic or other cable is used to connect the data acquisition nodes to the central unit.

The average cost of this system is about 65% of the hardwired mimic architecture. The problem still remains that most of the intelligence is embedded in a centralised unit, and so the same issues of reliability, performance and scaling exists as in the previous architecture.

This central unit also can be used to communicate with a control centre (i.e appear as a dumb RTU to the master station), and this further exacerbates the problem of reliability, since if the unit fails, both remote control and local control are unavailable.

Fully Distributed

Figure 5 shows a very similar system, except instead of a central unit performing the bulk of the processing, the acquisition nodes now contain intelligence so that LCRs and plant processing can take place locally. There are essentially two flavours of this type of system; one where each node can run LCRs and perform local processing, but cannot communicate easily with the other nodes to share data and control (typical of PLC type systems), or requires all nodes to be functional for communications to take place. The other flavour is where each node is a full peer on the network, and the database is truly distributed; nodes can access peer data across the network, and interact with other nodes, without requiring the services of a centralised unit.

The fully distributed nature of this architecture allows the system to be reliable in the face of node failure, and also to scale to different sizes of installation easily. Plant upgrades are easy, since the telemetry and control can be placed physically close to the equipment. The MMI is typically another node on the LAN, but with extra database and facilities for displaying mimic diagrams.

In terms of functionality and reliability, this architecture is the most cost effective, since a high degree of control may be obtained, there is no single point of failure, and the user has the advantages of the distributed telemetry (i.e no central marshalling of cabling).

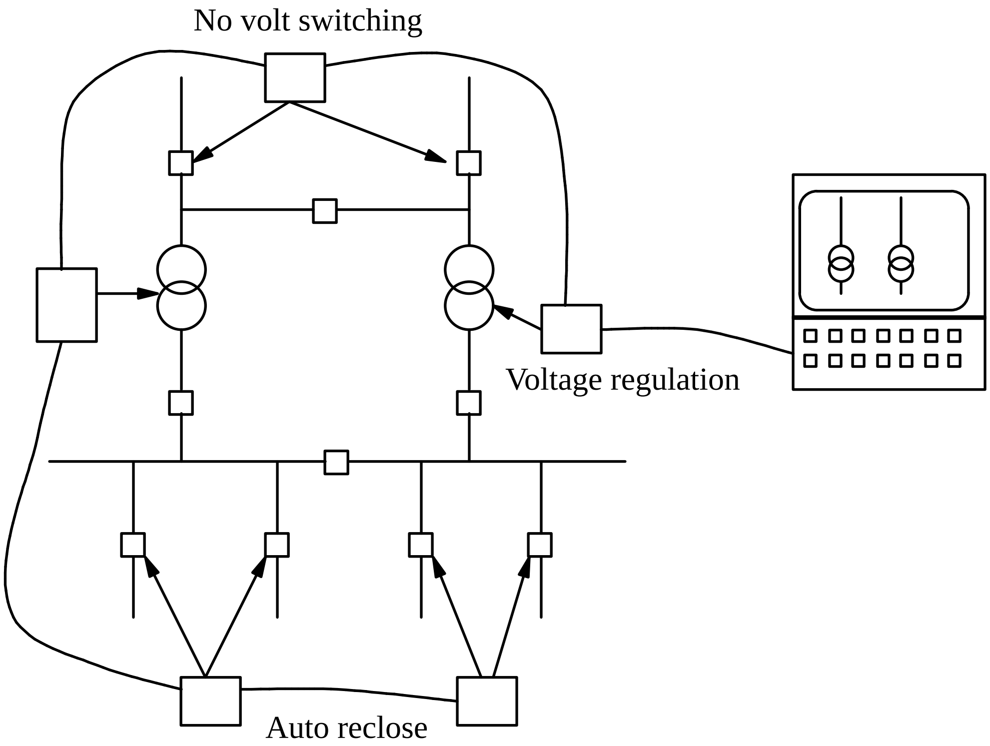

Figure 5: Fully Distributed

Since the cost of an intelligent controller is not orders of magnitude more than a dumb acquisition node (mainly due to the decreasing cost of electronic hardware), and the capability of these units is becoming increasingly sophisticated, placing localised processing on these nodes is becoming common. This trend is continuing, even getting to the point where plant equipment suppliers will be placing controllers with standard interfaces into their equipment, allowing direct interconnection with the SA/M system.

The Software and Communications Architecture.

A common misconception is that most of the SA/M problems are solved by specifying a particular hardware architecture that (for example) allows distributed telemetry and control. From the experiences garnered in the 4 generations of Megadata equipment, this is only one part of the solution, and a small part at that. It is a common mistake to focus on the hardware solution, and forsake the key elements of the database, communications, and application facilities of the SA/M system.

Rather than deliver a *fait accompli* of SA/M applications, Megadata chose to develop an application framework centering around some key elements that allowed the customer to develop their own sophisticated applications. These key elements are:

Distributed Object Database

Sophisticated applications by their nature deal with complex data models, and any SA/M system allowing these applications to operate must have as a foundation a database subsystem that allows these complex models to be developed, built, and distributed throughout the SA/M system. Rather than attempting to describe the telemetered data in a fixed and flat database schema using simple analogue or digital points, Megadata's SMS database uses an object orientated approach, where each plant equipment type can be represented as a different *class*, and each instance of a class (termed an *object*) can represent a real world object such as a circuit breaker, transformer etc.

These database objects can be connected together into a hierarchy that describes the relationship of each object to others (such as high voltage CB connected to a particular transformer). This allows the user to build and configure the SA/M using familiar types of data, rather than attempting to relate these real world objects to some fixed representation using digital and analogue data.

These hierarchies of data objects can be distributed to different nodes upon the network, and application programs are written that can access the objects transparently across the network e.g. if one node wishes to determine the state of a particular transformer (which is being telemetered via a different node), the client node will automatically discover the node ‘owning’ the transformer and access the data in the transformer object directly. At no time does the client node need to look at any of the underlying data structure of the transformer object such as the raw telemetry points, CB statuses etc., it can just access the transformer record which contains the processed data for that transformer object.

New classes and objects are easily created, configured and downloaded to the SA/M system as new applications are developed that require more sophisticated data manipulation. SA/M schemes that do not provide this level of object orientated database processing and distribution will not be a good foundation for the development of future applications.

Open Communications.

From the Prospect Electricity experience, it was clear that a flexible networking and communications architecture was required to meet the needs of the future. Such requirements were seen such as interconnection of remote Distributed Intelligence Units (DIUs) using serial lines, Ethernet, 802.4 Token Bus operating over twisted pair or carrier band, connection of distribution reclosers etc. Future communication options included substation-to-substation interconnection using ISDN, switched telephone network dial up for remote MMI and download, and interconnection with off-the-shelf communication products such as routers, terminal servers etc.

To provide for such a sophisticated range of communication options, and yet not to develop a proprietary solution, an open communications standard was required. The Internet Protocol suite (TCP/IP) is used as the main communications networking protocol with SMS, and has proved to be a major factor in the flexibility of the communications options available. Industry standard protocols such as SNMP, TELNET, TFTP, the X Window system etc. are all available for use.

Interoperability is becoming important in all levels of the control infrastructure, so that the SA/M can be an integral part of the enterprise wide communications system. The use of proprietary protocols is a major drawback to any substation management system, as it locks the user out of many choices of equipment and services, and should be avoided if possible.

Local Control Routines.

Customers wishing to develop sophisticated applications need to be able to develop, test and install LCRs easily in an SA/M system. The LCR subsystem must be robust, and integrated with the rest of the distributed object database. The LCRs must also be highly configurable and allow complex data manipulation to be performed. PLC or ladder logic style control routines were found to be too low level and cumbersome to allow complex applications such as were being developed by Prospect Electricity. The LCRs must also be parameter driven, so that only one master copy of the LCR is maintained and downloaded, but that many instances of the LCR can run, each with different parameters.

Early versions of LCRs used the C programming language, but C is not a robust language in this environment, and the learning curve for C is quite high for most control engineers. Debugging compiled languages in the substation environment is also problematical.

The use of Megadata’s Sequential Control Language (SCL) allowed Prospect Electricity to develop a large number of customized LCRs quickly and with confidence. SCL was found to be much more robust and easy to debug than C LCRs; control algorithms expressed in SCL tend to be much shorter and easier to maintain and read than ladder logic or C.

The control language is also extendable so that new unthought of applications can be accommodated as and when they are developed.

The overall approach for Megadata’s SMS has been to deliver a system that allows the customer to reach the full potential for SA/M, without the customer having to design around or struggle with the implementation of the application.

In comparison, there are certain architectures that do *not* allow the easy development of SA/M applications; SA/M systems are *not* SCADA systems, in that the traditional SCADA system is designed for operator monitoring and operator control, with fairly dumb telemetry. SA/M systems tend to have localised automatic control and monitoring, and have a different emphasis than SCADA systems.

PLC based SA/M systems are generally not flexible enough to provide for good substation management applications. The closed proprietary nature of PLC systems is the most glaring problem, and PLC systems are very poor as a foundation for integration as part of a complete SA/M solution. The data manipulation, communications and application development support are usually poor, and do not provide the sophisticated application support that is required for SA/M.

Pathways to Substation Management.

What is the best way for utilities to develop a SA/M strategy, and then procure and install SA/M? The common wisdom is that SA/M costs a significant amount to install and commission, but there are a number of ways of migrating existing installations to use SA/M without a large outlay, and gain the immediate benefits.

The main situations arise when older substations are undergoing a refit, and SA/M is to be installed; sometimes these substations may already have an existing dumb RTU for use with a master station, or it may have a hardwired mimic panel.

Figure 6 shows how SA/M can be integrated transparently into an substation with an existing RTU.

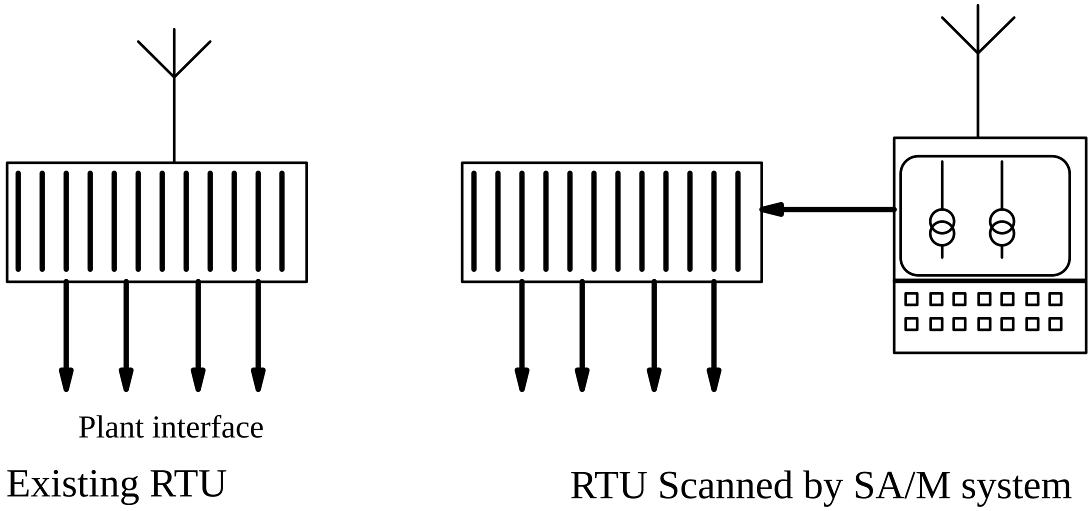

Figure 6: SA/M With Existing RTU

Rather than removing the old RTU and performing the expensive exercise of replacing the existing marshalled cable and I/O termination with new distributed telemetry, the existing RTU can be used in place, scanned by the SA/M system, which is scanned itself by the master station. New plant equipment can be directly connected to the SA/M system directly.

When an existing mimic is to be replaced, the existing cabling can be reused as the telemetry I/O cabling for the SA/M system.

When initially installing SA/M, there is no requirement to place a MMI display within the substation; MMI functions can be achieved via a remote colour laptop display that field staff can connect as required. Remote MMI operation can also be achieved via a dial up modem link.

Thus SA/M benefits and applications can be brought into effect quickly, without affecting the installed control infrastructure. As more and more applications are brought online, the SA/M system can be easily extended by placing more nodes on the network.

Distribution Automation.

SA/M may be used as a foundation for Distribution Automation (DA), by interfacing to field devices such as reclosers and sectionalisers. The DA algorithms can operate within the substation management system, and using the data collected from within the substation and from the field devices, control the distribution network.

Communication to the field devices may take place from dedicated communication nodes as part of the SA/M network, and data from the field devices processed and placed within the SA/M distributed object database for access by any other node on the network.

This principle may be extended to any proprietary interface such as protection relays, where the equipment is scanned, and the data stored as an object within the scanning node, and made available for access via the distributed object database.

Thus the SA/M can act as ‘glue’, normalising the interface to widely varying telemetry devices, and allowing applications to see a consistent and coherent view of the distribution network, no matter where or how the data was obtained.

Other Applications.

Providing a system that was a good foundation for developing applications has proved to be a major success, as Prospect Electricity has developed several major new SA/M applications. One example is SCADA Integrated Load Control (SILC), where a DIU is used to replace a Zellweger frequency injection controller unit. There is an immediate cost benefit, since a DIU is about one tenth the cost of a Zellweger controller, but since the DIU is part of the whole SA/M system, the ripple control can be programmed via the MMI, and the load control system is integrated into the substation control hierarchy.

Another application is the use of facilities sharing in the Parramatta CBD area, where several substations are linked together; these substations make greater use of reserve equipment such as sharing a standby transformer between two or three zones. In the event of failure of plant equipment, the network is reorganised so that the load is picked up by the rest of the system.

This is done by each substation’s SA/M sharing data with the other substations, and issuing instructions to take remedial action when necessary.

Efforts are continuing to developing new applications that extend the SA/M system; future work involves substation to substation communication via ISDN, allowing all substations to participate within the enterprise Wide Area Network. The communication boundaries are also being extended downwards to integrate reclosers and sectionalisers.

Conclusions.

The costs/benefits of various SA/M architectures were examined, and it is seen that the right architecture for substation management allows major new customer applications to be developed, as well as providing an open and flexible communications and networking strategy. Two other key elements in the application development is a distributed database that allows plant equipment to be modelled according to object orientated principles, and a control language that allows sophisticated algorithms to be easily developed.

Substation Management is increasingly important in today’s world, especially as authorities are being asked to provide more reliable and efficient supply of electricity, often with dwindling resources. Nowhere is this more evident than in the particular climatic and geographic situations that Australian authorities endure. SA/M is a major tool for these authorities to survive into the next millenium.