ENGINEERING ANM TRAFFIC FOR ADAPTIVE HANDLING OF LIMITED TELECOMMUNICATION INFRASTRUCTURES

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ABSTRACT

Active Network Management (ANM) is heavily dependent upon the network operators' telecommunications infrastructure to ensure effective control over the Distribution Network that it is being applied to. As a result, the reliance upon data communications channels becomes more acute and the focus sharpens on the integrity of ANM. Connectivity between the constituent nodes within the hierarchy of ANM control must be highly engineered.

Out-dated telecommunications assets, funding mechanisms and a skills shortage within the network operators has limited available connectivity capacity and has a detrimental effect upon control nodes to interoperate sufficiently in the context of ANM.

We shall emphasise making 'best-use' of existing telecommunications channels and media whilst planning and preparing for the availability of adaptive, highly available connectivity when it becomes realistic and affordable.

A Case Study of how this is being achieved in the industry by Smarter Grid Solutions (SGS), a leading exponent in the development and deployment of Active Network Management solutions to network operators will be explored to demonstrate how a representative ANM system that uses deterministic middleware can automatically, and dynamically, manage the quality and availability of communications channels and media to deliver consistent performance across the ANM system. A variety of communications infrastructure elements will be discussed on how effective such an approach may be.

INTRODUCTION

Recent developments in Active Network Management (ANM) for power distribution networks have highlighted a new set of requirements for the telecommunications infrastructure needed to ensure that acceptable service levels and control regimes that are inherent within the ANM approach be achieved.

This paper will examine the traffic engineering requirements for effective deployment of ANM upon power distribution networks, whilst considering recent learning from actual installations that have been put into operation recently.

A discussion on the limitations of existing telecommunications infrastructure and the rationale of why it was built in its current form will be outlined. Further to this we shall examine best practice from complementary industry sectors in how these limitations can be dealt with, recognising the technological shifts and associated characteristics that are somewhat aligned with the realisation of ANM for power distribution networks.

Conventionally, specific classes of control and measurement traffic used in operational telecommunications networks have been derived from traditional systems built for Supervisory Control And Data Acquisition (SCADA). For many years this has served its purpose well, where the data needs of the Control Room Engineers operating the power distribution networks, were relatively simple. Primarily, the use of SCADA for implementing planned Network Outages and reacting to faults has been accepted within the industry for over forty years. A major shift in operating approach, that adds layers of control functionality embedded within the power distribution networks takes autonomous actions in real time is now a reality..

Distribution utility telecommunications infrastructure that has historically been built to support the data transfer for SCADA systems is insufficient for ANM-type traffic. Although point-to-point and multi-drop data links have traditionally been used to carry SCADA traffic, these have severe limitations when overlaying ANM as a control strategy on the power distribution networks. Put simply, ANM traffic has much higher requirements in terms of latency and reliability than SCADA-type traffic, mainly due to its higher criticality level from a power network control perspective.

DISTRIBUTION ACTIVE NETWORK MANAGEMENT

Background

Fundamentally ANM has been developed to allow autonomous control of power network devices used to alleviate enduring constraints placed upon the power delivery networks any moment in time. In order to achieve this it is important to ensure that the requirements to effectively, efficiently and safely deliver power to a diverse population are met. The real-time nature of power production and consumption necessitates that extremely specific design criteria are used in the specification and engineering of the resultant control systems. The constraints that present the greatest difficulties can be overcome by two specific applications of Active Network Management.

- Power Flow Management: Distribution-connected Generation beyond a firm level introduces the possibility of overloading the network in the event of a circuit outage. Actively managing power flow implements generator control that is dependent on reliable real time measurements and robust control logic.
- Voltage Management - although voltage issues have been traditionally avoided by careful selection of line reactance and resistance in the planning stages, ANM can be implemented in existing distribution networks to exercise autonomous control over the real and reactive power flows within a network area. This is achieved by controlling generator real and reactive power, using line voltage regulators, or the implementation of a reactive compensation device such as a Statcom. The Voltage Management application is dependent on reliable real time measurements and robust control logic, activated as necessary to alleviate voltage issues in a co-ordinated manner.

Common to both applications is the reliance upon telecommunications and control technologies that ensure reliable, highly available functionality that operates across network areas, voltage levels and disparate device types.

Innovation

Grid modernisation through the introduction of autonomous control regimes, as represented by ANM, has to be delivered on an incremental basis. This vision has to bring together and ensure interoperability between the diverse technologies that compose ANM upon the power distribution networks. It is clear that significant innovation will be required at an intensity currently unknown in this market.

In the context of the operational power system, ANM is establishing a layer that links SCADA and the Protection, Automation and Control systems denoted in figure 1. There is clearly a role between such traditional network management layers/functions and ANM must therefore exhibit characteristics commensurate with both upstream and downstream components and systems. For example, ANM must be visible and controllable to the engineers in the control room, as SCADA currently is, whilst also operating in a fashion that is commensurate with existing automation and control as implemented in substations and on the wider physical network. The ANM layer provides the opportunity to evolve the way the network is planned and operated to enable increased connection and utilisation of renewable generators, energy storage, demand response and ancillary services that have yet to be defined. As the key linkage between dedicated protection and control schemes, to the reactive, information-rich level of the Control Room, ANM fills the void where just-in-time, proactive control is making a huge difference to the effective operation of networks.

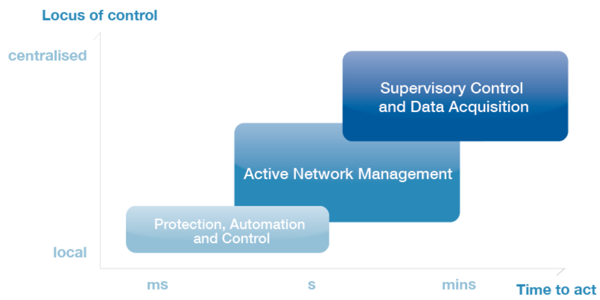

Figure 1.

Comprehensive usage of state logic, failsafe mechanisms, distributed algorithms, operating margins and hierarchical control methodologies is necessary to facilitate an enduring, wide-scale build-out of ANM systems that can be effectively applied to resolving constraints within power delivery networks.

Overall ANM system integrity is a function of the telecommunications infrastructure, as its reliability, availability and latency metrics all affect the control actions taken upon the population of controlled devices that are components of any ANM system.

Hierarchy of Control

Active Network Management within the Smart Grid will increasingly rely upon the capabilities forged by complex hierarchical control systems, and distribution utilities rolling out projects and services reliant on these capabilities will need a telecommunications infrastructure that can enable the building and interconnection of a wide range of technologies. Typically these are:

- Individual real-time ANM controlled devices interacting with physical assets across voltage levels;
- Small networks of real-time devices solving specific power system constraint issues on the networks in an autonomous manner;
- Large networks of real-time devices co-ordinated in a systemic manner to concurrently manage various, and often conflicting, network issues over multiple geographic areas or even voltage levels;
- Data Exchange Protocols that facilitate real-time control across a variety of telecommunications fabrics;

- Embedded ANM control algorithms, intelligent sensors, data handling and exchange mechanisms within the power network;
- Creation of linkages between all necessary active elements or objects to allow 'schemes' to operate/inter-operate seamlessly whilst leveraging adaptive telecommunications components and underlying technologies;

Fail-to-Safe

Best practice in the industry suggests ANM systems should be designed to incorporate failsafe functionality at all layers where state/field control is present. Control modes are designed such that, in case of the following events:

- Communications failure;
- Device not responding;
- Failure of measured analogue or digital value;

Predetermined control actions and backstop logic is in place to ensure graceful degradation and recovery of the power system elements under ANM control.

Sensor Data Acquisition

Integrating field data from gateways, distributed systems and network management devices, transducers, sensors and substation computers is becoming increasingly complex. In a sector that has not had to deal with such an explosion of operational data before it is a real problem. Where previously the volumes and types of data flowing to centralised SCADA and/or other control systems were constrained the emergence of advanced applications such as ANM have highlighted requirements for increased situational awareness and network visibility. This in turn has meant that, in order to accommodate this potential flood of data the distribution utility must revisit their operational plans to procure and deploy the necessary telecommunication channels systems that will carry operational data acquired from sensors. Without judicious application of sensible data acquisition strategies there is potential for data streaming from these devices to overwhelm upstream control systems such as ANM. Innovative solutions to this issue are long overdue.

Serial Data Communications

SCADA communications over a serial or analogue channel have typically been used by network operators for both control and measurement data. Serial communications require each device on the same channel to use the same settings so that the master device can communicate with each slave device on the channel. This remains the case whether these serial analogue systems are over various wired, fibre, or wireless media. For systems which are dispersed geographically, modem lines are still a common method for SCADA systems to utilise telephone lines third party carriers to connect the centralised control room equipment to the devices out in the field.

Where SCADA for power distribution management is contained within a regional area that can be covered with copper or fibre circuits, the controllers, RTUs and other field equipment are typically connected over multiplexed point-to-point circuits. The underlying technology is often still based on serial analogue channels.

IP Networking

Modern day technological landscapes have seen the Internet Protocol (IP) become a mature and dominant protocol at most core/WAN telecommunications networks, including the IP backhaul segment. Although, IP is still in its infancy in terms of adoption within smart grid communications networks, a variety of issues need to be addressed before full adoption or recommendation of an end-to-end IP layer convergence, for example IPV6 addressing and significant CyberSecurity concerns. There is no doubt that best practices developed within the telecommunications industry will be brought across to the smart grid industry to accelerate development of IP within this area.

Telecontrol

Where telecontrol is effectively remote control of devices and field-based assets, Active Network Management utilises autonomous, deterministic control superimposed within the network that supersedes most of the functions of telecontrol. Telecontrol normally requires human intervention, whereas ANM does not.

Much of telecommunications infrastructure used for operational technologies has focused on supporting telecontrol. As a result, investment in the SCADA and telecommunications infrastructure has focused for many years on supporting out-dated telecontrol systems that do not rely upon the advanced techniques and mechanisms that are embedded within ANM. These are discussed below.

Polling

Conventionally, SCADA systems that are spread over Wide Areas utilise polling to periodically request field level information from the network sensors. Although, This approach has been used for many years, there are however many disadvantages with this approach, particularly where unnecessary data is retrieved when no change has occurred. The primary benefits in using the polling system is that of cost; this system can be installed and maintained quickly and easily by the network operator. The technological simplicity of the system has also been embraced for many years by operational staff.

The polling mechanism means that an increasing amount of delay is introduced into data retrieval. Although there have been a number of ANM installations that have used polling in a small way, the impact on the operational performance of ANM schemes can be quite significant, and has been noted in the operational analysis of these installations.

Report By Exception

Reporting by exception conserves valuable bandwidth by transmitting only field level information that has changed outwith specified limits. In addition to making existing communications networks more efficient, it also enables the multiplexing of field data on single channels across the infrastructure. The primary benefit is the reduction in the number of communication channels required to transfer data. Also, where there are a large number of remote devices uploading data streams across the infrastructure, report by exception ensures that this can be achieved in a much more compact and efficient manner. Also it reduces the delay in retrieving only data that is necessary. There is however, some increased cost with the installation of report by exception systems. The necessary protocols and logic handling at each end of a link is more complex than with a polled system. For example, where there is a significant outage event on the distribution network, many data points will change status in a very short space of time and subsequently reported this change to the Control Room. This can lead to a flood of data being transmitted in a very short timescale. Depending upon the available channels and communications capacity, this can lead to significant data synchronisation issue post-event.

RE-ENGINEERING THE DATA PATH

ANM requires a systems engineering approach to information exchange. ANM requires much more than simplistic Fire-and-Forget data uploads. Complexity is added with control hierarchies, as indicated earlier.

Hub and Spoke

Clustering of complex systems commonly results in a Hub and Spoke configuration. In its most basic architecture, each controlled device has a dedicated linear connection to the data hub at a higher control level. In other aspects, this architecture may be considered a star topology with the data hub typically having multiple dedicated communication links out to Distributed Energy Resource (DER) devices. Each communication link can, in reality, be of any medium type: wired or wireless. This has been noted in pivotal ANM system deployments over the past decade and remains the model for the existing platform elements that are currently being built and deployed. Although this philosophy has satisfied the purposes of participating distribution utilities to date, and shall be applicable to a number of future projects that subscribe to ANM schemes of this form, the future, more complex, needs of the market dictate that an alternative strategy is developed.

Publish-Subscribe

SGS is developing capability in the publish-subscribe paradigm for future ANM data exchange. At its simplest publish-subscribe data exchange can be thought of as follows: Applications that communicate through a publish-subscribe paradigm require the sending applications (publishers) to publish messages without explicitly specifying recipients or having knowledge of intended recipients. Similarly, receiving applications (subscribers) must receive only those messages that the subscriber has registered an interest in. Figure 2 illustrates this arrangement.

Publish-subscribe provides greater network scalability and a more dynamic telecommunications network topology. This is especially true where IP-based connectivity has been developed. Although there are publish-subscribe mechanisms that are transport-layer agnostic, the case study SGS has exemplified utilises the IP stack as the baseline for the implementation discussed here.

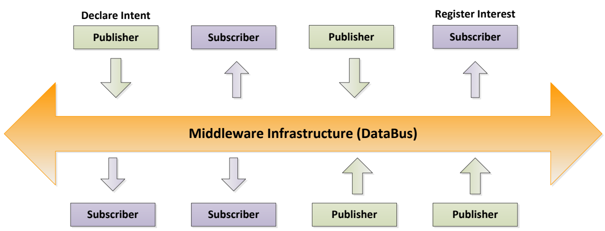

Figure 2.

This is in effect, the antithesis of Polling where a channel must be in place with dedicated end-points having knowledge of each other's presence. Where polling uses a 'pull' approach, publish-subscribe messaging uses a 'push' approach, in that data is 'pushed' to recipients who have a registered interest in the data. This approach takes the Report By Exception mechanism to a much higher functional order.

Deterministic Publish-Subscribe

The Object Management Group (OMG) Data Distribution Service (DDS) has been developed as an open standard over the past decade. It is a platform-independent mechanism for data centric publish/subscribe middleware systems.

To ensure that for critical real-time systems the data exchange retains deterministic performance, a novel approach to traffic engineering was taken. Based on software technology developed for military systems the telecommunication-dependent behaviour of DDS can be controlled, and tuned to the needs of the target domain. In this case the Smart Grid, through ANM. The DDS publish-subscribe technology uses refined, proven software to support large-scale, high-performance, and constrained-bandwidth systems across a variety of telecommunication infrastructure types.

DDS specifies a standard Application Programming Interfaces (APIs) and protocols that provide relatively easy and quick integration adapters across multiple platforms whether embedded or enterprise based, as depicted in the figure above.

The term Quality-of-Service refers to a general concept used to specify and control the behaviour of the communication service. The concept specifies that indication of 'what' is required rather than 'how' this is done. In particular, QoS provides the ability to manage the use of key resources such as:

- Network bandwidth;
- Persistence;
- Timeliness;
- Reliability of the data exchange across the telecommunications infrastructure.

All objects that are involved in the communication have their own QoS parameters. Each of these controls a specific aspect of the behaviour of the communications service. QoS policies at the publisher side must be compatible with those at the subscribing end to maintain acceptable data exchange. Also, communication is only established if the offered communication properties of the publisher meet the requested behaviour of the subscriber. The utilisation of QoS settings particularly addresses the needs of distributed real-time ANM applications because it provides predictability and resource control. In addition, the flexibility that underpins publish-subscribe is maintained.

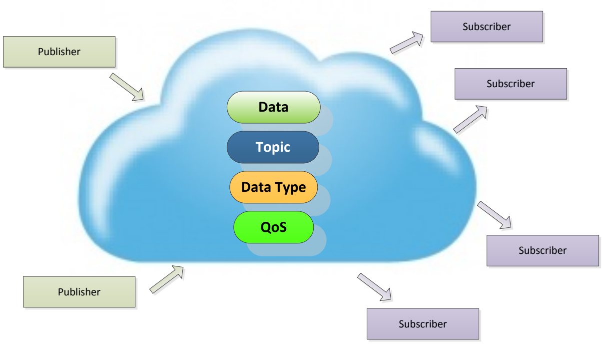

Figure 3.

As denoted in figure 3 above, multiple Publishers and Subscribers exchange strongly typed data through a common topic. The use of DDS allows flexibility and scalability to be in-built with low-latency data communications for distributed applications such as ANM. DDS is a peer-to-peer communication model requiring no gateways, servers, or software daemons to enable data exchange. A robust Quality of Service model controls the actual data-level communications. QoS are commonly used individually or together, as in SGS' ANM deployments, to affect a variety of communications aspects, including reliability, performance, and persistence of data, system resources utilisation. This results in tighter operating control of the power system devices located upon the distribution networks by the ANM schemes.

SUMMARY

In examining the limitations of existing telecommunications infrastructures that can dynamically and reliably support ANM traffic we have identified possible solutions to maintaining highly available data paths between the necessary systems and devices that are the constituents of Active Network Management. By leveraging deterministic middleware, in the form of real-time publish-subscribe technologies, SGS has proven the efficacy of re-deploying a technology stack developed for a complementary industry sector for the benefit of the smart grid. The QoS model offered by DDS allows adaptive use of an array of heterogeneous telecommunications infrastructures that have previously been underused by, or otherwise unavailable to, network operators.

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