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THE ROLE OF COMMUNICATION SYSTEMS FOR SMART TRANSMISSION

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SUMMARY

The electric power grid constitutes a key asset in National Critical Infrastructures. Throughout this paper, the term Utility Communication shall include the wide field of technical communication means, methods and applications that are not only used by entities like power-generation /transmission / distribution companies but also by pipeline- or railway-operators

The communication system is essential to run utilities core business in a reliable, efficient way. Quite often Utility communication is just perceived as an unavoidable cost factor but some utilities managed to expand their offerings and communication infrastructure in a way to turn it into a profitable business by selling or leasing assets or managed services. Without an efficient communication network modern Power Systems would be unthinkable. The communication network conveys mission critical teleprotection commands, SCADA signals for the remote control of unmanned stations to transfer data and load values from sites across the Power systems to central control Centre and transmit control commands to the sites. And most critically, the communication network carries many of the vital signals that have to be instantly exchanged in real time between different locations to ensure optimum coupling of the Power System. In short, communication networks help Power Utilities keep electricity flowing all the way from generator to the consumer. The deregulation has brought an increased cost pressure, and need to minimize power losses.

To achieve these goals, a robust, high performing and cost-efficient communication infrastructure is required. Technically there is no unique solution that can be proposed, because each utility has already existing infrastructure, network topologies, and specific applications. The paper addresses the important role of reliable utility communication networks and services for modern and high performing power grid operation. The protection of power lines and other high voltage assets as well as latest utility related standards (e.g. IEC61850 & IEEE C37.94) put most stringent demands on real-time performance and reliability of communication.

An overview of commonly used communication media / technologies for wide-area networks (WAN) for transmission is presented

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Introduction

This paper discusses upon the overview of the communication Technologies and their optimum application for secured and reliable transmission of electrical energy. To achieve this task it is important to select field proven equipment with proven technology from reputed manufacturer having vast experience in communication for Power system

Key requirement of Utility communication network v/s applications

Today Power Utilities face the challenge of implementing and operating a communication system that covers key requirement for mission critical applications with no compromise and at the same time to gain maximum benefits from advanced communication Technologies.

Mission critical information

Within the bundle of communication traffic, the mission critical traffic can be generally defined as data information that coming from application that play a vital role for the operation of Power system. It minimizes the risk of blackouts and protects the power infrastructures from damages. The transmission of such kind of information is the key issue for the reliable transmission of electrical energy.

Technology and Trends of Modern Communication System for Transmission

Modern communication systems for the electric Power industry are characterized by high speed backbone communication networks and low speed backup and access channels. Usually, the backbone network is realized with fibre optic system allowing high volumes of information at very high speed. Broadband backbone networks gradually supersede the traditional Power Line carrier Communication System, especially for data transmission between dispatch offices or between dispatch offices and main node stations where several access links from small remote stations come together and traffic volume aggregates.

However, installation and maintenance of high-speed backbone networks are quite expensive, especially if existing HV power lines have to be upgraded with new ground wires incorporating optical fibres (OPGW). If the volume of transmitted information is relatively low, the application of Power Line Carrier systems is still economically justified.
This clause addresses some selected communication technologies, which can be considered for specific utility applications.

Communication Technologies

The deployment of optical fibres for communication started in 70's and became one of the major driving forces for the fast growth in broad band communication. During last 4 decades different network technologies have been introduced. The evolution process in the communication sector is ongoing. In the following section we will concentrate on the most important transport and networking technologies for the operational communication in Power utility.

Transport Technologies

PDH (Plesiochronous Digital Hierarchy) – Initially the FO systems were based on PDH. This technology uses bit stuffing method using TDM techniques. As a result PDH does not allow direct insertion and extraction of individual channels leading to highly complex multiplexing and de multiplexing with higher bandwidth limitation. The interoperability between different manufacturers limited hence do not have flexibility for present transport requirement but still widely used at access level.

<u>SDH (Synchronous Digital Hierarchy</u>) – In order to cope with higher bandwidth demand and to overcome the described short comings SDH has been defined by ITU-T in late 80's. In SDH network nodes is synchronized to high accuracy common clock. SDH supports interoperability between different manufacturers. With dense wave length division multiplexing (DWDM) bandwidth can be further enhanced at optical level by using different wave lengths on same fibres.

Networking Technologies

<u>ATM (Asynchronous Transfer module</u>) – In the 90's data application introduced new requirements for broadband ISDN (Integrated Services for Digital Network). ATM has been seen as the answer to the problem of integrating bursty data traffic and voice services. The traffic to be transmitted is split in to cells with equal length. Each cell carries source and destination address and it is routed through the network. ATM offers different service categories emulating circuit switched and package switched network. It is powerful technology with a drawback of very complex signalling

<u>IP (Internet Protocol</u>) – IP is a packet switching technology developed for communication between computers. The technology earlier used for local applications (LAN) and spread out in to wide area network. IP based solutions are cost effective. It decreased the demand for ATM based data networks. IP is a dominant at access level. Since IPv4 cannot guarantee class of service, IPv6 has been introduced to overcome the short comings of internet addresses and QoS of IPv4. Despite high expectations IPv6 yet to be successful in the market due to huge installed base of IPv4 and emerging MPLS.

<u>MPLS (Multi-Protocol Label Switching</u>) – It is a new emerging technology defined by Internet Engineering task force. (IETF) that combines the features of IP and ATM. It is based on switching technology and offers enhanced quality features. A label in layer 2 header identifies the path a packet should traverse. It is seen as possible feature communication solution offering flexible bandwidth allocation combined with QoS. Although MPLS offers QoS control, it does not have truly deterministic characteristic. This technology is under dynamic development and many IETF specifications to be finalized.

Application of Technologies in Power utility

At access level IP plays an important role for SCADA and Video applications. Voice over IP have not been used to large extent in operational networks due to high investment cost and no crucial advantageous to utilities. It is expected that VOIP solutions will make its way in future for operational telephone services.

Higher demand from substation monitoring and automation led to growth in bandwidth need. Therefore SDH has become dominant transport technology because of stable standards, short switch over times deterministic time and support ring configuration. Driven by growing IP traffic MPLS comes in to focus as an adequate technology. It has non deterministic propagation time and the switchover time to alternate route is vaguely specified by IETF as "short as 10s of millisecond). The delay partly inherent to MPLS and limits the practical use in operational networks.

At the same time SDH has been enhanced by new ITU-T standards based on physical SDH layer, the general framing procedure standard (GFP, ITU-T G.7041) in cooperation with virtual concatenation (VCAT) and link capacity adjustment scheme (LCAS, ITU-T G.7042) defines an optimized data encapsulation protocol for transportation of multiple protocols.(e.g. IP/Ethernet). With additional functionality IP over SDH, SDH offers similar possibilities to MPLS, but ensuring deterministic time behavior. Therefore SDH remains the most important and proven backbone technology.

COMMUNICATION SYSTEMS FOR POWER UTILITIES

Power Line Communication system

Power Line Communication system – Then & Now
The Power Line Carrier Communication System is proven Technology across the globe and provides guaranteed services to Power Utilities under any network conditions especially for telecommand application.

The recent trend is to employ PLCC systems as backup communication systems for telecommand and important data channels in EHV transmission systems.

Traditional analog PLCC systems are field proven and best suited for transferring mission critical telecommand signals over EHV lines. They also accommodate low speed data upto 2400baud in 4 KHz bandwidth along with telecommands. The main advantage of analog PLCC is its capability to perform satisfactorily during low SNR conditions. The concept of integrated teleprotection coupler in Carrier equipment ensures high degree of security, dependability and MTBF figures.

The ever-ongoing automation of power stations and substations brought about new bandwidth requirements related to transmission systems. The new demand is to transmit several voice channels and data with the speed up to 9600 bps or even higher. Moreover, SCADA systems adopting the IEC60870-5-104 protocol require IP connectivity for accessing the remote nodes for inter-Centre data exchange. In order to fulfil these requirements the traditional analog PLCC technology was enhanced using high-speed digital modulation principles, hence creating Digital Power Line Carrier (DPLC) systems. Today, these DPLC systems can provide a maximum transmission speed of up to 64 kbps in the transmission bandwidth of 8 kHz. Digital Power line carrier equipment now supports IP connectivity. DPLC can support data rate up to 256 Kbps. The modern digital Power line carrier equipments are bandwidth efficient hence support higher data rate compared to carrier equipments working with analog modulation principles. In order to have higher data rate in DPLC it is important to have good SNR conditions in Power line carrier system otherwise desired data rate cannot be achieved. Therefore DPLC systems are very sensitive to noise.

It is well known that the level of corona noise on the HVAC power line is variable with respect to weather conditions. For HVAC lines the corona noise level increases under foul weather conditions (rain) and decreases during fair weather conditions. From theory it is also known that the maximum data transfer rate depends on the signal-to-noise ratio (SNR) at the receiver input: it can be increased for fair SNRs and needs to be decreased for low SNRs in order to prevent errors or even a complete link failure due to the threshold characteristics of digital transmission systems. The conclusion is that an optimum system would self-adjust its transmission speed according to the prevailing line conditions. The automatic speed adaptation techniques are used in DPLC to obtain maximum throughput for data transmission. DPLC also introduces considerable delay hence application which is sensitive to latency cannot be run on this system e.g. differential protection.

The DPLC that was used in the application described above employ Multi Carrier Modulation (MCM), enhanced with automatic transmission speed adaptation to counter the corona noise effects and to exploit the channel for highest average transmission speed.

Applications of IP over DPLC:

The possibility to create a WAN using DPLC is an economical solution when true broadband data transmission is not required or is economically not justified. Today, the maximum speed over DPLC is about 256 kbps, which is higher than standard Internet access provided by dial-up modem connections (typically operating between 19.2 to 48 kbps). In contrast to commercial off-the-shelf modem technology, automatic speed adaptation as implemented in the DPLC systems will ensure that the average data throughput is maximized.

There are several possible applications for this kind of IP connection where in latency is not critical.

FO based Telecommunication systems.

Large Transmission and Distribution networks are as on date being realized with optical fibre based SDH system. SDH being a transport layer function that allows various type of services co exist within single high bandwidth optical stream and fulfills the stringent requirement of protection and control. These services can be applied to the functions of differential protection, teleprotection, SCADA, AMR, IED communication, video surveillance etc. making it possible to realise a stable and fast network for protection and automation of the power network.

SDH technology is widely used and well established in transport networks of electric utilities, fulfilling the stringent QoS[1] requirements for control- and protection. SDH is however said lacking the flexibility and bandwidth efficiency of packet-switched solutions which becomes even more important if the assets are used in conjunction with providing services to 3rd party customers.

IP is continuing to establish as a standard protocol in mainly Ethernet based communication networks. Historically IP is purely seen as best effort technology which excluded it largely from being applied for mission critical real time application between the substations. Ongoing developments gradually paved the way for using IP services that put certain requirements on real

1 Quality of Service; stands for mechanisms to guarantee certain performance parameters, e.g. timing, jitter, bandwidth

time performance. Driven by Utility specific applications existing Ethernet technology has developed towards derivatives with leaner and faster overhead processing. One of the results is protocols in the context of IEC61850 for today's Intra station LAN communication.

On the other hand combining the best of both worlds lead to solutions which are using Ethernet over SDH (EoS) often called next generation networks. Following key features of EoS solutions need to be highlighted specially for utilities.

- EoS does not affect any of the TDM[2]-services: mission critical applications like teleprotection keep their absolute timing-behavior. Switch-over-time in case of link-failures remains less than 5ms (Ref: ABBs FOX-family with integrated teleprotection).
- GFP[3] / ITU-T G.7041 and related standards allow guaranteed Ethernet-bandwidth. It's a question of configuration if several applications shall share it or if individual applications (e.g. SCADA, Video over IP and 3rd party traffic) shall have their own & guaranteed capacity.
- TDM - & EoS services benefit from the SDH-protection schemes with less than 50ms restoration-times. These can be combined with the various flavors of Spanning-Tree and Routing protocols. Decisions, which protection scheme shall apply for which service has to be derived from balancing aspects like availability of extra-bandwidth, restoration time and fulfillment of Service Level Agreements (SLA).

On top of all TDM- & Packet-based services, an optical WDM[4]–layer can be considered, that allows transmitting or even switching different signals at individual wavelength's on an 'all optical' base.

These days' standards such as IEC61850 and IEEE C37.94 are frequently mentioned in conjunction with Utility Communication.

IEC61850 is a suite of standards about substation automation, which also describes related communication requirements. Apart of 'non-time critical' services (e.g. file-transfer), IEC61850 defines so called GOOSE[5] -messages for substation internal communication. GOOSE carries typically tripping and interlocking information which has stringent conditions in terms of reliability and transmission-time over the substation-LAN. To comply to these requirements, messages are directly handled with special mechanisms at layer 2. The physical connection is optical or electrical FE/ GbE[6]. Today IEC61850 is defined for communication within a substation; the standard is however to be extended for inter-substation communication. Here Ethernet over SDH with its high availability, resilience and strict timing will be a future proof option for carrying mission-critical IEC61850 services.

IEEE C37.94 is a standard providing plug-and-play transparent short-haul communications between protection relay and multiplexer, which then carries the protection signal via the backbone to the remote side. The standard defines clock recovery, jitter tolerances, physical connection method, and the equipment-failure actions for all communications link failures.

2 Time Division Multiplexing
3 Generic Framing Procedure acc. ITU-T G.7041
4 Wavelength Division Multiplexing
5 Generic Object Oriented System Events
6 Fast Ethernet / Gigabit Ethernet

C37.94 is a TDM-oriented service well suited to be transmitted via SDH and PDH, provided the multiplexer and its management system support the appropriate interface

Radio Communication System

Radio can today be used for the In-Plant communication requirements such as AMR, DCS. More and more Power utilities are going in for Distribution Automation (DA) for Optimum utilisation of Electric Energy and to give reliable and quality power supply to the consumers. DA System are based on extension of intelligent control over electrical power grid functions to the distribution level and beyond to control industrial and residential loads with a finer level of precision than is currently possible.

Main Elements of a DA systems are:

- A Central Control & Monitoring Unit
- Smart / Intelligent RMUs located at various locations
- RTUs
- Communication Medium to Transmit Control Signals / System data to / from Central Control Unit to various distributed RMUs / RTUs

A single radio or two radios serving as Main and Standby, can be applied at the control center with each other substation having its own radio in Point-to-Point or star communication topologies with the control center. It can also be possible to achieve linear communication in store and forward mode wherein a substation communicates its information to the next substation and so on and the last in line communicates all the information thus gathered to the control center.

Reliability and maintenance of Communication system- Avoiding failures in Utility Communication networks

The impact of failures in Utility Communication networks can be from just annoying to disastrous. Communication within a substation has always been under full control of the utility itself. However, there was a trend of outsourcing the responsibility for the regional- or country-wide communication infrastructure, but not in all cases this turned out to be a wise decision. Normally, public operators are revenue driven and have little interest and poor know-how in the specific requirements of utilities. Hence, utilities can be much better off having their own communication infrastructure, than relying on public networks and outsourced services.

It's a technical fact, that each equipment has a certain probability to fail. The MTBF[7] can be improved by hardware-protection measures (e.g. duplicating modules). Compared to highly integrated equipments (e.g. a Multiplexer with integrated C37.94 or tele-protection interface) the system availability of solutions consisting of several somehow combined boxes is much lower. In addition, the MTTR[8] is higher due to the lack of a unified network management system (NMS).

More important than the MTBF of individual equipments is, the overall service availability, which depends significantly on intelligent network design and chosen technology. The following

[7] Mean Time Between Failures
[8] Mean Time To Repair

summary just highlights few aspects to be considered when designing a utility communication network.

- Bandwidth needs of the applications: regular exchange of complete files (e.g. XML) versus irregular update of switch positions upon an event (e.g. binary information).
- Meshed / ring topologies with SDH carrying TDM plus LAN-traffic (→ EoS) grant for fast traffic protection schemes and for continued service availability.
- Available resources and means of communication: fibre /copper; frequency bands for wireless solutions, etc.
- Combine different transmission technologies and use media diversity for mission critical services, e.g. fiber-optics with PLC. Such strategy reportedly has avoided severe problems e.g. during ice storms and earthquakes when OPGW's[9] failed or were cut, but PLC still maintained the service for teleprotection and voice
- Using Ethernet is not just plug & play if mission-critical signals shall be transmitted. Traffic engineering and continuous monitoring of network-load is required; Over-provisioning may help today but is not a viable solution in the long run. LAN-users may add equipment and applications that generate unpredictable behavior and may trigger proprietary fast protection mechanisms to fall back to slower standard modes (e.g. STP[10]).
- Careful selection of utility proven and type-tested equipments for harsh environment (→ EMC[11], temperature) is a first important step for successful implementation of a reliable network. But without professional integration and installation, the required stability and availability may never be reached.
- Running the utility communication over a dedicated network with very few and strictly managed gateways reduces the risk of outages caused by malicious attacks from the outside world.

Recommendations

- It is recommended that Communication system must be under full control of Utilities.
- MTBF shall be improved by hardware protection
- Design intelligent communication network and select right, proven technology. One network management system for FO and PLCC is better for simplified maintenance.
- Select vendors who can provide long term service support.

Conclusion

A highly reliable communication system is key to run the core business of a Utility in a safe and professional way. Poor performance of third party service providers emphasizes the need for Utility owned network. Technology wise, one can see a clear trend towards Ethernet but especially for Wide Area networks. EoS offers very obvious advantageous and legitimates future oriented investments. Puzzling boxes on the long run is not the most promising approach. Doing a proper system planning and integration together with an experienced partner guarantees that the network will perform as expected and also will cope with latest trends.

[9] Optical Ground Wire
[10] Spanning Tree Protocol
[11] Electro Manetic Compatibility

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