REVIEW OF INDUSTRIAL COMMUNICATION NETWORKS IN THE CONTROL OF SMALL-SCALE AUTONOMOUS POWER SUPPLY SYSTEMS

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Abstract

This article gives a review of modern networking technologies and standards used in the development of distributed control systems. Study of related scientific and professional literature has been performed, and basing on it a multi-level model of digital network structure in the field of small-scale autonomous combined power systems has been proposed. Necessity of integration of autonomous powering into SmartHouse systems and related distributed computing and networking issues are reflected as well.

As there is a wide variety of industrial networking standards used, this review covers and groups more frequently used protocols and stacks from the view of OSI (Open Systems Interconnection) reference model and layers of industrial automation. The aim of this article is to give a reference-point in the development of distributed control systems in the field of small-scale autonomous power supply and integration of them in SmartHouse systems.

Key words: industrial communication network, autonomous combined power system, SmartHouse.

Introduction

With increased expansion of dwellings and small farming facilities in rural regions with undeveloped energetic infrastructure, a problem of inaccessibility of energy resources arises and various autonomous solutions can be considered as the only solution. It can be referred to both heat energy supply and electrical energy supply to power miscellaneous household appliances, electronics, lighting and for use in farming and water supply needs. In a number of cases in rural regions of Latvia, setting up of an individual autonomous power supply system that uses one or more renewable energy sources, battery bank and a back-up generator is a reasonable solution, because of expenses of connection to public electrical power network. For example, in accordance to 'Methodology of calculation of connection fee to public power network' (approved by the council of Public Utilities Commission, document No.145, 11.12.2002.) installation costs of a power line depending on its parameters vary from 3000 to 20000 LVL per kilometer.

The purpose of an autonomous combined power supply system is to provide electrical power independently from public network by combining several mutually complementary sources of energy. In practice, systems with wind generators, solar cell panels and, in some cases, small water-power plants are used. Integral parts of such systems are also a battery bank for voltage stabilization and temporal power supply and a reliable back-up generator with combustion engine driving. It can be used for long-term powering if wind and solar energy is unenviable and batteries are depleted, and also if additional power is needed, e.g. for washing machine operation. All of this equipment should be supervised by a centralized automatic control system to provide the consumer with electrical power of good quality and ensure normal mutual interconnection of all components of the system (Osadčuks and Galiņš, 2007a; 2007b; 2008).

However, the costs per kilowatt hour (i.e. costs of exploitation) of autonomous electrical power system using today's technologies are still higher than energy provided by public electrical grid although the difference has tendency to go down. Therefore the key of use of self-produced energy is the economy and effectiveness. It is calculated that investments in effectiveness of use of energy save five times of expenses of generating equipment. It is true for both electricity and heat usage (Kemp, 2005). Energy effectiveness of buildings is studied by another area of science and technology: SmartHouse. It unites energy metering solutions as economy of resources is connected to precise accounting of them, technological solutions (economical lighting, heating, ventilation, air conditioning, heat insulation, etc.), security systems and use of optimal automatic control algorithms to improve the overall level of comfort. SmartHouse covers also communications: 'triple play' services (Internet, telephone and cable TV). Detailed researches have been performed and numerous technologies and end-user devices have been developed in this area. By integration of all of these technologies a new concept of an universal high-level centralized home interface, automation and monitoring solution – 'residential gateway' – has been proposed (Намиот and Шнепс-Шнеппе, 2008).

In order to increase the effectiveness of both producing party (the autonomous combined power supply) and consuming party (home automation systems) it is purposeful to integrate them on one of higher levels of automation and implement a centralized control.

Due to advances in microprocessor systems (integrity of chips, power consumption and manufacturing costs) it becomes economically justified to embed cheap microprocessor units, which can perform both control and digital interface (to other processors and human user) functions in a major part of sensors and executive devices. Thus it is possible to create a complicated multi-level distributed control system based on digital communication networks. Most of modern industrial automatic control systems are implemented using this distributed approach replacing legacy centralized control solutions based on analog signal networks (Кругляк, 2002; Vince and Kovacova, 2007).

There are several hundreds of digital communication network open and closed (commercial) standards, which are used in implementation of distributed control in various levels of automation. Unlike home and office networking, these standards provide higher level of determinism, specialized data structures and high reliability when used in stress environments.

The aim of this article is to present a review of industrial digital communication network standards, which could give a reference point in selection of optimal solution in the implementation of autonomous combined power supply systems and integration of them to SmartHouse for the system level and for the developer of end-user equipment.

Materials and Methods

Every terminal device (node) connected to the digital communication network can be taken for an intellectual unit, which unites necessarily functions to control the given technological process and interface to other devices on the network. The following functionality of a common terminal device in an industrial application can be defined (Кругляк, 2002):

- receiving commands and data from other terminal devices;
- reading values of connected analog transducers and switches;
- processing of control algorithm accordingly to technological process;
- delivering control impacts to connected actuators accordingly to technological process and/or commands obtained from other terminal devices;
- sending the collected information to other terminal devices on the network.

As in conventional computer networks, data interchange in industrial networks can be described using OSI (Open Systems Interconnection) reference model, which structures the data exchange functionality between nodes of a network into seven layers: physical, data link, network, transport, session, presentation, and application layer. Above the application layer, the actual user application comes. A number of industrial network standards implements only selected layers. For example, there are standards that define functionality only in physical layer describing prerequisites of networking in industrial applications with electromagnetic interference, thermal and corrosive stress environments, etc. Examples are RS-485, RS-422, Meter-Bus.

The communications in different layers can also be structured by ranks of the nodes. There are master-slave, server-client, and subscribing models in higher layers, and peer-to-peer and also master-slave (differently ranked) models in physical layers. In opposite to conventional computer networks, industrial applications make a heavy use of differently ranked node devices in the physical layer as in order to be economically reasonable, the network architecture should be chosen with taking into account of tasking, self-independence and complexity of terminal devices that can differ significantly in a single application.

The number of network standards that are used together in industry can be explained with essentially different requirements to networks. All the standards can be grouped by these requirements into hierarchical layers of automation. A version of common layer structure in industrial applications is given by K. Кругляк (2002). There are four layers of hierarchical automation (begging with the lowest): transducer and actuator layer, low level automation, segment automation of a technological process, and production level automation (Fig. 1.).

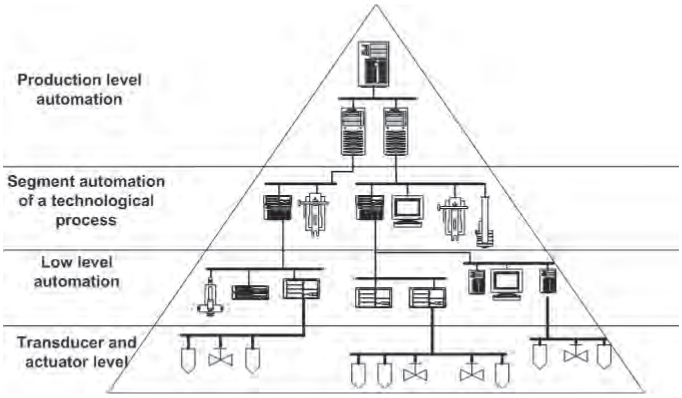

Figure 1. The hierarchy of automation and control networking.

It should be pointed out that all the data communication equipment (hubs, switches, repeaters, interfacing devices, etc.) is considered as an integral part of a network and therefore lies in corresponding layers of the hierarchy.

The distribution by layers also allows to minimize problems of compatibility of various networks used. For this purpose the bus masters and interface converters should be grouped at the boundaries of the layers.

At the lowest layer of transducers and actuators, several to tens of data bytes per frame are enough for communications between the terminal devices. Common devices of this layer are various subsystems of analogous and digital transducers, networks of intelligent digital transducers, data logging devices, electrical drives for motor control, valve, positioners, relay modules, etc. The basic characteristic requirements for networking in transducer and actuator level are deterministic operation in real time mode, simplicity of implementation of OSI model, minimal wiring (number of wires in a transmission line; it is a pair mostly), in certain cases the ability of powering network devices from the communication line and requirements for hazardous industrial environment.

For sensor arrays e.g. in temperature or gas composition sensors for measurement in larger areas the maximum number of nodes and radius of network is also important. As the end nodes of network due to number of them and conditions of operation (sensor arrays, actuators) should be as simple, power-economical and cheap as possible, the master-slave network architecture is mostly used in this layer of automation.

Examples of standards in this layer are AS (Actuator/ Sensor) interface (Половинкин, 2002), Meter-Bus, CAN (Controller Area Network), ModBus, Wake, LIN (Local Interconnect Network), X10 (network over mains power lines), wireless ZigBee, Z-wave, and MiWi.

In the layer of low-level automation, the length of data frames may vary from tens to hundreds of bytes as both amounts of user data and service information (headers, length fields, checksums, etc.) are increased, more complex addresation can be used, and OSI layers can be used more widely. Characteristic devices are controllers of machines and master nodes of transducer and actuator layer networks. Data interchange consists of technological commands from higher layer and data acquired from sensor systems. Therefore data throughput requirements are increased in comparison to lower layer. The examples of network standards in this layer are: Profibus-DP, Profibus-PA, CAN, Interbus, Foundation Fieldbus, DeviceNet. In a number of situations, industrial Ethernet can also be used (Кругляк, 2003).

In the layer of segment automation of technological process, the coordination of machines in automatic and manual mode has been performed. Operating modes of discrete machines and segments of a system (e.g. production facility) are organized and fault elimination, monitoring of operation, data logging and delivery to higher level are managed as well. The terminal devices used are industrial computers, high-end PLC (Programmable Logic Controllers) and HMI (Human Machine Interface) terminals, and other manual controls. Data transmitted consists of complex control commands, comparatively larger data arrays of monitoring and statistical information, updates of control equipment firmware, and HMI related data (drawings, agendas, user instructions, etc.).

Network specifications used in this layer: Profibus-FMSand industrial Ethernet. Peer-to-peer communication architecture is mainly used.

Production level automation layer groups personal computers and servers, which display the operation parameters of technological process, provide the lower layers with various informative services, archives and stores statistical data, maintains databases, creates reports, interfaces to the Internet, and performs administrative functions. The real-time requirements in contrast to lower layers are decreased and are limited to requirements of common local area network. Conventional home and office Ethernet equipment can be used in this layer.

The boundaries of automation layers described above are not strictly regulated and the layers can overlap, if it is economically reasonable. For example, the performance of CAN interface is relatively high (throughput of up to 1 Mbit s^{-1}, deterministic operation, and low latency) and it is available as a hardware module in a number of middle range microcontrollers (e.g. PIC18F4XX, dsPIC33FJ256GP, AT90CANXX). Therefore it is possible to use CAN in interfacing to transducers and sensors and in data interchange between more sophisticated controllers in low-level automation layer. The same situation is with Ethernet networks. Hardware solutions on a single chip for interfacing Ethernet networks in physical and data link layers of OSI model have become available recently, e.g. ENC28J60/SP chip, which is supplied in 28-pin dual inline package and implements Ethernet to UART (Unified Asynchronous Receiver and Transmitter) conversion. Manufacturers of microcontrollers also support Ethernet networking by providing full implementation of TCP/IP stack as freely available software library. It allows to integrate this type of networks to the lowest level of automation. There is also an extension developed: Ethernet/IP (Industrial Protocol). It works in session-presentation-application layer as object-oriented CIP (Control and Information Protocol) in order to achieve real-time functionality of Ethernet networks. But due to activity of lower OSI layers, actual determinism cannot be fully achieved.

Results and Discussion

Theoretical literature, a number of application notes and specific developments have been studied, and the digital communication networking hierarhchic structure of autonomous combined power supply system with integration in SmartHouse applications has been developed (Fig. 2.).

The lowest layer contains transducers and actuators of autonomous power system and SmartHouse installations: sensors of parameters of autonomous power grid (voltage, current, energy consumption metering), associated transducers of certain generators and power converters (anemometer, pyrometer, fuel level, operating temperature, etc.), and SmartHouse equipment (outside and indoors visible light sensors, thermometers, motion detectors and other security devices, remotely controlled dimmers and relays, blind controllers, etc.).

At the layer of low-level automation there are controllers of more sophisticated devices that use in their operation data from the sensor layer below: wind generators, solar cell panels, complex lighting control of rooms, simple HMI, like lamp switches and gauges of autonomous powering conditions, access control systems, etc.

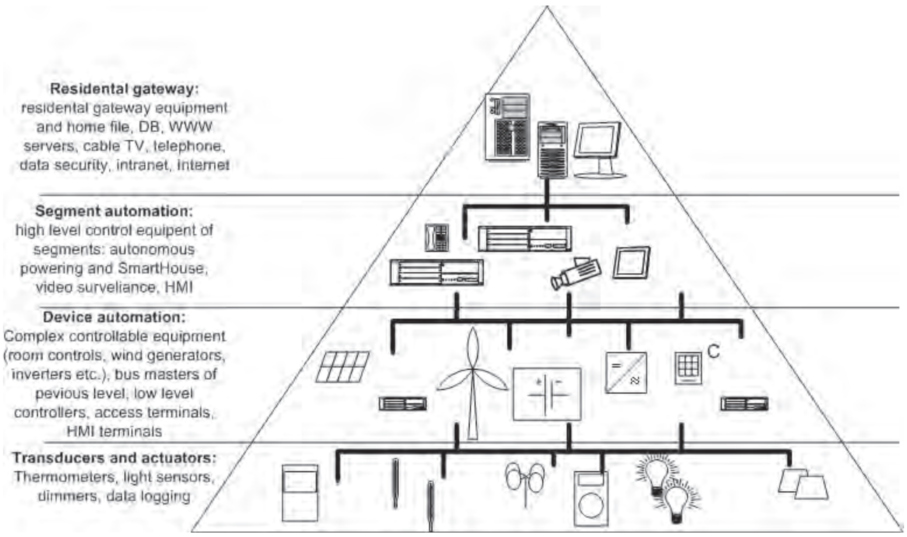

Figure 2. The hierarchy of automation and control networking in autonomous combined power supply and SmartHouse.

At the layer of segment automation, high level control of discrete segments can be implemented. In this case, the segments are autonomous powering and SmartHouse. This level also contains HMI points (touch panels with graphical user interface) and video surveillance system.

The highest layer is formed by local intranet, central node of home automation – residential gateway, triple play services, and data security equipment.

Figure 3 summarizes and groups by layers of hierarchical automation and OSI reference model the networking standards and technologies listed in this article and used by authors in projects connected to room automation.

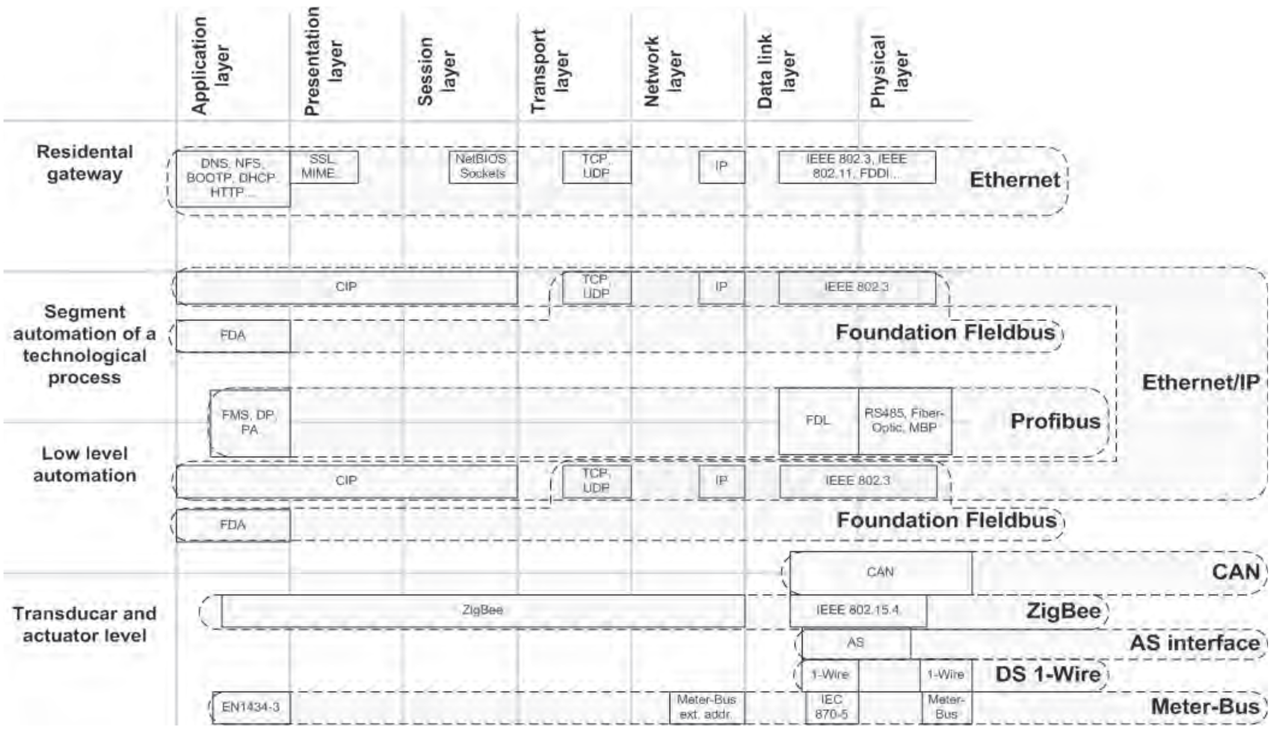

Figure 3. Grouping by layers of hierarchical automation and OSI reference model of several more frequently used industrial networking standards.

Conclusions

The common hierarchical multi-layer model of distributed industrial automation and networking and the particular model for autonomous combined power supply and home automation allows to structure overall system by using groups of industrial network requirements and accordingly select specific standard or technology of industrial networking. It can help in selection of optimal communication interface for particular project of both discrete device development and implementation of overall system.

The distribution by industrial network requirements allows also to minimize problems of compatibility of various network used in a single project, if bus masters and interface converters are grouped at the boundaries of the layers.

The idea of integration of autonomous combined power supply system and SmartHouse installations can help in increase of effectiveness of both of them as these actually are deeply linked systems by functionality. One part is a producer and the other one – a consumer.

This article gives only a review of mostly used industrial networking standards and only general recommendations in selection of optimal networking solution for particular project, and more sophisticated methodology is to be developed.

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