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SMART GRID AS INTEGRATION TECHNOLOGY FOR ENERGY SUPPLY AND TELECOMMUNICATION NETWORKS

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Our high-tech XXI century is, in particular, the century of “small power supply systems” due to the use of advanced information and communication technologies in energy networks. Creation of combined systems called Smart Grid opens great prospects for the development of both of these industries (energy and IT) and is intended to provide a synergetic effect. This paper examines existing models of Smart Grid, the suitable basic networking technologies, as well as typical usage scenarios for integrated intelligent networks.

Introduction

Smart Grid is a technology for integration of electric power supply and telecommunication networks in order to increase the energy efficiency of both types of networks, reduction of CO_2 emission under the ***Kyoto Protocol*** considering, decentralization of existed architectures for an integrated network (i.e. one of the main principles of Internet construction) and improving of its efficiency (efficient switching, routing) under use of alternative and renewable energy sources (like wind, solar, EM-smog) combined with use of hybrid hydrocarbon-electric vehicles (***PEV, Plug-in Hybrid Electric Vehicles***), with optimization of network management techniques and billing services (***Smart Metering***) within the conventional power supply networks, as well as increasing of its safety, security and ***QoS*** in such integrated networks for power supply and telecommunication [1, 2].

The concepts «***Grid***» and «***Smart Grid***» should not be confused. The (intelligent) grid network solutions are used for time-consuming computing tasks (simulation, planning, forecasting etc.) based on the (virtual) server clusters or supernodes with use of conventional Internet protocols. Nowadays ***Grid*** is a weighty part of innovative Cloud-technology (for instance, by ***IaaS, Infrastructure as a Service***) [3, 4] when the (mobile) client access to computing power is very easy. The most important task which has already become a “classics” of the grid technology is a rational and decentralized redistribution of computational workload between participating (virtual) servers, clusters or supernodes in the computing life-cycle of time-consuming engineering, scientific or economical tasks.

Therefore, the concepts «***Grid***» and «***Smart Grid***» are co-related areas of research. But the ***energy efficiency is not a direct scientific and technical challenge for purely computational grid technology*** [3 – 5]. Heat and redundant energy occurs here only as by-product, and even a harmful product ("heat waste products” of modern network technology).

Active deployment of the environmentally friendly, so «green» ***Smart Grid*** technology goes on today in many developed countries, for example, Australia, European Union, in particular, Germany and Austria, USA, Canada, People’s Republic of China and South Korea, which would like to provide and reinforce their own energy independence for the future. Several leading universities, for instance, National Technical University of Ukraine “KPI” (NTUU "KPI") and Dresden University of Technology (TUD) carry out the corresponding research subjects on the mentioned area and already possess certain “know-how”.

The slogan of the coordinated actions might be for all stakeholders as follows: “***From Internet of Data and Web Services to the Internet of Energy Services***”. Nowadays there are numerous international organizations and well-known companies that are developing the technology and corresponding devices for ***Smart Grid***. Among them are: ***IEEE, CENELEC, Cisco, Deutsche Telekom, Siemens*** etc. [6 – 16].

The existing basis for local-area solutions of ***Smart Grid*** is built on the following well-known network technologies: ***Powerline, Homeplug, WiMAX, PoE (Power over Ethernet), KNX, LON (Local Operating Network), WSN (ZigBee, EnOcean)*** etc. [3, 4]. But there is also a necessity to develop integrative solutions for net decentralization (one of the main principles of Internet construction), to improve its efficiency, to facilitate use of alternative and renewable energy sources (like wind, solar, EM-smog) and to stimulate the development of so-called efficient ***Energy Storages*** (batteries, peculiar energy depot) aimed to store redundant or excess (electric) energy.

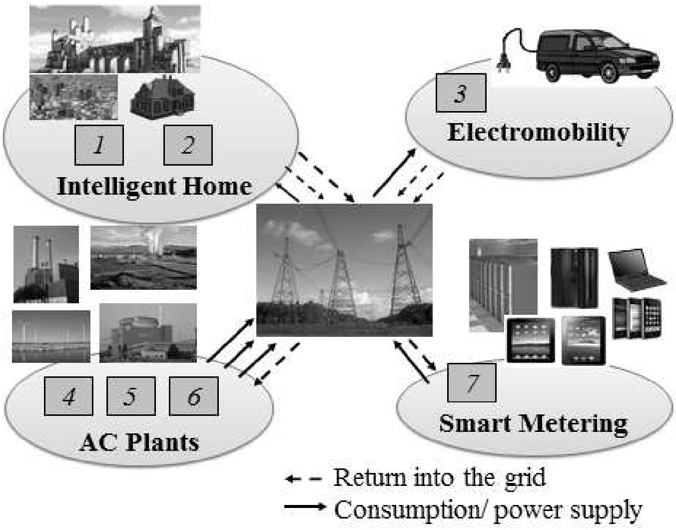
To reach this goal we need first to list scientific and technical development challenges for an integrated network (***Smart Grid***) on the existed basis of standard network architectures, requirements for such networks, and then to develop their basic models. How will it all work together? Let us consider the following two scenarios.

Scenario 1. What will be a middle-class network connection for a ***SME (Small and Medium Enterprise)*** in 2020? Only one cable will provide such services as electricity, telephone, Internet, digital high-definition television and Cloud services. Space heating will be realized via derivation and recycling of redundant energy from multiple (virtual) servers. The wired and wireless automation local-area as well as piconets like ***LON, KNX, ZigBee, EnOcean*** will be used to serve and control the in-door climate. Management of such integrated network can be performed through ***Ethernet LAN/ WLAN*** links as well as convenient protocols like ***IP, ICMP, SNMP.*** The program support, configuration and tuning of the intelligent network are realized with use of mobile devices (smartphones and tablets), mobile apps and through the offered ***Web Services/ Clouds*** [3 – 5].

Scenario 2. The scenario depicts a vision of ***Siemens AG*** – one of German leading companies in the field of network technologies and products. According to Fig. 1, in the future ***Smart Grid*** is designed to connect four major components [6], which operate both as consumers/ producers and electric ***Energy Storages.*** Among them are the following:

1. Intelligent Buildings (***Intelligent Home***) with solar panels and local-area networks for climate automation like ***Field Bus*** and ***WSN (Wireless Sensor Networks).***
2. Enterprises for generation of (electric) energy (so called ***AC Plants***) based on traditional or alternative and renewable sources (like wind, solar, EM-smog).
3. Electric mobility based on hydrocarbon-electric hybrid vehicles ***PEV*** that accumulate power and can afterwards "upload" it to the network (***Electromobility***).
4. Intelligent counters and meters (***Smart Metering***), which automates the processes, carry out the monitoring and network management aimed to low-energy consumption on the basis of improved tariff models with respect to the workload parameters and traffic, both analogue to packet-switched networks.

The considered components {1-4} may both use and release the excess (electro-)energy and stored redundant currents in the network.



Legend:
AC – Alternating Current; HVAC – Heating, Ventilating and Air Conditioning; PEV – Plug-in Hybrid Electric Vehicles.

Fig. 1. Smart Grid Technology Highlights by [6]: *(1)* Automated Ambience; *(2)* HVAC; *(3)* PEV; *(4)* solar, atom, gas, hydro and wind power plants; *(5)* geothermal plants; *(6)* combined heat and power couplings and storages; *(7)* on-premise monitoring.

Services Architectures and Multi-Level Models

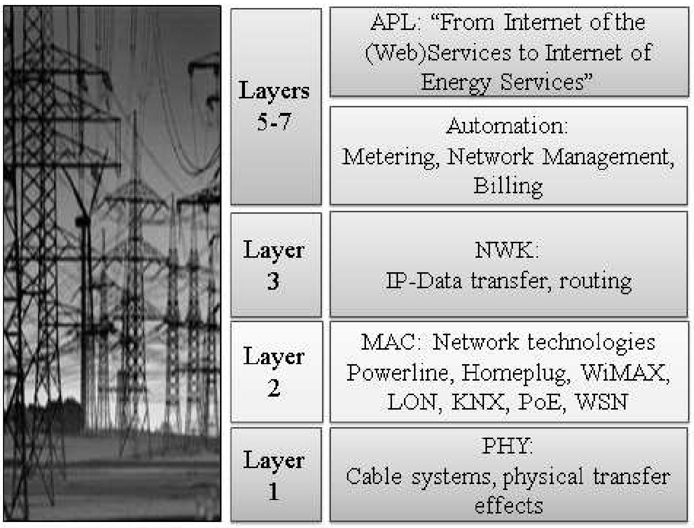
Integrated architecture of ***Smart Grid*** has to repeat in a certain extent the well-known ***OSI*** network architecture (Fig. 2). But it must also be multi-dimensional, i.e. has to reflect not only the abstraction levels with multiple defined interfaces, functions and services, but the various types of network technologies and domains of its use, types of consumers and service providers, device types, access control techniques, schemes to billing and payment for the consumed services.

Let us consider the existing multi-layered and multi-dimensional models for ***Smart Grid*** which are oriented to shared use of telecommunications:

1. ***NIST Smart Grid Conceptual Model*** (USA).
2. ***IEEE Smart Grid Model***.
3. A proprietary model of ***Cisco Smart Grid***.
4. Common architecture of ***ITG@VDE Smart Grid*** (Germany).
5. Next development of model (4), the ***EU Smart Grid Architecture Model*** (European).

One of the first developed on the area models, the Model (1), called ***NIST Smart Grid Conceptual Model*** (***National Institute of Standards and Technology in USA***)***,*** provides abstraction of properties of the integrated intelligent network based on classic three-level representation, including the following levels: ***1.Power and Energy, 2.Communications, 3.IT and Computer*** [7].

The universal Model (2) was offered via ***IEEE***-forum. ***IEEE Smart Grid*** is a professional organization for standardization and co-ordination among the ***Smart Grid*** stakeholders within ***IEEE***. Universality of the mentioned ***IEEE Smart Grid Model*** consists of creation and description of a meta-system called ***Smart Grid***, which extends the rules, interfaces and functions for individual intelligent networks to the so called ***Smart Grid Domains*** also based on the following three-level: ***1.Power and Energy Layer, 2.Communication Layer,*** and, finally, ***3.IT and Computer Layer***. ***IEEE*** organization shifted the focus of considering to the ***Communication*** and ***IT and Computer Layers*** both (2,3) as the determining levels for electricity distribution in ***Smart Grid*** (***Power and Energy Layer***) [8].



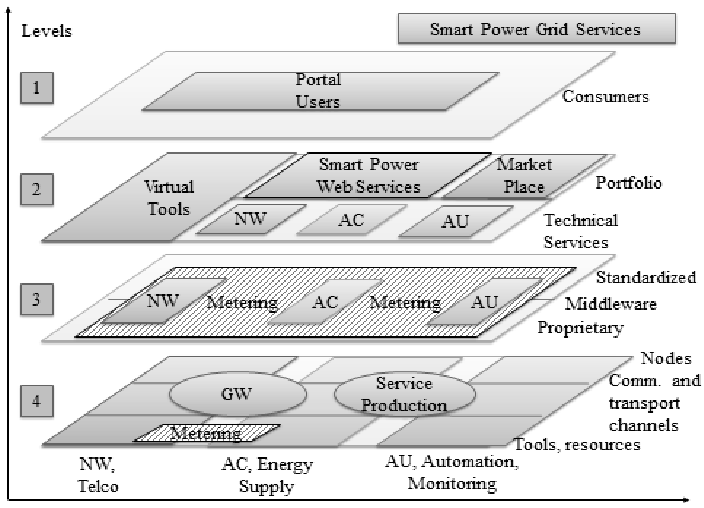
Legend:
APL – Application, NWK – Network; MAC – Media Access Control; PHY – Physical.
Fig. 2. A simplified architecture for Smart Grid.

The following proprietary Model (3) was provided by company ***Cisco***, one of the world leaders in the field of network technologies and products [9]. The model takes into account the development aspects of integrated (mobile) power transmission and telecommunications in the context of hardware and software that is produced via the company. Nowadays the company ***Cisco*** provides design and implementation, deployment and support of infrastructure and services for ***Smart Grid***, as well as the numerous communication systems for the power supply sub-stations, automation networks (***Field Area Networks***) for power supply nets, data security (***Cisco Switches, Routers, Firewalls ASA-CX***) for the ***Smart Grid***, creates the virtual storage centers for data processing (***Network Storages, Cloud Computing***), thus extending those capabilities of ***WAN*** architectures. The ***Cisco Connected Grid Network Management Solutions (NMS)*** offer the infrastructure, access tools, monitoring and management facilities for IP-able devices integrated into ***Smart Grid.***

Furthermore, let us consider the advantages of a common architecture for ***Smart Grid architecture***, proposed by ***ITG@VDE*** (Germany). Existing network technologies can be easily integrated into the framework of Model (4). The installed services are independent of the basic network infrastructure (refer ***OSI***). Common architecture for ***Smart Grid*** allows adequate modeling of integrated networks of energy and information at different levels of abstraction. Model (4) of ***Smart Grid*** can be used recursively or hierarchically to describe the inter-operability between different providers offering their services (Fig. 3):

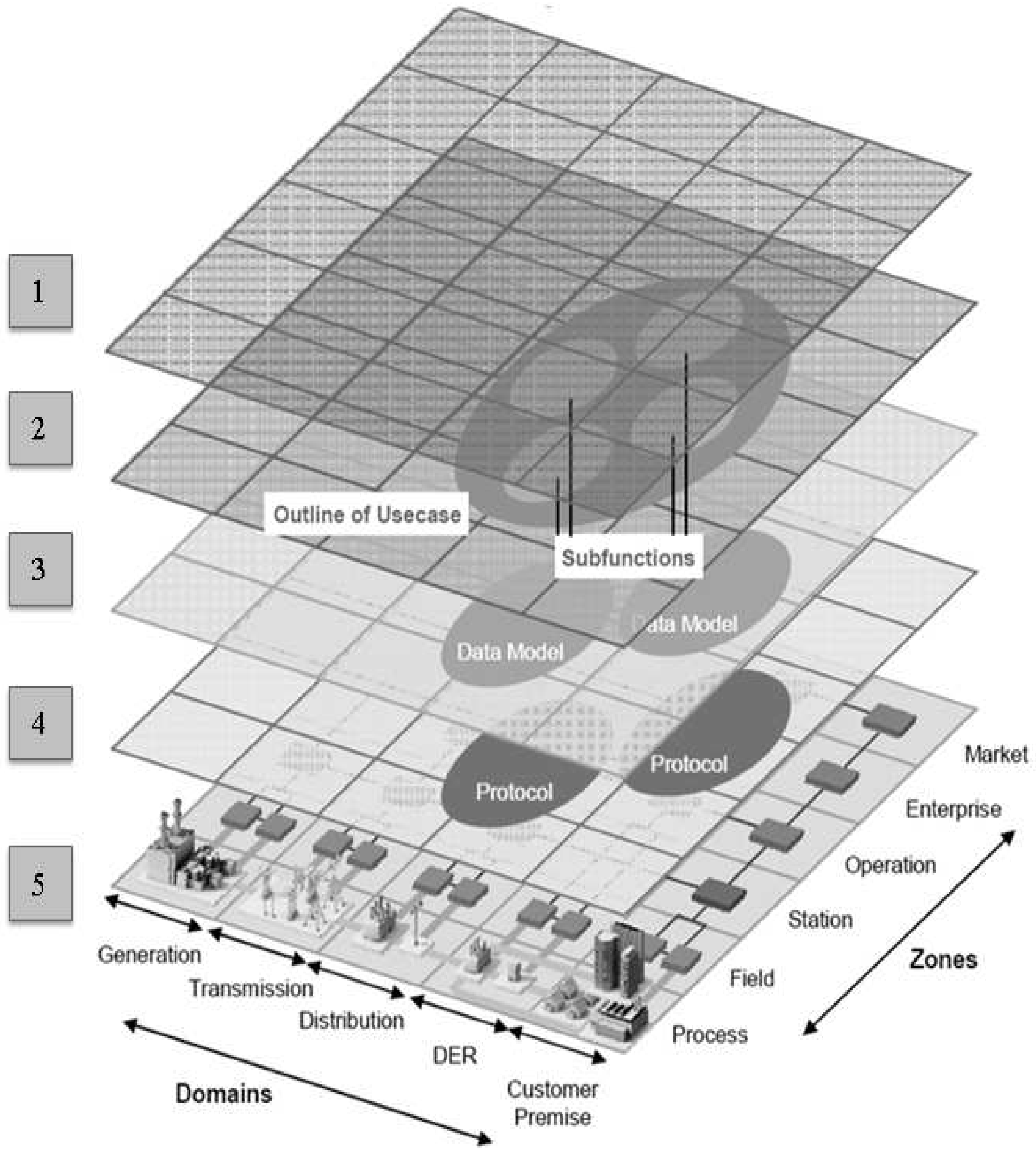
(a) (mobile) communication;
(b) electrical energy supply;
(c) Smart Metering (intelligent control and telemetry);
(d) Smart Power Web Services.

The presence of the common architecture of ***Smart Grid*** provides nevertheless a wide field for activities and describes the ability of the model to innovations [10–13].



Legend:
GW – Gateway; AC – Alternating Current (energy supply nets); AU – Automation (and management) networks; SPGWS – Smart Power Web Services; NW – Network; Metering – control and telemetry; Market Place – allocation and reselling of services.
Fig. 3. Common 4-layer architecture for Smart Grid [10 – 13] and the types of energy supply and data supply services: *(1)* Consumers; *(2)* Services and virtualization; *(3)* Info-objects and service communication; *(4)* Infrastructure/ PHY.

As the further development of this well-known und recognized Model (4) a more complex multi-dimensional European Model (5) called ***EU Smart Grid Architecture*** (Fig. 4) should be considered. The model



Legend:
Domains: DER – Distributed Energy Resources; GTD – Generation, Transmission, Distribution (production); CP – Customer Premise (delivery);
Zones: Process, Field, Station, Operation, Enterprise, Market (PFSOEM).
Fig. 4. EU Smart Grid Model [14, 15]: *(1)* Business Layer; *(2)* Function Layer; *(3)* Information Layer; *(4)* Communication Layer; *(5)* Component Layer.

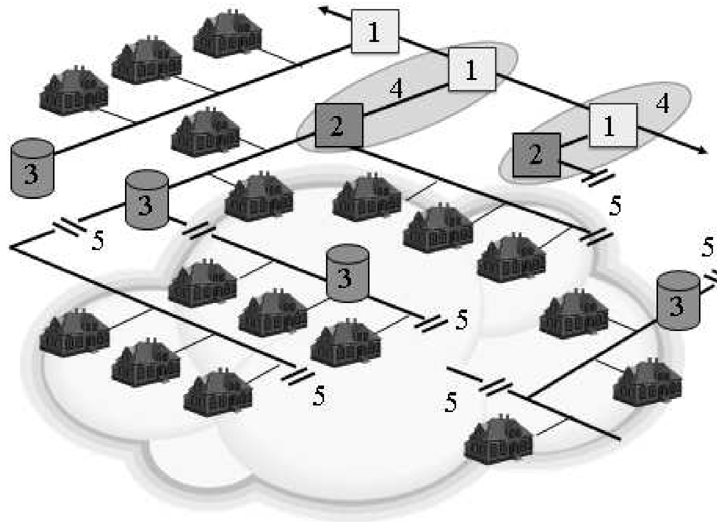
ness, Function, Information, Communication, and ***Component*** as well as there are two next dimensions called ***Domains*** and ***Zones*** [14, 15].

Smart Grid Development Trends

The European Commissions on networks, communications and technology in Brussels also believe that ***Smart Grid*** will play an important role in increasing the meaning of renewable and alternative energy sources for low-energy consumption, delivery savings and CO_2 emission decreasing. Without integration between telecommunication and information networks the established goals are unattainable. ***Smart Grid*** is therefore a significant part of a long-term research and technology development program called ***Horizon 2020*** [16].

Let us consider the trends in ***Smart Grid*** systems in Germany. For example, from the Prof. R.Lehnert (Telecommunication Department at Dresden University of Technology) point of view [17], "…in a "greener" world renewable energy sources are the key to reduce the CO_2 footprint. These energy sources are typically non-stationary. This factor requires much more complex control of the grid. To enable this, the energy distribution network has to become more intelligent due to new services, distributed generation of energy (virtual power plants) and new safety and security requirements. It will finally be a Smart Grid». Nowadays new demands on reliability and security to the support communication network appear. The approach under consideration enables close system integration, optimal distributed power generation via virtual power plants, efficient control on the electricity distribution, and deployment of new network services, which are becoming more intelligent simultaneously. It has been proven, that a particular attention should be paid under current conditions to the deployment and use of ***PLC*** (***Powerline Communications)*** technology (Fig. 5).

The ***German Association of Electrical and Electronics Engineers VDE*** (in German "Technisch-wissenschaftlicher Verband der Elektrotechnik und Elektronik") insists on planned efforts for transforming the traditional electricity networks and creation of intelligent nets. In several European countries this approach has become a significant part of the national energy policy. In this case, we consider not individual decisions for "several thousand kilometers of cable or 100 million euros" but integrated solutions for the ***Smart Grid*** that must be developed. The main objective is reconstruction, flexibility of the entire system, re-design with elements of the infrastructure modernization, increasing of capacity and number of power plants [10 – 13].



Legend:
LV – low voltage; MV – middle voltage.
Fig. 5. Smart Grid representation as a Powerline Communication System: *(1)* MV part of substations; *(2)* LV part of substations; *(3)* street cabinets; *(4)* substations (MV+LV); *(5)* interruptions (open meshes).

Meanwhile, the development approaches in ***Smart Grid*** systems in the world economy are very individual. Let us consider some of them in detail [10, 11]:

1. **Australia.** The development orientation of intelligent energy supplying networks and ***Smart Grid*** has been pursued in 2009-2010. ***WiMAX*** networks within ***Smart Grid*** networks maintain such applications as substation automation, hybrid electric vehicles (***PEV***), as well as domestic smart meters, so called ***IHD (In-Home Devices)***. However, the final implementation of ***Smart Grid*** in Australia is restrained by the lack of appropriate multilateral obligations between the stakeholders that maintain communication networks integrated into the ***Smart Grid***, and a relatively small number of charging stations for electric vehicles ***PEV***.
2. **China.** In the scope of the "current five-year plan" for the People's Republic of China a construction of national-wide monitoring system for national energy networks named ***WAMS (Wide Area Monitoring System***) has been started. The ***WAMS*** uses the offered devices called ***PMU (Phasor Measurement Units)*** from the prominent Chinese manufacturers to improve the reliability and security of the national ***Smart Grid*** solutions. Electrical energy production and distribution,

broadband data channels are tightly and restrictively controlled by the state. Therefore, compliance and conformity to existed standards and processes on the way of transition to a national ***Smart Grid*** is guaranteed practically.

3. **South Korea.** The state plans to reduce the overall consumption of conventional energy sources by 3% and electricity by 10% despite rising industrial demands due to the implementation of a nationwide ***Smart Grid*** till 2030. The start has been taken in 2009; the planned amount of investments for the system development for the next twenty years is about 24 x 10^{15} USD in equivalent to the national currency in South-Korean Won (KRW)!
4. **European Union.** The development of intelligent networks towards ***Smart Grid*** is a part of the ***European Technology Platform*** for the period up to 2020, developed by ***CENELEC*** (in French "Comité Européen de Normalisation Électrotechnique"/ ***European Committee for Electrotechnical Standardization***) [14 – 16]. The Committee ***CENELEC*** is occupied in charge of European standards in the field of electrical engineering. Together with ETSI (***Telecommunications Standards Institute in the EU***) the Committee works on European system of technical regulation and standardization including the mentioned ***Smart Grid*** techniques, models and tools.
5. **USA.** The ***Smart Grids*** support became a part of the U.S. federal policy toward legislatively approved energy independence and security of one of the strongest economies in the world. The planned in 2009 amount of investments towards the middle-term development of this new technology will reach up to 11 trillion dollars, i.e. 11 x 10^{12} USD.

An Example of Smart Grid/ Cloud Computing Implementation

On application of up-to-date powerful high-end servers within the contemporary data centers with the installed broadband optical links (so called ***Fibre Channel***), a significant amount of heat stands out as a harmful by-product. Some companies occupy themselves already with the mentioned problem and develop their own solutions for the disposal of heat excesses for e. g. domestic heating and air-conditioning facilities ***HVAC (Heating, Ventilating and Air Conditioning)***. Among them is the company ***AoTerra GmbH*** in Dresden, Germany. Firm ***AoTerra*** has developed several corresponding products and solutions (Fig. 6), inter alia there are so called ***AoCloud*** (own virtualized data center) and ***AoHeat*** (own smart grid) [18].

The clients use the in-door located services of virtual computing centers, the standardized ***Cloud***-services like ***Infrastructure as a Service (IaaS), Software as a Service (SaaS)*** and ***Platform as a Service (PaaS)***, as well as other applications like ***Cloud Computing (Compute Service, RAID/ RAIC, SAN, NAS, Open Stack, Webhosting, Virtual OS, Own Cloud)*** [19, 20]. Redundant heat as a "by-product of processing" is withdrawn via server 19"-racks in the ***Energy Storage***, which provides circulation of hot water in the pipes within a building and heating of potable water.

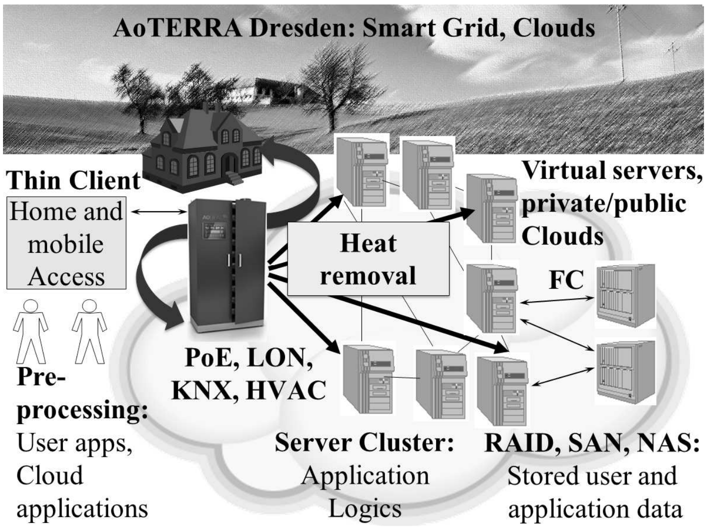
The central system for ***HVAC facilities*** are supplied with use of ***PoE (Power Over Ethernet),*** as well as wired and wireless automation local-area and piconets like ***LON, KNX, ZigBee, EnOcean*** [1 – 5]. The mentioned technical solution provides a higher ***PUE*** value (***Power Usage Efficiency***) up to 0.95 (cp. with the conventional Grid/ Cloud-solutions, where it is necessary to remove the excess heat as by-product, to install more air-conditioning devices and provide them with power supply).

Conclusions

In some developed countries an integrated intelligent network on the sample of conventional Internet is rapidly set up (a net with ***Open Mesh Platforms for Energy Services***). The network possesses ability to use standardized software interfaces, as well as mobile apps with offered ***Web Services*** and ***Cloud Services***.

Thanks to the standardization of ***Smart Grid*** (to the intentions of the organizations like ***NIST, IEEE, VDE, CENELEC*** etc. accordingly) software and hardware-independent access and communication between the components are guaranteed.

The standardization of the open networks structure towards ***Smart Grid*** is nowadays one of the development priorities as for energy and telecommunications industry in the USA as well as in Europe. The combined services of such networks will have an opportunity to attract an increasing number of stakeholders and users in the nearest future (about 2020-2030). Nowadays there is the opportunity to create a large range of its own "smart applications" and "smart services" within the ***Smart Grids***.



Legend:
PoE – Power Over Ethernet; FC – Fibre Channel; HVAC – Heating, Ventilating and Air Conditioning; KNX (Konnex, former European Installation Bus); LON – Local Operating Network.

Fig. 6. Redundant heat and energy recycling in the systems of Smart Grid/ Cloud Computing on the example of AoHeat [18].

Thus, the development of such integrated electric power networks and telecommunications will soon receive a necessary impulse. The ***Smart Power Grid Services*** (i.e. electricity) will be freely delivered, disposed to the market and freely handled there. The effect will be analogue to the today's ongoing revolution of smart phones and tablets on the mobile communication market that has arisen as a result, for instance, of deployment of such already familiar and contemporary concepts like the directory ***App Store*** (***Apple***) or open source ***OS Google Android***.

It is expected that the integration technologies and models for electrical networks and telecommunications discussed in this work will lead to reducing of overall conventional energy sources consumption, CO_2 footprint under the ***Kyoto Protocol***, further decentralization of the supplier networks (based on the principle of Internet construction). ***Smart Grid*** has increased in middle-term the energy efficiency under use of alternative and renewable sources (like wind, solar, EM-smog), inspire the optimization techniques for network management and service billing (***Smart Metering***) for power supply systems and telecommunication integrated networks both by increasing the safety, security and ***QoS***.

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