Towards an information infrastructure for the future Internet of energy

Stamatis Karnouskos [1] and Orestis Terzidis [1]

[1] SAP Research, Vincenz-Priessnitz-Strasse 1, D-76131 Karlsruhe, Germany

Abstract. A deregulated energy market, characterized by the growing use of decentralized energy systems and the increasing range and complexity of interactions between providers and consumers, cannot be realized without an adequate IT infrastructure. The challenges that rely ahead towards realizing this service-based information-driven Internet of energy are substantial. We offer an industrial insight on how this future energy domain could be, identify research challenges that information and communication technologies (ICT) will have to deal with, and point towards directions that need to be followed in order to effectively support this emerging infrastructure.

1 Motivation and insight

We have entered a new energy era where the world's economic regions dependent on each other for ensuring energy security and stable economic conditions. Future goals include improving energy efficiency, increasing penetration of renewable energies, diversifying and decentralising energy mix and enhancing competitiveness of industry. Deregulation of energy market is an important instrument in achieving these goals. The intention is to establish a free and competitive market for energy production and distribution by breaking up the value chain – production, transfer and distribution of electrical power. This will lead to profound and lasting changes as a much more decentralised and diversified infrastructure emerges. New energy technologies for co-generated heat and power and increased use of renewable ones such as biomass, solar energy and wind power will need to be integrated in an intelligent, information-based global energy infrastructure. Consequently, the share of decentralised power generation – by industrial or private producers – will increase and have a dominating effect on existing infrastructure, technologies and business practices [5].

The integration of small highly distributed energy production sources and their coupling with advanced information-driven services will give rise to a new infrastructure that we refer to as Internet of energy. In such a complex and dynamic system it is expected that distributed energy producers and consuming entities will be highly interconnected also via information flows. In that sense we have a paradigm change from existing passive and information poor to active information rich energy networks, which reverses the trend of one-way flow since the electricity networks were initiated. Such a future infrastructure is expected to be service-oriented and give rise to new innovative applications that will drastically change our everyday environment.

In the future service-based Internet of energy (depicted in Figure 1), several alternative energy providers, legacy providers and households are interconnected. Via smart meters, one is able to interact with a service based infrastructure and perform actions such as selling and buying electricity. More advanced services are envisaged that will take advantage of the near real-time information flows among all participants. Furthermore the energy consuming/producing devices will be no more considered as black-boxes but will also get interconnected, which will provide fine-grained info e.g. energy optimization per device.

Power engineering alone, however, will not be able to transform the energy markets. New, highly distributed business processes will need to be established to accommodate these market evolutions. The traditional static customer process will increasingly be superseded by a very dynamic, decentralised and market-oriented process where a growing number of providers and consumers interact. Such an infrastructure is expected to be pervasive, ubiquitous and service-oriented. The architecture of such distributed system landscapes has to be designed, standards must be created and widely supported, and comprehensive and reliable IT applications will need to be implemented.

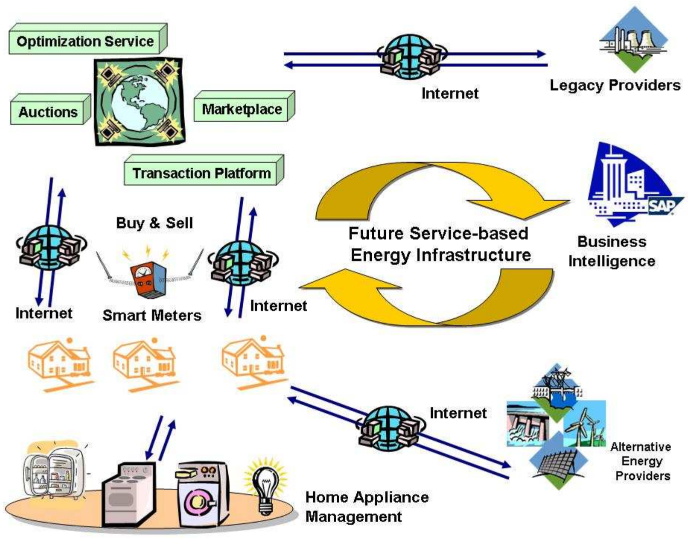

Fig. 1. Future service-based Internet of energy

ICT will make it possible for future distributed energy systems to be self-managing, self-sustaining and robust, and will enable dynamic reorganisation and coordination of services markets. Therefore the Internet-based infrastructure will be tightly coupled with the energy domain, and used to support the development of new mechanisms for trade based on supply and demand in the electricity market. Different models and scenarios for a highly distributed information-based energy infrastructure will emerge. Transaction platforms will provide services such as electronic marketplaces, facilitating the commercial activity associated with the buying and selling electricity and its derivatives, not only for utility companies but also for decentralised consumers and producers.

We are moving towards the "Internet of things", where almost all devices will be interconnected and able to interact. The same will hold true for energy metering devices. New information-dependant intelligent energy management systems will be needed for an infrastructure capable of supporting the deregulated energy market. Intelligent smart meters will have to be installed for millions of households and companies and connected to the future transaction platforms. These smart meters provide new opportunities and challenges in networked embedded system design and electronics integration. They will be able to provide almost real-time data that in turn will have a significant impact on existing and future energy-management models. Decision and policy makers will be able to base their actions on real-world, real-time data. Households and companies will be able to react to market fluctuations by increasing or decreasing consumption or production, thus directly contributing to increased energy efficiency.

2 Existing efforts

Building such an information infrastructure for future energy networks is not expected to be trivial nor simple applicability and tuning of existing technologies and concepts is expected. Several projects funded by the European Commission as well as at national level have attended to tackle aspects of such an infrastructure.

The SmartGrids [1] technology platform is a new concept for electricity networks across Europe. The initiative responds to the rising challenges and opportunities, bringing benefits to all users, stakeholders and companies that perform efficiently and effectively. SmartGrids drafts visions, goals, and strategies for developing future power grids that meet economic and consumer requirements. It is here that having a suitable IT infrastructure in place, is key to ensuring that commercial transactions and the control of energy remain intact, the goal being to utilize central power plants and smaller, decentralized power generation companies in the best way possible in order to realize a reliable, cost-effective energy supply.

CRISP [4] focuses on distributed intelligence in electrical networks. Here, information is gathered on how to deploy distributed and networked information systems for monitoring and controlling electrical networks using decentralized energy production. The project reveals that using information and communication technologies in decentralized power production applications can bring about decisive results. Key topics researched include a) the use of software agents and electronic markets for automated negotiation, communication, optimization, and control, b) the automated coordination of supply and demand (www.powermatcher.net) and c) clearing of incorrect postings and data inconsistencies.

SESAM [2] pursues the vision of an energy system in which conventional large-scale power plants are complemented by a number of small, decentralized plants. By linking self-organizing energy markets, a virtual power plant is created from these small, decentralized plants. SESAM's vision sees households and industry incorporating Intelligent Energy Management Systems (IEMS) that not only regulate the use of decentralized energy conversion plants, but also plan for the following day as to when electrical consumers e.g. refrigerators will be turned on/off with respect to current power prices.

SELMA [3] provides a secure architecture for a) authenticating measurement data, b) access security and c) certifying software. The architecture incorporates existing constraints including present, international standards for communication and security as well as economic factors and regulatory conditions in the measuring device environment. The security concept that is tailored to all business processes related to energy consumption measurement. The measurement data signature can be used to easily validate measured consumption data anywhere in the process (up to and including invoicing). It also makes it possible to automate the maintenance process for measuring devices by downloading validated and certified software packets, thereby considerably lowering maintenance costs.

Several other projects [6] are tackling parts of the challenges that are to be faced in a fully interconnected future energy infrastructure. The European Commission's next research program (FP7) will focus on further resolving these issues and providing an advanced energy infrastructure by 2020.

3 Research challenges

The formation of new relationships between energy providers, distributors, dealers, and customers, who, themselves, can act as producers, has dramatically increased the complexity of the energy market. This increased complexity requires innovative IT solutions. Building on the experience gathered from previous research, new concepts and approaches must be developed, implemented by prototype, and tested in practice, the goal being to create an IT infrastructure for the deregulated energy market. Efforts should focus on finding realistic/viable approaches where the interests of those players involved are considered in addition to fielding purely technical questions. Authorities, utility companies, operating companies, software providers, providers of measurement systems, and power engineering providers must explore new cooperation models in a deregulated market.

An overall system architecture to assist the deregulated power market, especially decentralized energy systems will have to be designed and implemented. The core business processes covering all aspects e.g. (consumption and generation of electricity, derivative trade, requirements and production planning, maintenance of plants, etc) will have to be adapted. Integration of embedded systems (e.g. meters and sensors) as well as the communication capabilities in the envisioned infrastructure need to be enhanced. Modelling highly distributed business processes, developing market-driven mechanisms for load balancing, proactive planning of system load profiles using derivatives, development of new business and market models, allowance for planning and scheduling, and assurance of interoperability are just a few other topics that need to be specially defined and developed in this area.

Generally research efforts will have to deal with the opportunities and challenges associated with the goal of closely linking ICT and energy. Development of an appropriate security, safety and risk concept and architecture for an electronically-based energy market will be the core. In addition, an interoperability framework will need to be developed to enable the interoperation of the abundance of interfaces and systems that will inevitably result from a highly decentralised electronically-based energy market. Service architectures, platforms, methods and tools focusing on a network-centred approach will need to be developed to support the networked enterprise. Understanding and managing the complexity of a critical infrastructure such as the energy sector is crucial and implies systemic risk analysis, resilient distributed information and process control frameworks.

4 Short term research directions

From the business and application perspective a number of important aspects also need to be resolved. Directions for the short term should focus on:

Transaction Platforms: One central question involves the consumption and generation of electricity and the interlinked commercial transactions. The object of research here is the business and legal identification of new market forms that are compatible with the revised general conditions. The direction the deregulated energy market will take in the years ahead is uncertain, but will be shaped to an extent by the behaviour of today’s market participants.

Therefore there is industrial motivation to explore the different scenarios and not to leave the market structure of the future to chance, but instead actively shape it.

Linking Decentralized Meters & Control Units: Today's technology for electronic measurement, display, and analysis of energy data is comparably underdeveloped. There is need for new, electronic meters and control units to provide an infrastructure capable of supporting the deregulated energy market. Smart meters are a special form of embedded system featuring a central unit, on-board memory, and diverse communication options. They can operate "forwards" or "backwards", depending on whether a participant consumes or produces electricity. The unit can also create an energy profile of the household or company and is able to react to fluctuations in the market by intelligently increasing or decreasing consumption or production. This vision can even be taken one step further by also equipping each end device (motors and machines of all types) with sensors that calculate power requirements and forward this information back to the smart meter and the associated service infrastructure. Such system can take into account production and capacity planning in order to keep operation as cost efficient as possible. The goal is to create a link between these meters and the above-mentioned transaction platform for the energy market. This link must be feasible for millions of households on a decentralized basis, thus necessitating easy and reliable installation ("plug & trade").

Linking Production Planning: Most energy consumers are not aware of their daily energy consumption, and it is also not common practice to plan for energy requirements. As such, utility companies generally are not in a position to predict the needs of their customers and have no choice but to provide quick-access overcapacities, which in turn lead to expensive energy production. Today's price models are structured so that peak consumption leads to peak prices. Here, there is interesting potential for streamlining energy systems and thereby lowering costs. In commercial and industrial environments, for example, it is common to use production planning systems that incorporate operative, time and quantity-based planning of machine resources. In practice, such systems are used as part of SAP solutions, for example. Energy requirements calculated using production planning can then be checked against the power market to optimize energy costs. With the help of derivatives (options) for planned power requirements, planning can be synchronized with the power market via proven mechanisms. These mechanisms can, in turn, play an increasingly important role, especially in the context of rising energy costs. Data formats and interfaces must be standardized to allow costs and energy consumption to be minimized through operative planning.

Infrastructure Security: It goes without saying that having an appropriate security concept in place is critical for an electronically-based energy market to succeed. As a result, this concept must be developed as an integral component of such an infrastructure. Secure methods for exchanging data between decentralized measuring points and the utility companies and customers using open networks such as the Internet must be in place. A comprehensive security architecture likewise must be developed that also takes the transaction platform and its requirements into account. As an electronically-based energy market increases the flow of private information, steps must be taken to ensure that solutions protect personal data from being misused. In addition to scalability and robustness, a sufficient security concept is the key non-functional factor in designing an electronically-based energy market. Here, consideration also must be paid to the stipulations of joint European security and reliability standards.

Linking Energy Management Systems: Future energy management systems (EMS) will be linked via landline or wireless-based systems for recording and regulating the energy flows of a consumer or producer. One particular problem, however, is how to deal with expensive peaks in consumption. In a more general sense, the objective of an energy management system is that of acquiring, using, and producing energy in the most efficient way possible. Generally, an energy management system is used in a commercial or industrial application, but there is good reason to believe that a lighter EMS will also applicable in consumer pools and even in individual customer dwellings. Linking such systems to the electronic energy market can introduce entirely new options for increasing the overall efficiency of energy grids.

Interoperability: The highly distributed system architecture of an electronically-based energy market gives rise to an abundance of interfaces between different systems. The interoperability of all of these heterogeneous systems presents a decisive challenge to the functionality of the overall system. First, data formats need to be specified. Agreeing on such conventions not only necessitates the use of structures, or syntax; semantics also play a critical role. State-of-the-art IT concepts such as ontology and decision algorithms can be used as well. The next step involves the design of a system-wide process. Here, the appropriate methods researched on interoperability as it applies to corporate information systems, will be further developed for use in conjunction with electronic energy markets.

5 Conclusions

Today, we are at the dawn of an era that we would describe as the start of the 'Internet of Energy'. Existing efforts in the energy domain can be compared to the Internet-based ICT efforts of the 1970s and early 1980s. Once a highly distributed and service-based energy infrastructure is in place, we will see cost-effective new innovative concepts and technologies flourishing that will empower us with new capabilities and tools to attack old problems. It is expected that many research challenges will have to be tackled effectively, and the distributed applications as well as the technologies developed the last years will once more have to be tested in real world scenarios. It is expected that in the mid-term this will gain importance and may even be one of the reasons that will fully justify the business capabilities of the Internet. The energy domain and its combination with ICT will present tremendous challenges and opportunities for both businesses and citizens in the years to come.

6 References

1. European SmartGrids Technology Platform - Vision and Strategy for Europe's Electricity Networks of the future. European Commission, March 2006, ISBN 92-79-01414-5, http://ec.europa.eu/research/energy/pdf/smartgrids_en.pdf , www.smartgrids.eu
2. SESAM Project (Selbstorganisation und Spontaneität in liberalisierten und harmonisierten Märkten), http://www.sesam.uni-karlsruhe.de
3. SELMA Project (Sicherer ELektronischer Messdaten-Austausch), http://www.selma-project.de
4. CRISP Project (distributed intelligence in Critical Infrastructures for Sustainable Power), http://www.ecn.nl/crisp
5. G. Pepermans, J. Driesen, D. Haeseldonckx, R. Belmans and W. D'Haeseleer: „Distributed generation: definition, benefits and issues". Energy Policy, Vol. 33, Issue 6, April 2005.
6. Rosalie Zobel, Erastos Filos: The Impact of ICT on Energy Efficiency. eChallenges 2006, 25-27 Oct. 2006, Barcelona, Spain, IOS Press ISBN: 1-58603-682-3.