Smart Energy

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The digital transformation in the energy sector

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Summary

A successful energy transition is inconceivable without extensive digitization. In view of the complexity of the task of digitizing the energy sector and all of the associated systems, previous efforts at defining essential components of digitization (such as concretely usable reference architectures and research into the resilience of the future energy system) currently still appear insufficient and uncoordinated. These components include smart management approaches capable of integrating market mechanisms with traditional management technologies, and comprehensive security concepts (including effective data utilization control) that need to go far beyond the BSI security profile for smart meters. The digitization of the energy system needs to be conceived and operated as a transformation process designed and planned for the long term with reliable milestones.

20.1 Introduction: The digital transformation megatrend

Digitization facilitates the smart networking of people, machines, and resources, the ongoing automation and autonomization of processes, the personalization of services and products, as well as the flexibilization and fragmentation, but also the integration of business models across the entire value chain [8]. In the context of this definition, digitization is increasingly understood as a process of transformation, which gives rise to the opportunity to scrutinize processes and procedures fundamentally and align them to revised or often even completely new business models.

Reimund Neugebauer, *Digital Transformation*
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In order to achieve this, standard system architectures in most cases need to either be fundamentally revised or completely recreated so that conventional, modernized, and new products and services can be offered via new network topologies and communications. The term "smart ecosystem"[1] was coined for these kinds of new business models developed during the course of digitization. The fundamental characteristic of the smart ecosystem is the interplay between individual business models within a larger overall system oriented towards economic goals. The information technology basis for this is formed by standards and open IT platforms with low transaction costs, high reliability, and security for technically implementing the business models. Internet technologies provide the universal infrastructures for connecting business partners with one another as well as linking the digital representations of things, devices, installations, goods, and services (so-called "digital twins") with the physical objects accessible via the Internet (Internet of Things, IoT).

This transformation has already led, in numerous domains, to business models previously linked to physical objects and personally provided services being superimposed or even substituted by a dematerialized data economy (hybrid value creation) in the course of digital transformation. Digitally provided services are thus increasingly in the foreground:

- Amazon delivers without being a producer, Uber provides transport without having its own fleet, Airbnb lets rooms without owning accommodation.
- Digitization avoids unprofitable downtime of assets through predictive maintenance.
- Digitization replaces investments in facilities with service rental (logistics, heating, lighting, etc.)
- Digitization facilitates new contract models, e.g., on-time arrival contracts for train journeys (Siemens)
- Digitization adds value to traditional products (John Deere FarmSight)

Key developer and operator competencies within a data economy are cloud and IoT technologies, (big) data analytics, machine learning, and deep learning.

The act of fundamentally revising business processes frequently comes up against the limits of applicable legal frameworks. Data protection and the protection of privacy take on new meaning during the process of intensive digital networking and need to be revised in order to guarantee sufficient protection on the one hand,

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[1] A smart ecosystem integrates information systems that support business objectives and embedded systems that serve technical objectives so that they operate as one and can pursue shared overarching (business) objectives.

and to permit new and economically sustainable business models on the other hand. Alongside economic reasons, the (current) lack of an internationally harmonized legal framework may lead to the relocation of firms to countries with more accommodating legislation.

In highly regulated fields such as healthcare, food products, transport, and the energy sector, legal regulations and compulsory standards such as the EU's General Data Protection Regulation[2] should be taken into account in good time and, where necessary, should be revised in order to not delay the transformation process unnecessarily or even smother it completely.

20.2 Digital transformation in the energy sector

The digital transformation in the energy sector is a process that will unfold relatively slowly over time, and will most likely require several decades. This is due to the following factors:

- The long-term nature of investment decisions regarding extremely expensive network infrastructure and power plants requires decision-making that provides economic security, which is particularly difficult against the backdrop of the far-reaching structural change provoked by the energy transition. It must nevertheless be ensured that this aspect is not misused as a reason for unnecessary delays in digitization, which is needed so urgently.
- The weight of regulation in those areas of energy supply that operate as a natural monopoly limits innovation since the regulatory adjustments necessary for operating new equipment and business models generally lag behind the innovation itself.
- The transformation process affects several sectors of the energy industry that have thus far operated separately (electricity, gas, heating) and impacts associated sectors (transport, home automation, industrial automation). Due to the dominance of the renewable energy sources of wind and sun and their volatile feed-in, the electricity sector represents the controlling variable here to which the other sectors must adjust.

In the course of the process of digital transformation, traditional energy sector products will fade into the background and be replaced by other services with cash value qualities. Formerly, products such as electricity, heating, and gas were primar-

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[2] EU General Data Protection Regulation (GDPR, EU Regulation 2016/679), effective May 25, 2018

ily invoiced according to the physical unit of work (in multiples of watt-hours, Wh), that is, according to a volume tariff, or sometimes according to the maximum supply availability (in multiples of Watts, W). The quality of the energy supply from centrally managed, high-capacity power plants was usually very high but was not an explicitly stated component of pricing. In other words, the costs of security of supply and power quality[3] have thus far been priced into the volume tariff.

The development of renewable sources of energy and the politically formulated climate goals both result in the dismantling of power plants (nuclear phase-out and planned phase-out of coal-fired power plants for decarbonization purposes) within the electrical energy grid. Centrally provided security of supply, network services[4], and power quality will thus be lost. In the future, they must be provided and invoiced by the renewable energy feeder operating in a decentralized manner, and will thus gain the significance of tradable products.

Additional new products could, for example, include fixed levels of service even during critical conditions within the energy network, similar to the Service Level Agreements (SLAs) in the information and communications (ICT) sector. For industrial customers, scattered examples of such products already exist; in the course of digitization, they may become standard, ensuring for example that basic, low-energy functions are maintained and dispensable devices are selectively turned off during periods of extreme electrical energy undersupply, where until now complete subnetworks had to be shut down. Developing this thought further means that instead of paying for used, fed-in, or transported energy, **flexible markets** will develop in the future where changes in the feed-in, requirements, or consumption profiles can be traded, managed, and invoiced in cash value as flexibly as possible and calculated by digital systems. Flexibility is above all a product motivated by the technical necessities of operating a system with highly fluctuating renewable energy feed-in levels. Essentially, it focuses on the costs of operating under unbalanced network conditions and only prices the actual amount of energy flow indirectly, particularly since the marginal costs of renewable energy plants tend towards zero.

In the future then, energy quantities or power ratings will rather play the role of unchangeable physical limitations for the digital markets. Even today, the actual

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[3] In simple terms, **power quality** refers to the maintenance of the target voltage (230V) and the target frequency (50Hz). The actual voltage may thus deviate by 10 percent and the frequency by 0.2 Hz. Greater deviation may entail damage in connected systems (both producers and consumers), and power supplies are thus generally subjected to emergency shutdown.

[4] **Network services** refer to technically necessary functions, e.g., reactive power generation, black-start capabilities (restarting after a blackout), and provision of short-circuit power (maintaining the flow of electricity in the case of a short circuit such that fuses can trigger).

significance of the demand and consumption charges is already greatly reduced even though invoicing is still based on consumption and demand. Occasionally, there are discussions regarding the kinds of flat rates common in telecommunications. But the current energy mix, efficiency demands, and climate goals still stand in the way of flat rates for energy.

Before digitization can really transform the energy sector in the manner described above, however, distribution grids must be extensively equipped with information and communications technology on the one hand, and new roles must be defined for the operators of this technology within a data economy on the other hand.

Table 20.1 Theses on digitization in the energy system of the future

1	Necessary key technologies such as the Internet of Things and Industry 4.0 are either already available or will soon be usable (5G).
2	Energy flows are increasingly accompanied by information flows – smart meters are just the beginning. Similar to the manufacturing sector, “digital energy twins” and an “energy data space” [14] are developing.
3	Energy-related data is becoming a valuable asset – an energy data economy is developing.
4	The significance of sector coupling and of markets is growing. Interactions between previously separate systems (e.g., electricity, gas, heating, e-mobility) are being developed in the process; digital ecosystems are coming into being that are tightly networked with one another.
5	The digitized energy system is trustworthy and behaves as expected.
6	Self-learning, adaptive structures support ongoing planned as well as erratic changes in the energy system.
7	The energy system of 2050 will have significantly higher resilience requirements due to its decentralized and heterogeneous nature; at the same time, decentralization and heterogeneity are also part of the solution to the challenge of resilience.

20.3 The energy transition requires sector coupling and ICT

Ambitious climate goals can only be achieved via massive decarbonization. The German approach of largely replacing fossil fuels while simultaneously phasing out nuclear energy requires a massive expansion of renewable energy installations for years to come. Wind and sun are available in Germany, but water power only to a limited degree. Biogases are only able to supply limited quantities of energy, especially due to the emerging competition with the food production industry. Thus, supply based on sun (PV and solar heat) and wind is extremely dependent on the weather and the time of day – in other words, we have volatile or fluctuating feed-in. Fluctuation – which may mean both a dramatic temporary oversupply of electrical energy and a massive undersupply (volatility) that may last for days – has to be handled appropriately, without reducing the usual security of supply. A portfolio of measures and goals for solving the problem is under discussion:

- **Efficiency measures** for reducing the energy requirements of devices and installations:
  While measures to increase efficiency are basically to be supported since they reduce energy costs and make it easier to achieve climate goals, they make very little contribution to solving the problem of fluctuating provision of electrical energy. Energy efficiency can also be increased by means of non-digital technical improvements, for example by reducing heat losses, pressure losses, or friction. In, numerous modern devices, however, smart digital controls are responsible for increased energy efficiency, for example in the case of smart drive control systems in pumps. The design of these control systems has thus far been oriented towards optimization of their operation in the face of energy costs that are neither time- nor load-dependent. It is only by opening the systems' communications to signals from the supply network (e.g., coded as variable tariffs) that these control systems can also become useful to the network. This is termed "demand-side management".

- **Adapting consumption to supply** (demand-side management, DSM, for load-shifting and for activating storage capacity in end-customer installations):
  The energy requirements of devices and installations can (also) be regulated with a view to the current grid situation – e.g., by changing load profiles or utilizing storage capacity in the devices and installations in order to influence the period/amount of energy use or energy provision. This flexibility potential can then be used to compensate for oversupply or undersupply in the electricity grid. Only through extensive digitization and communicative interconnection of both the energy networks and the feed-in and consumer installations can this kind of network-supporting behavior via DSM be achieved.

- **Sector coupling** in order to make the flexibility potential of other energy systems (gas, heating, cooling) usable for the electricity sector:

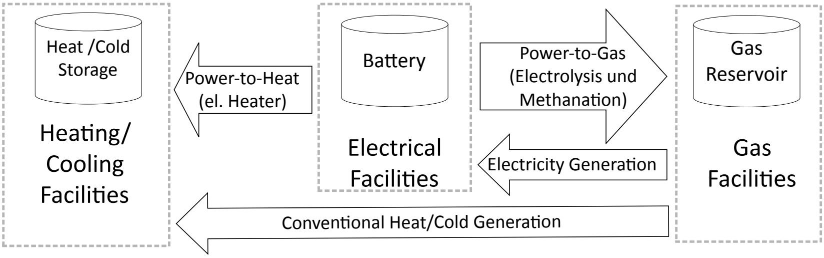

Fig. 20.1 Sector coupling of heating, electricity, and gas (Fraunhofer IESE)

In sector coupling, flexibility potentials are harnessed in a way that goes beyond the possibilities of DSM: either alternative energy sources are momentarily used to cover energy demand in the face of a shortfall of electrical energy (e.g., by using gas instead of electricity), or the storage capacity of another form of energy (heating, cooling, etc.) is used to adjust the load profile on the electricity side, which is generally cheaper than using a battery (see Fig. 20.1). Sector coupling is considered to have the greatest potential – in terms of quantity and cost – for providing the necessary flexibility for the electricity grid of the future. It can be used in both small end-customer installations, such as in the kW domain as bivalent heating using a choice of either gas or electricity, and in the MW domain, e.g., for energy suppliers providing additional electric heating for heat storage in district heating networks. If there are significant excess supplies of electricity, variants of sector coupling with lower levels of effectiveness may also be economically feasible, such as power to gas (electrolysis, methanation) or power to liquid (production of liquid fuels) [5].

- **Market mechanisms:**
  Flexibility requests arising from volatile feed-ins or imbalances in the system and flexibility offerings resulting from demand-side management and sector coupling may in the future be traded on new electronic markets in order to achieve a balanced power economy within the electricity network, primarily through the use of market mechanisms. Market mechanisms are favored politically, and the quest for new business models that identify and test out these mechanisms is under way. A number of research projects to this end are investigating the potential interaction of technical, market-related, and adapted regulatory conditions (e.g., [9][15][16]).

With the exception of energy efficiency, the four approaches described above can thus be implemented exclusively by using digitization: Devices and installations connected to the electrical energy system need to be digitalized and networked communicatively in order to identify, communicate, negotiate, and ultimately measure and invoice flexibility potentials offered and requested. The term “**smart energy**”, frequently used in this context, refers to the change from centralized control based on predicted consumption to decentralized control, where the actual offerings and requests are balanced out regionally as far as possible, using market mechanisms in real-time. Only if these market mechanisms fail will it be necessary to revert to controlled measures (control loops), which will then override these market mechanisms temporarily and regionally. The energy system of the future must thus have a range of automated control strategies at its disposal to be utilized according to the situation at hand. Significant research work is still required in order to define and test these strategies with a view to ultimately guaranteeing resilient operation. In order to accommodate decentralized feed-in and control, the traditional centralized hierarchical arrangement of electricity grids must be replaced by a cellular hierarchical arrangement.

20.4 The cellular organizational principle

Geographical imbalances in generation and consumption ultimately need to be balanced out via electrical grids. Extreme imbalances (regarding amount of energy, power, and local distribution) require correspondingly powerful and thus expensive grids.

For historical reasons, the topology of today’s electrical grids is organized hierarchically and is split into various levels of voltage. While large distances are bridged with voltages in the region of several hundreds of thousands of volts (transmission grids), this voltage is reduced via transformers across several grid levels (medium-voltage grids) until it finally reaches the 230/400 volts (distribution grids) required for residential connections.

In the past, energy was fed-in at the highest voltage levels by large power stations. From there, the electrical energy was distributed to the wider region. The flow of energy within the wiring and the transformers was unidirectional. Security of supply, securing of the power quality, and provision of grid services primarily took place via interventions at the high-voltage levels. The hierarchical grid structure was tailored to this centrally controlled generation by means of small numbers of large power stations (operated with nuclear or fossil fuels).

In the course of the energy transition, the number of these large power stations will decrease, while at the same time more and more energy will be fed-in to the middle and lower voltage levels from renewable energy installations (decentralized

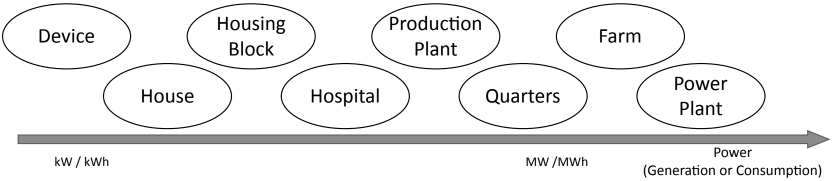

Fig. 20.2 Examples of cell sizes (Fraunhofer IESE)

feed-in). Energy will have to be able to be transported bidirectionally since overload caused by temporary local excess feed-in from renewable energy installations will have to be transferred from their grid section to the higher voltage levels for onward transmission. Wiring and transformers would need to be upgraded for this purpose, or the generating installations would have to be deactivated temporarily. Sector coupling and DSM could also make it possible to temporarily raise local consumption in a targeted manner in the respective grid section. A similar process applies for insufficient feed-in within the grid section.

Provided that regional generation and consumption are approximately balanced in the case of decentralized feed-in, the grid load will decrease. Sector coupling and DSM provide effective levers here. However, for cost reasons these regional "cells" cannot be completely independent. In addition, we have differing geographical concentrations of wind (northern Germany) and sun (southern Germany); electrical transmission and distribution grids will thus not become obsolete [4]. Digitization may, however, very well limit the grid load or the necessity for development, at least at the distribution grid levels.

Fig. 20.2 shows examples of potential cell sizes arranged along an informal scale. The cell concept is a recursive concept. This means that higher-level cells (e.g., districts) may be formed of lower-level ones.

The challenges of decentralized feed-in suggest **cellular** control structures with **subsidiary hierarchical** distribution of roles. Sector coupling and DSM take place within the cells. Cells are able to achieve energetic balance between one another and within the hierarchy (see Fig. 20.3).

Cellularity is also a requirement from a system security point of view: centralized systems generally have a single point of failure. As soon as an essential (non-redundant) system component fails or is compromised by a physical attack or a cyber-attack, the system as a whole is no longer capable of functioning. Systems operating in a decentralized manner are harder to attack due to the greater number of components that have a role in operations, and the attack's reach is, in the first instance, limited to the components attacked or their respective cells. Cells can thus limit the spread of

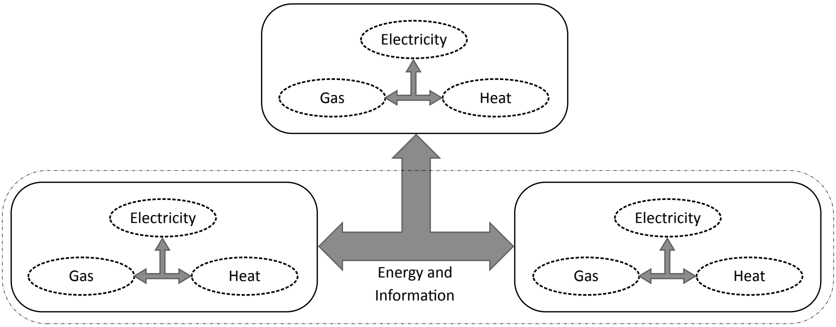

Fig. 20.3 Schematic diagram of a hierarchical cellular structure with sector coupling (Fraunhofer IESE)

undesirable grid conditions. Nevertheless, in the age of the Internet and automated attacks, this advantage may be lost if the architecture of the cell control systems does not contain suitable lines of defense, or if the ICT in the cells is identically implemented and thus any weak points disclosed can be attacked on a broad scale with limited effort. **Diversity**[5] of software implementation instead of digital monocultures in control rooms, operating systems, and control algorithms makes broad-scale attacks more difficult. Diversity is thus a desirable – if costly – system property, since economies of scale are lost and any solutions found are more difficult to transfer.

Digitization makes it possible to utilize flexibility as a "currency" within the energy system of the future. With flexibility as a product, new roles and actors will be defined in the course of digital transformation, and new business models will arise. The sector is currently beginning to think about which new personalized products could be conceivable and profitable. A few examples are:

- Software plus consultancy services for planning and designing cell infrastructure (for existing stock and new plans).
- Software for continuously monitoring cells vis-à-vis a range of indicators, e.g., climate protection contributions, energy flows, material flows, logistics, security status. Services around the generation, analysis, and distribution of this data.
- Various control rooms for actors at the cell level (aggregators, contractors, data resellers) with corresponding data aggregation and processing functions.

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[5] Diversity in implementation is not in contradiction to urgently needed standardized interfaces and exchange formats. The latter are indispensable for efficient operation. The implementations "behind" the interfaces, however, should differ, as viruses and Trojan horses are written for the most common types of software.

- Measurement and analysis software for end customers (prosumers), landlords, energy suppliers, aggregators, and other roles with corresponding services.
- Analysis software for identifying and implementing value-added services for suppliers, aggregators, and end customers.

20.5 Challenges for energy ICT

In recent years, the information and communications sector has clearly demonstrated that large ICT systems can be built and operated to be highly reliable, powerful, and profitable. Leading examples are the Internet or the global mobile telephony systems. In this respect, the digitization in the course of the energy transition – involving several hundred million devices and installations across Germany in the long term, or billions worldwide – is no more demanding in terms of numbers and ICT performance than global mobile telephony, electronic cash, or IPTV.

Effective mechanisms for data security and data usage control are essentially well-known. The issue now is to consistently build these into the resulting systems right from the start instead of having to upgrade them later.

With significant participation from Fraunhofer, current German flagship projects are demonstrating how industry standards have been systematically created for years in the area of industry-relevant embedded systems in order to advance comprehensive digitization. Examples include AUTOSAR [9], BaSys 4.0 [10], or the Industrial Data Space (IDS) [11]. Flagship projects for the energy systems sector with comparably high demands are just starting: see projects within the programs SINTEG [15] and KOPERNIKUS [16]. The criticality for society and industry of the ICT systems of the future energy infrastructure will be key to their design. Based on the high availability and power quality that is customary in Germany, the future energy system, which will be several orders of magnitude more complex[6], should deliver at least the same availability and power quality.

Every system accessible via the Internet nowadays is exposed to a stream of increasingly sophisticated cyber-attacks, which is growing by far more than a factor of ten every year [18]. The energy system of the future, too, will be based on Internet technology and will be a valuable target for attacks from the Internet. Despite all precautionary safeguards and redundancy, breakdowns due to energy installation

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[6] In Germany, more than 560,000 transformers and more than 1.5 million renewable energy installations were already part of the electricity grid as of 2015 [17], but there is hardly any communication among them yet. A hypothetical area-wide smart meter roll-out would add around 40 million networkable meters, not counting controllable consumers and batteries.

damage, extreme operating conditions, and breakdowns in the electrical grid, as well as due to the breakdown of communication networks and faulty behavior due to targeted physical and cyber-attacks on installations and grids are all to be expected. In particular, these situations may occur in complex combinations or may be provoked in a targeted manner. There is thus absolutely no doubt that breakdowns will occur in a system of this complexity. The attack vectors are becoming ever more complex and more difficult to recognize.

In addition, the energy system of the future will be configured significantly less statically than the present system. With the huge number of generating and consumer installations, physical additions to and disconnections of installations will, from a statistical point of view, occur far more frequently. Not to mention the fact that when market participants are permitted to act freely, their affiliations with service provider balancing groups will change (virtually). Electromobility – particular the use of fast-charging systems – equally implies a temporary reconfiguration within the network, with the end customer probably wanting to be assigned to their home energy supplier while traveling (roaming).

In the context of a constantly changing system and simultaneously high requirements for security of supply as well as for safety and security, the conventional "fail-safe" design principle[7] is no longer adequate. The system instead needs to be "safe to fail" [6]. This means that even when significant components break down or their performance degrades, the remaining system automatically responds to the situation without breaking down completely[8]. Mechanisms for achieving this include, for example, runtime adaptations or optimization; a range of "self-x" technologies are thus indispensable for the energy system of the future:

- **Self-diagnosis:**
  The system needs to constantly monitor essential system parameters and indicators in order to assess its current condition with respect to security, stability, and reserves.
- **Self-organization** (adaptation, self-healing):
  As soon as important system parameters are in danger of becoming critical or have already become critical, the system must assess alternative configurations and move towards more stable and secure conditions via reconfiguration or a changed behavior profile.
- **Self-learning:**
  Systems as complex as the energy system cannot be programmed or configured manually. Even the most minor changes would entail unreasonable overhead.

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[7] The system no longer works, but transitions to a safe state in any case.

[8] In the automotive sector, this operational state is called fail-operational.

The system itself needs to capture its condition, connected installations, as well as their parameters and typical profiles, map them to models, and actively use the results for control purposes (model learning).

- **Self-optimization:**
  A cell's many and diverse optimization goals may change dynamically. Climate protection goals, for example, may vary in their importance according to the time of day or year. The system needs to be able to adapt itself to optimization goals, which may in part be contradictory and vary according to different timescales.

The foundation for fulfilling all of these requirements is the massive collection, processing, and secure sharing of data. To do this, an **Energy Data Space** (EDS) must be created as an adaptation of the Industrial Data Space (IDS) [12].

A fundamental ICT **reference architecture** needs to be defined that, in particular, specifies and permits the implementation of all of the key requirements with respect to security (with the goal of being safe to fail), sets standards, but does not stand in the way of a multitude of implementations (goal: diversity).

Whereas in other sectors overarching ICT standards are being created in a targeted manner, e.g., via AUTOSAR [9] for automotive engineering or BaSys 4.0 [10] and IDS [11] for the field of embedded systems and Industry 4.0, the ICT landscape in the energy field thus far still resembles more of a patchwork rug.

20.6 The challenge of resilience and comprehensive security

The energy transition is characterized by decentralization, both regarding the generation of energy and the control of the energy system, by volatile supply and by massive digitization. Set against the backdrop of this far-reaching upheaval, a suitable concept of resilience needs to be defined and operationalized for the energy sector [13]. In order to achieve this, and in order to make fundamental decisions on the system design, the responsibility for the provision of system support services in this context must be redistributed. These services include, for example, maintaining voltage and frequency, supplying reactive power, providing secondary operating reserves, tertiary control, black-start support, short-circuit power, and also, where necessary, primary operating reserves (cf. also "The Role of ICT" in [7]). How much decentralized ICT is actually necessary and sensible for which tasks also needs to be defined primarily against the backdrop of resilience and real-time requirements.

As explained in the previous section, the future energy system will not be configured statically and will need to assert itself in the face of changing and at times unexpected influences and attacks.

Resilience is the ability to adapt to previously unknown and unexpected changes and simultaneously continue to provide system functions.

Modern definitions of the term "resilience" refer to its close relationship to the concepts of security, forecasting, and sustainability [2][6]. To this extent, resilience is not a schematic response to negative influences but also incorporates the ability to self-adapt and to learn.

Traditional risk analyses are reaching their limits due to the complexity of the energy system. They are also only suitable to a limited degree for identifying new and unexpected events. In the future, criteria will therefore be required for operationalization and quantification of the resilience of the energy system during operation. In some cases, however, the criteria, methods, and indicators for measuring resilience first need to be developed. Monitoring technologies need to be combined with a systemic approach in order to identify the energy system's potential vulnerabilities already during its transformation (i.e., without interruption) [3]. Functioning examples of how system security and functionality can be monitored and ensured during operation – even in the face of changes to the system configuration – are well known from other sectors (Industry 4.0 or commercial vehicles).

In the energy system of the future, a previously unknown interaction between physical and virtual elements will develop. As a result, suitable new strategies for redundancy also need to be worked out. The tried-and-tested "n-1" rule for redundancy design will thus be insufficient to compensate for all of the diverse potentially erroneous interactions between ICT systems (which are corruptible), potentially maliciously influenced markets, regulated subsystems, and unchangeable physical constraints. The property of being "safe to fail" always extends across all of the system's physical and virtual components – resilience is a property arising from complex interactions that is specifically organized in each cell based on the individual configuration of the installations within a cell. Suitable early warning systems and the implementation of elastic system reactions are pressing research questions.

Closely related to the issue of resilience are issues surrounding the forecasting of system behavior, the immediate observability of the system state, and the reliable transparency of system actions. How this kind of monitoring system should be constructed and how complex system states and complex interrelated processes can be represented in a way that is clear and understandable for the user is yet another important research question.

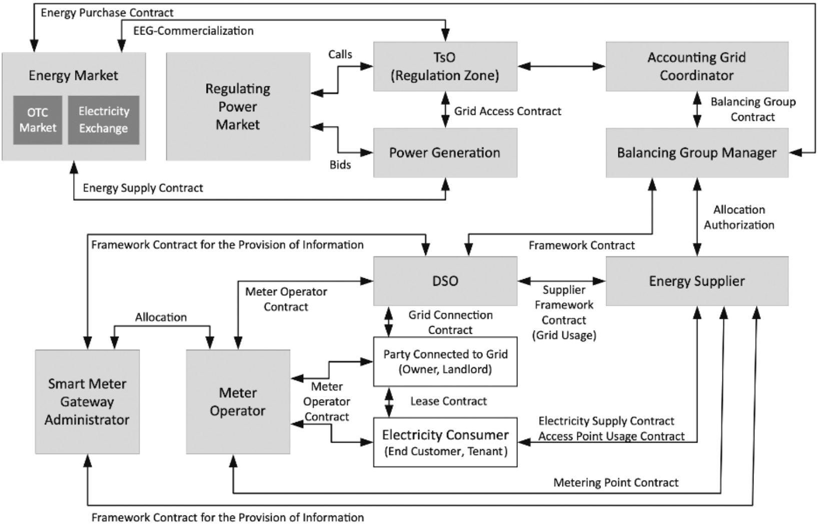

Fig. 20.4 Present contractual relationships between energy sector players (Bretschneider, Fraunhofer IOSB-AST)

Finally, set requirements and the services provided must be documented comprehensively and in a way that is subject to neither falsification nor dispute, and must be made accessible to invoicing. Until now, this has been regulated via a complex, static web of contracts (cf. Fig. 20.4) and corresponding reporting channels stipulated by the BNetzA (Federal Network Agency).

Consistent establishment of market mechanisms throughout the advancing energy transition will lead to very small volumes of energy (resp. flexibilities) being traded and the contract partners here (mainly “prosumers”) not being able to first conclude bilateral master contracts. The contractual agreements that are necessary to protect the large volume of brief relationships between the numerous actors within cells require contracts concluded by machine (“smart contracts”) that are founded on framework agreements concluded by humans. Here, too, there is a need for research in order to conclude legally protected agreements in real time between machines that must then be translated into system actions, monitored during execution, traceably documented, and correctly invoiced. At the moment, the blockchain approach is being propagated in this context. Its suitability remains to be verified.

20.7 The energy transition as a transformation process

The energy transition is a process that will require several decades due to its technical and societal complexity. During the course of the transformation process, old and new technologies will need to not only coexist but function in an integrated manner over a long period of time. The authors are convinced that now is the time to focus more intensively on the digitization of the energy transition. Only when the energy transition is understood as a complex and systemic transformation process can digitization actively support and successfully shape the necessary changes at the technical and societal level and help to press ahead with the transformation process. Very detailed support for this assessment is provided by the Münchner Kreis in its 50 recommendations [1].

In the past, there were many important innovations with respect to renewable energy technology. The accompanying digital networking and the resulting systemic challenges and opportunities have been neglected for a long time. Although it appears necessary and has often been discussed, the cellular approach has thus far been the focus of far too little research in the context of the energy system. The specification and implementation of resilience – ultimately a critical system characteristic affecting all of its components – also remain largely unexplored.

Last but not least, the success of the technical transformation process is, to a very large extent, reliant on long-term social acceptance and support [19], which must be continually verified and actively designed.

Sources and literature

[1] Münchner Kreis: 50 Empfehlungen für eine erfolgreiche Energiewende, Positionspapier, 2015.

[2] Neugebauer, R.; Beyerer, J.; Martini, P. (Hrsg.): Fortführung der zivilen Sicherheitsforschung, Positionspapier der Fraunhofer-Gesellschaft, München, 2016.

[3] Renn, O.: Das Energiesystem resilient gestalten, Nationale Akademie der Wissenschaften Leopoldina, acatech – Deutsche Akademie der Technikwissenschaften, Union der deutschen Akademien der Wissenschaften, Prof. Dr. Ortwin Renn Institute for Advanced Sustainability Studies, 03. Februar 2017 ESYS-Konferenz.

[4] Verband der Elektrotechnik, Elektronik, Informationstechnik e. V. (Hrsg.): Der zellulare Ansatz – Grundlage einer erfolgreichen, regionenübergreifenden Energiewende, Studie der Energietechnischen Gesellschaft im VDE (ETG), Frankfurt a. M., Juni 2015.

[5] Dötsch, Chr.; Clees, T.: Systemansätze und -komponenten für cross-sektorale Netze, in: Doleski, O. D. (Hrsg.): Herausforderung Utility 4.0, Springer Fachmedien GmbH, Wiesbaden, 2017.

[6] Ahern, J.: From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world, Landscape and Urban Planning 100, 2011, S. 341–343.
[7] H.-J. Appelrath, H. Kagermann, C Mayer, Future Energy Grid – Migrationspfade ins Internet der Energie, acatech-Studie, ISBN: 978-3-642-27863-1,2012.
[8] Bundesnetzagentur: Digitale Transformation in den Netzsektoren – Aktuelle Entwicklungen und regulatorische Herausforderungen, Mai 2017.
[9] Flex4Energy FLEXIBILITÄTS¬MANAGEMENT FÜR DIE ENERGIE-VERSORGUNG DER ZUKUNFT, https://www.flex4energy.de
[10] AUTOSAR (AUTomotive Open SystemARchitecture) https://www.autosar.org/
[11] Basissystem Industrie 4.0 (BaSys 4.0). http://www.basys40.de/
[12] White Paper Industrial Data Space https://www.google.de/url?sa=t&rct=j&q=&e src =s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwiHp6X9qr7UAhU Fl xoKHeBcAFUQFggvMAE&url=https%3A%2F%2Fwww.fraunhofer.de%2Fc- ontent%2Fdam%2Fzv%2Fde%2FForschungsfelder%2Findustrial-data-space%2FIndustrial-Data-Space_whitepaper.pdf&usg=AFQjCNGHaxIr7RxDWl6OPIaUZlwGaN0RZA&sig2=_mec3o8JzqMQDxLeQTkldw
[13] Dossier der Expertengruppe Intelligente Energienetze: Dezentralisierung der Energienetzführung mittels IKT unterstützen, Juni 2017
[14] Dossier der Expertengruppe Intelligente Energienetze: Branchenübergreifende IKT-Standards einführen, Juni 2017
[15] https://www.bmwi.de/Redaktion/DE/Artikel/Energie/sinteg.html
[16] https://www.kopernikus-projekte.de/start
[17] https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/ErneuerbareEnergien/ZahlenDatenInformationen/zahlenunddaten-node.html
[18] https://www.tagesschau.de/inland/cyberangriffe-107.html
[19] BDEW und rheingold institut: Digitalisierung aus Kundensicht, 22. 3. 2017, https://www.bdew.de/digitalisierung-aus-kundensicht