Opportunities of digitalization

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Opportunities of digitalization

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Background situation

Energy transport is limited by physical constraints. Whether there is material transfer (in pipelines, by ships, trains or trucks) or merely transfer of electrical current in power lines, adequate infrastructure (that is defined by its capacity) is needed. Moreover, while any fuel can be stored, electricity merely can be converted, and storage (such as in hydroelectric storage plants) typically comes with extra losses of 20 % or more and potentially with high capital expenses.

Energy consumption often follows distinct temporal patterns. Households need energy for lighting and heating in winter, and potentially for cooling in summer. With easy storage options, fuel transport nevertheless can be performed on a constant (low-cost) level. Fuels will be released from storage when needed, and peak transport only is required for the "last mile", the distance between a storage place and the user. It will depend on the situation to define what the "last mile" in practice means.

The way to provide electricity is more complex. In a balanced grid, electric generation and consumption must match at any given moment (otherwise the power system will collapse). In practice, this happens by pooling basic power supply (such as nuclear plants or coal fired power plants, also run-of-the-river hydro plants) for the base load with power plants that can be started when needed, such as hydroelectric storage or gas fired power plants. Storage (such as pumped hydro, flywheels, solid state batteries, flow batteries that store the energy in liquids outside the device, compressed air, or thermal storage) can also provide fast generation (or consumption) capacity if needed.

Challenges to the grid have become higher with renewable energy sources such as wind or solar. As such electricity sources provide sizeable shares of total power production (e.g., Germany or Denmark, on an annual average, about 37 % (Burger, 2021) and 61 % (DEA, 2021), respectively, from wind and photovoltaic) and as production from these sources depends on weather conditions, demand/supply matching problems get more pronounced. Distribution grids, designed for housing loads, also face serious congestion problems either due to "demand side" solar production or due to EV charging situations. High shares of fluctuating renewables also put fast production facilities that can counter-balance these fluctuations, e.g., expensive gas and hydro-storage plants, into the spotlight. To some extent the irregularity of renewable electricity production can be compensated by accurate weather prediction, such that forecast electricity production figures allow to more precisely dispatch electricity from other sources.

Smart grid preconceptions

While classically, production follows consumption, a renewable power system contains large shares of non-dispatchable generation. Ideally, consumption would follow generation whenever possible in this case. Here digitalization may take a key role.

Developing an electrical grid into a smart grid needs more than just a bundle of individual measures. It requires developing the grid into a digital platform. There are initial starting points, but the overall developments are not yet fully predictable. Initiators of such developments are

- Observability: real-time metering of electricity consumption to allow price signals with respect to peak or base consumption, PMU (phasor measurement units), power quality meters.
- Transactions: short-term contracts of power delivery on an automated marketplace. Booking / purchasing to be done via the internet. Both energy providers and consumers exchange "packages" of energy, taking advantage of the respective opportunity infrastructure offers for a given space and time.
- Flexibility and Storage: batteries, electric vehicles (with compensation of owners possible), demand response, smart cities, flexible industrial loads.
- Integration: smartly connecting energy systems across sectors (e.g., heat, gas, electricity, built environment), with dynamic markets (e.g., on neighborhood level or congestion markets), between TSO and DSOs, and between countries contributes to resilience and flexibility.

Such an infrastructure needs operating policies, and it needs to be protected against misuse as well as criminal acts scaling from vandalism up to electronic warfare. A smart grid needs to have a defined and secure way of payment, needs to be safe against interruptions (both the data transfer and the power lines themselves) and it needs to come with some redundancy (resilience), in order to buffer eventually appearing problems.

There are considerable issues to be sorted out with regard to data safety, data ownership, digital identity, and possible data transfer, comparable to the issues with data on mobile phone use. As a smart grid benefits immensely from the co-existence of the individual parts, ownership structures will be quite complex. A mechanism of identifying responsibilities regarding extension, service and repair of hardware compounds to be used by all partners needs to be elaborated.

Research focus

A complete electrical grid is a huge, expensive, and complex infrastructure. Out of the three possible scientific methods, analytical, experimental, and numerical investigation, it is often only the latter that is possible. Each element of a smart grid, a grid using information and communication technology to improve its operations, can be described in a numerical model, simulated in scenarios, and the result validated independently. The considerable challenge of model coupling to arrive at cosimulation of all relevant compounds has been described in detail by Palensky et al. (2017). Optimizing smart grids requires addressing the reliability of grid components, especially of sub-grids (micro-grids) near the consumer to maintain angular (phase in), frequency, and voltage stability in alternate current. Such systems and their structural design, also for future power systems, are shown by Peyghami et al. (2020).

Based on an understanding of the general operations of such a power system, further details may be derived. This includes the challenges of integrating battery energy storage systems, where components of such a storage system are analyzed, their applications compared, and size and locations in networks are discussed (Stecca et al., 2020). Advanced trading systems have been developed, based on communication technologies, taking advantage of blockchain technologies and thus allowing peer-to-peer energy trading directly between consumer and producer (Esmat et al., 2021). Decentralization is a key concept of such developments.

Also new challenges to energy systems are a subject of extensive studies. Misuse of communication systems may bring extra challenges. Cyber attacks may attempt to exploit system vulnerabilities (Pan et al., 2020). Understanding modes of attack and system vulnerabilities potentially leading to blackouts allows to design simulation frameworks to analyze impacts and to protect against such attacks (Rajkumar et al., 2020).

Expectations and limitations

While optimizing the use of physical devices that constitute a grid will not allow it to exceed any of the capacity limitations, its logistics can be substantially extended. Given the fact that capacity now is defined by peak capacity, and peak consumption may achieve up to 2-4 times average consumption, substantial transport and distribution improvements are possible. Optimization may even extend towards using buffer storage devices (from pumped hydroelectric to e-vehicle batteries) selected close to expected future users, such that transmission capacity is relieved.

The overall concept follows and actually is strongly determined by a market approach. There is considerable risk that such market approaches can be best used by market participants that possess financial flexibility – or in other words, that consumers that lack necessary financial backing would be at a disadvantage, having to bear the times/situation of high costs and being pushed more heavily into energy poverty. Also here, appropriate compensation and policy guidance will be needed.

References

Burger, Bruno (2021). Public Net Electricity Generation in Germany 2020. Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany.

DEA (2021). Energy in Denmark 2020 - Data, tables, statistics and maps. Danish Energy Agency, Copenhagen.

Esmat, A.; de Vos, M.; Ghiassi-Farrokhfal, Y.; Palensky, P. & Epema, D. (2021). A novel decentralized platform for peer-to-peer energy trading market with blockchain technology: Applied Energy, Vol. 282 , pp. 116- 123.

P Palensky, AA Van Der Meer, CD Lopez, A Joseph, K Pan (2017). Cosimulation of intelligent power systems: Fundamentals, software architecture, numerics, and coupling. IEEE Industrial Electronics Magazine 11 (1), 34-50.

Pan, K.; Dong, J.; Rakhshani, E. & Palensky, P. (2020). Effects of Cyber Attacks on AC and High-Voltage DC Interconnected Power Systems with Emulated Inertia; Energies, Vol. 13, 05583.

S Peyghami, P Palensky, F Blaabjerg (2020). An overview on the reliability of modern power electronic based power systems. IEEE Open Journal of Power Electronics 1, 34-50.

M Stecca, LR Elizondo, TB Soeiro, P Bauer, P Palensky (2020). A comprehensive review of the integration of battery energy storage systems into distribution networks. IEEE Open Journal of the Industrial Electronics Society 1, 46-65.

Rajkumar, V.S.; Tealane, M.; Ştefanov, A.; Presekal, A. & Palensky, P. (2020). Cyber Attacks on Power System Automation and Protection and Impact Analysis; 2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), pp. 247-254.