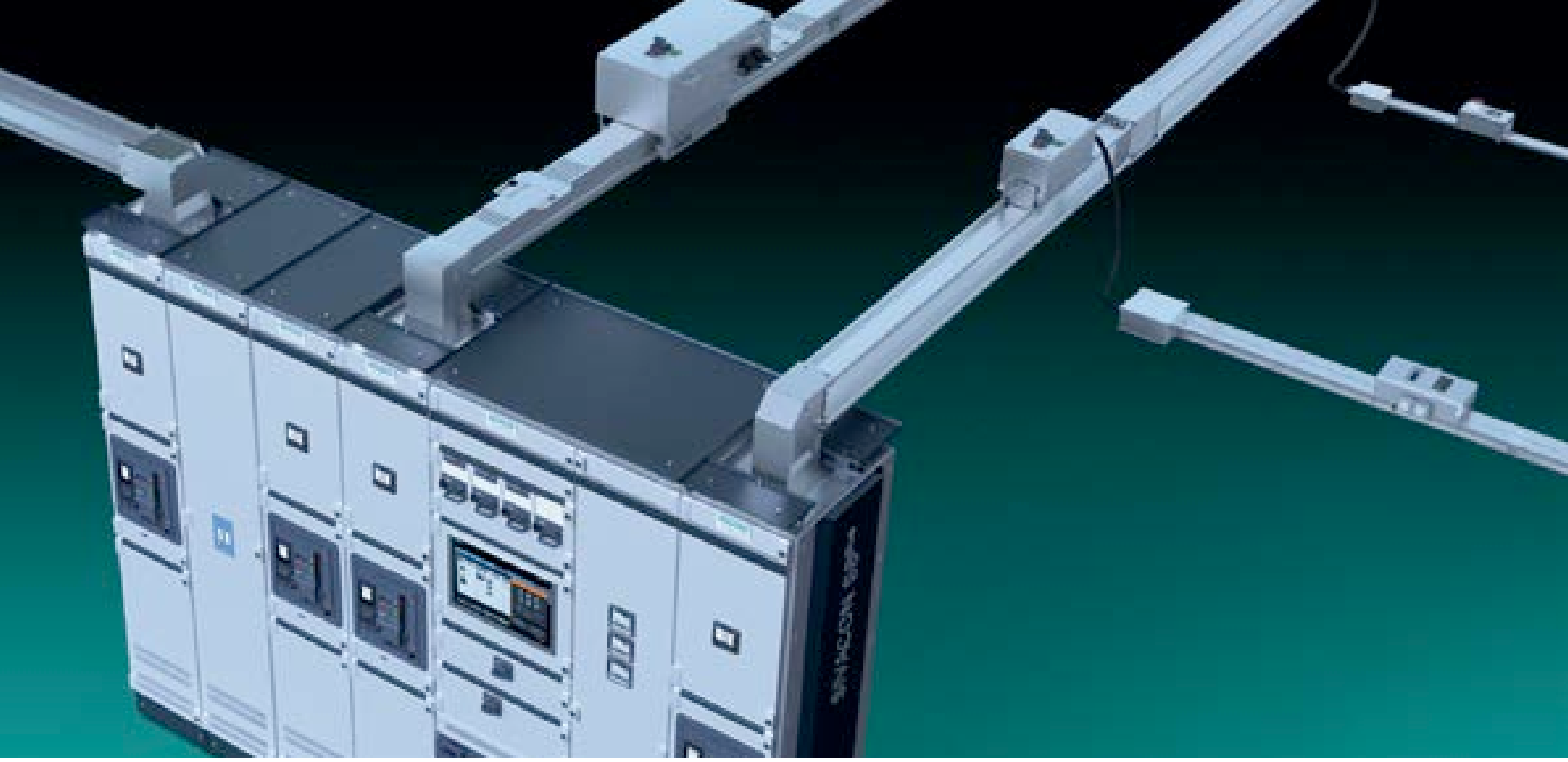

BASIC REQUIREMENTS ON "INTEGRATED INTELLIGENCE" FOR ELECTRIC POWER DISTRIBUTION

Intelligent
Power Distribution

Summary

"Energiewende" (German for energy transition) and "digitalization" are current keywords describing the further development of power supply, and thus especially of electric power distribution.

For a future-oriented approach, it is not enough anymore to determine and evaluate optimum product properties from a static point of view. Only a dynamic perspective takes into account factors such as changes in operation, economic influences, and time behavior of ambient conditions when analyzing and selecting products and systems for electric power distribution.

Connecting the opportunities of digitalization with the effects of a possible implementation of the Energiewende, the topic of "Integrated intelligence" emerges as a future trend.

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1. Introduction

Synthesis of Energiewende and digitalization towards “Integrated intelligence”

Energiewende – a term explanation

Energiewende has become an international term which is no longer translated. Contrary to the intention in Germany of regarding the Energiewende as a restructuring process in power generation which increasingly considers energy efficiency, the term is internationally equated with the “German Angst” of large power plants in general and is used to define the avoidance of CO_2 in the context of power generation.

The Energiewende should not be reduced to the installation of efficiency-optimized technology and the replacement of one power generation technology by another of comparable characteristics. One kilowatt hour of electrical energy that is generated and consumed cannot simply be replaced by another kilowatt hour, which unfortunately remains a widespread misconception.

Instead, the Energiewende should be understood as the continuous search for an economic and environmentally oriented efficiency optimum of power generation, distribution, and consumption. In this sense, the Energiewende is an ongoing process which makes project-specific planning indispensable.

Energiewende and electric power distribution

In the following, the Energiewende is considered particularly in the context of technical restructuring of electric power distribution for the infrastructure sector. Political and ecological backgrounds and estimations will be left aside as much as possible.

In the infrastructure sector, the changed operational boundary conditions of the power generation technologies must be assessed (under the existing conditions) in connection with supply and distribution aspects, and must be coupled with consumer behavior. The resulting complexity increasingly influences the planning of electric power distribution in the infrastructure sector.

Digitalization and planning

The term digitalization generally describes the change of processes, objects, and events resulting from an increased use of digital devices. This includes, among other things, the virtual modeling of objects and their behavior.

In the future, modeling of user behavior and the resulting development and consideration of scenarios will be equally important already during planning. Digitalization will therefore increasingly gain influence on the work of a planner. The BIM concept (Building Information Modeling) used in the construction industry and building technologies is taken up normatively in the international standard series ISO 29481, among others.

Limiting digitalization and the Energiewende to the operation of measuring points definitely falls short. According to this, digitalization would only need to be observed during system operation. Virtualization is, however, increasingly being demanded in the planning process already today.

Modeling and project processing based on the new BIM standard is requested for many planning projects. With the planning data, both system and operation can be optimized on the basis of possible and intended changes in operating conditions (see Fig. 1: Schematization of optimization potential in different project phases).

New dimensions: “Integrated intelligence”

Fig. 1 suggests that a virtual optimization of operation can have bigger impacts on energy efficiency than an energy management that is limited temporally to operation only, irrespective of the general reasonableness of energy management according to ISO 50001.

The connection of Energiewende, digitalization, and BIM ultimately results in “Integrated intelligence” and defines the new challenges for electric power distribution across the entire lifecycle. The consideration of project life and the simulation of time sequences will make an increasing impact on planning and its ongoing continuation in the future.

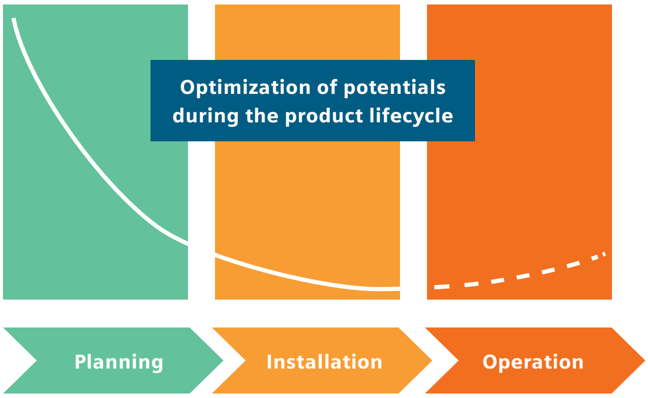
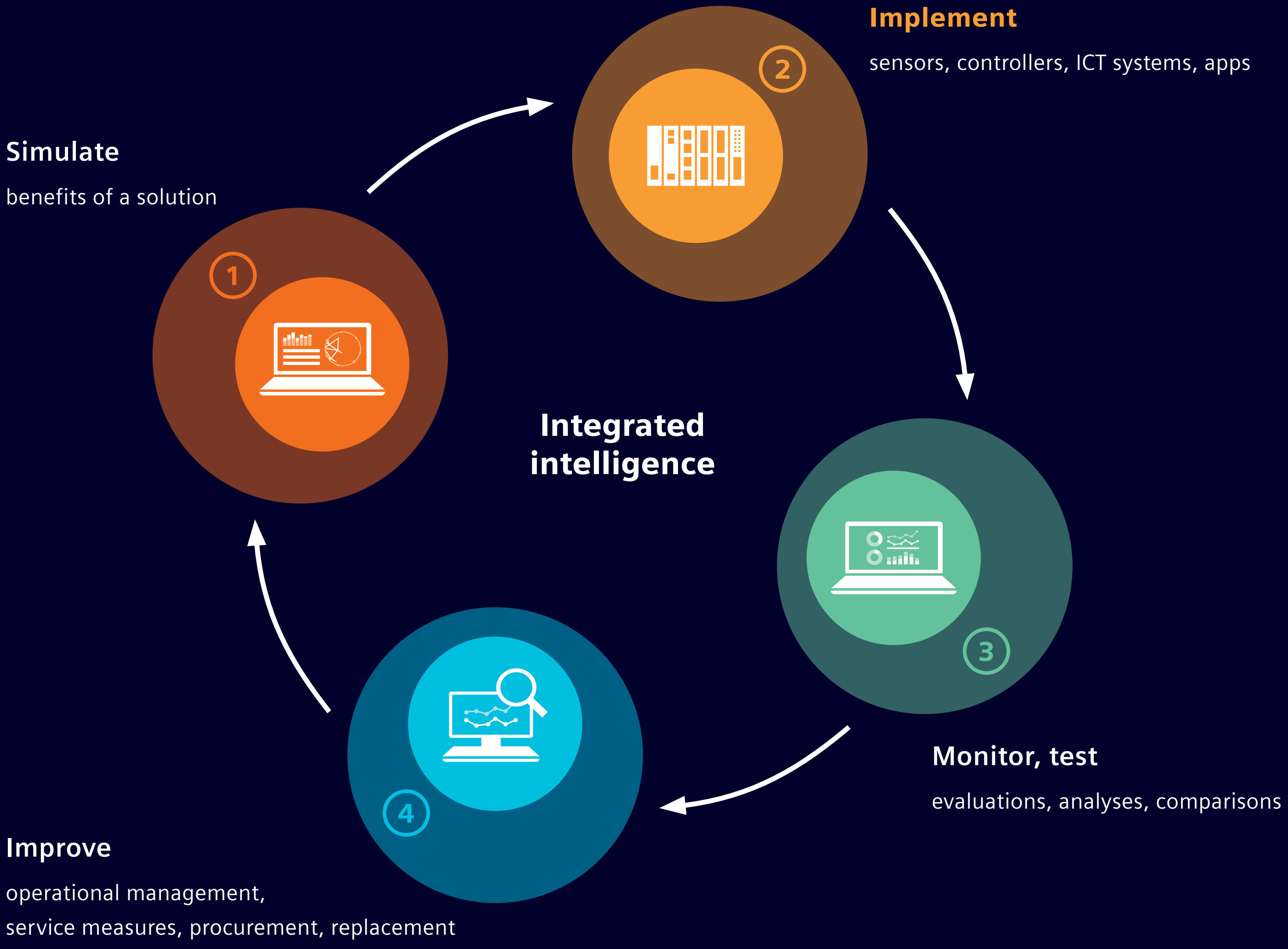


Fig. 1: Schematization of optimization potential in the different project phases



	Energy management system	Project lifecycle management
①	Plan	Planning
②	Do	Installation
③	Check	Operation
④	Act	Analysis & decision

Fig. 2: Optimization process of "Integrated intelligence" on the basis of energy and project management

Time as an influencing variable in system planning

The volatility of renewable power generation, the use of energy storage, the development of conversion technologies for energy carriers, such as electrolysis and fuel cell, as well as the digital communication options between producers, distributors, and consumers make time an important factor in system planning: This creates a planning environment for electric power supply in which the operating period of a system must be simulated as realistically as possible. Besides the integration of devices, systems, and installations as well as their optimization, handling, and documentation via determined programs and tools, this also includes the depiction of time aspects of electricity usage, so that these aspects can be incorporated in the planning, too. Apart from maximum and minimum values for currents, voltages, and resistances, the planner will thus also increasingly have to consider the time sequence of system operation.

Time must therefore be carried along as a characteristic feature for measured values or as a parameter for simulation variables. Typical time characteristics of parameters (e.g., synthetic load curves, environment-dependent weather forecasts, and load-dependent efficiency curves) allow for a first approach to simulations and improve the transparency of complex processes already during planning.

During operation, the comparison between the time series for measured values and the time characteristics used for the simulations enables verification and continuous improvement. Possibly, starting points for operational changes and even improvements can be identified, practically as the basis for an energy management system (EnMS) according to ISO 50001 [1].
In the end, energy management serves to optimize the time control of power demand or the time-dependent provision of power, as the following applies physically:

Energy = Power x Time

Integration of energy management and project management

ISO 50001 states the improvement of “energy-related performance” as the purpose for energy management, and planning as the basic step in the management process (PDCA cycle: Plan – Do – Check – Act), which is thus seen as a contribution to the Energiewende. In analogy to the PDCA management cycle, the project life-cycle can be divided into planning, installation, operation, analysis, and decision. Digitalization plays an important role in “Integrated intelligence” (Fig. 2) for realizing and automating the steps, as well as for the optimization process.

An “Integrated intelligence” is built up from energy management and project digitalization. A digital energy twin serves for simulation. Product properties and functions, operating states and operating values, as well as processes and actions are simulated with data technology. The real devices, their measured values and operating states, as well as the ambient conditions (weather, time, persons with their actions and their heat dissipation, ...) are observed and recorded. Digital verifications compare the simulation with the real conditions and also check the violation of limit values and rules. Automated analyses and evaluations lead to decisions which are translated into instructions and close the automated process cycle.

2. "Integrated intelligence"
in electric power supply

Energy management as a part of the Energiewende is commonly simply associated with the monitoring and recording of data. And digitalization today is usually seen as the translation of analog actions and processes into data streams and data technical evaluations, and as a comprehensive process automation with the help of data technology. Nevertheless, both have been possible for decades already and are frequently implemented today. The true advantage of linking energy management with increasing digitalization, especially as it relates to power distribution and operational management, is the combination to an "Integrated intelligence".

This includes, for example:

- Interconnection of the most different processes and work environments
- Extreme variability of the work and production environment for any desired operating periods and changeable framework conditions
- Any desired modeling, simulating, and testing systems with the corresponding analysis functions and the possibility to implement the results of the analyses almost immediately
- Development and evaluation of adaptable optimization goals depending on the most different parameters (energy efficiency, ecological footprint, time, costs, space requirement, transport ways, ...)
- Design, preservation, and constant extension of experience, knowledge, and verification systems for planning and management
- Higher security by interconnecting different risk factors and their ongoing observation and monitoring

The technical basis for "Integrated intelligence" lies in the merging of power distribution technology, sensors, automation systems, information and communication technology, as well as the interconnection of power and energy grids with data and communication networks. The integration of many subsections of the digital transformation such as industry 4.0 or IoT (Internet of Things), smart grid, smart building, autonomous mobility, AI (Artificial Intelligence), and BIM will mark the next stages of development towards an intelligent power distribution.

The required dynamic organization and equipment control of process and automation environments, as well as monitoring and controlling of operating states for energy management are ensured by an open IT platform such as MindSphere™. Large data volumes of countless devices can be recorded and analyzed efficiently in real time. Experiences and measured values can be interconnected intelligently in data models and implemented in predictive improvement measures. Smart data applications provide support during operation and maintenance. They allow for predictions of potential failures of an asset or individual components, and contribute to minimizing system downtimes and inefficient modes of operation as well as to optimizing system and personnel safety.

3. Structural design
of intelligent power distribution systems

Communication-capable protection, switching, and measuring devices from the SENTRON portfolio, the new Sensformer® transformer series, the SIMOCODE pro motor management system, as well as the SIMARIS control diagnostics station of the SIVACON S8^{plus} low-voltage switchboard and the communication capability of SIVACON 8PS busbar trunking systems provide for an optimally designed power distribution.

The systems and components interact with each other intelligently in the communication network via standardized interfaces and protocols such as PROFINET, PROFIBUS, and Modbus. This way, electric power distribution can be adjusted optimally to automated operating, machine, and process sequences, thus ensuring a safe and flexible power supply (Fig. 3).

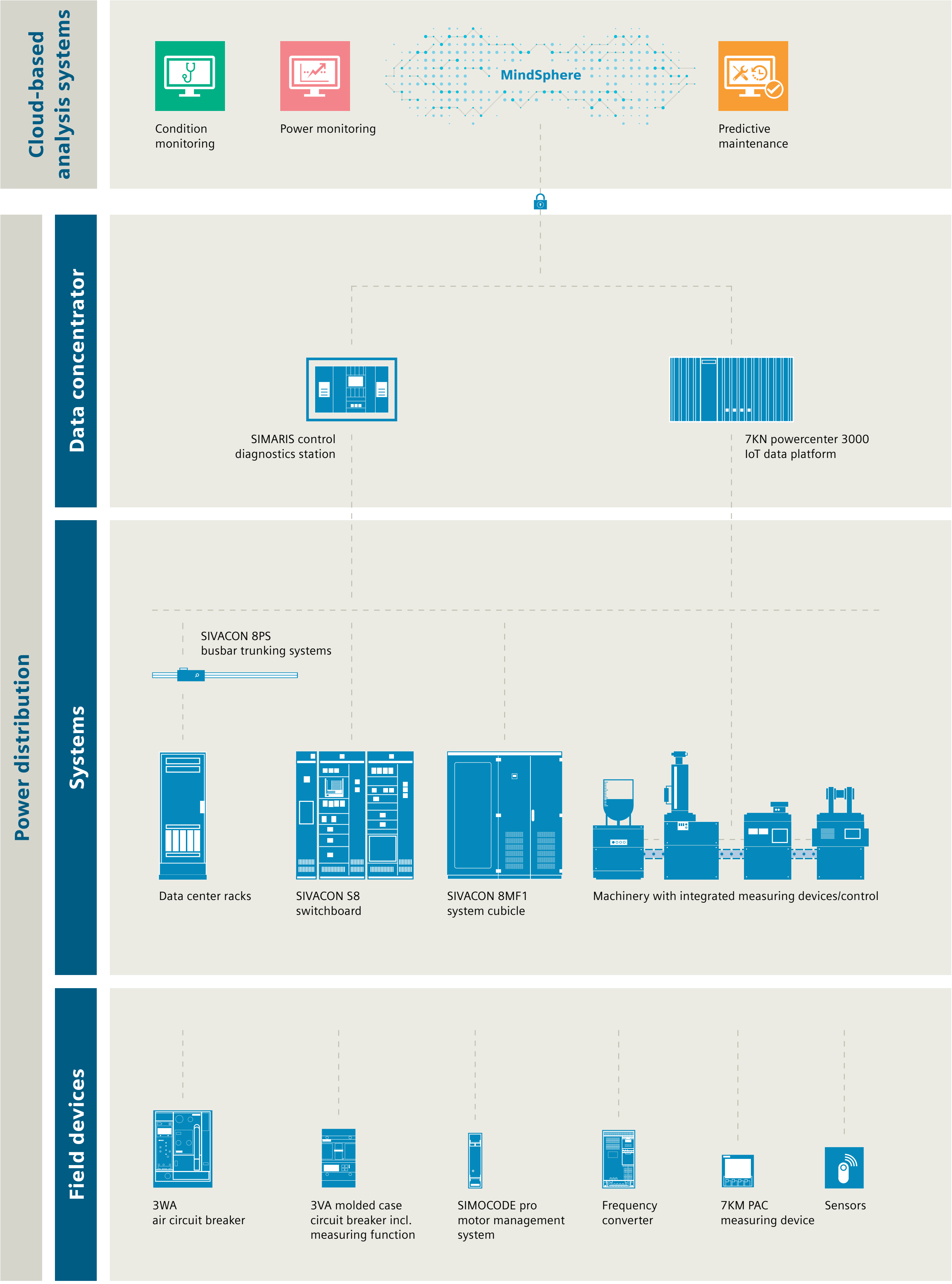


Fig. 3: Future-oriented inclusion of electric power distribution into “Integrated intelligence”

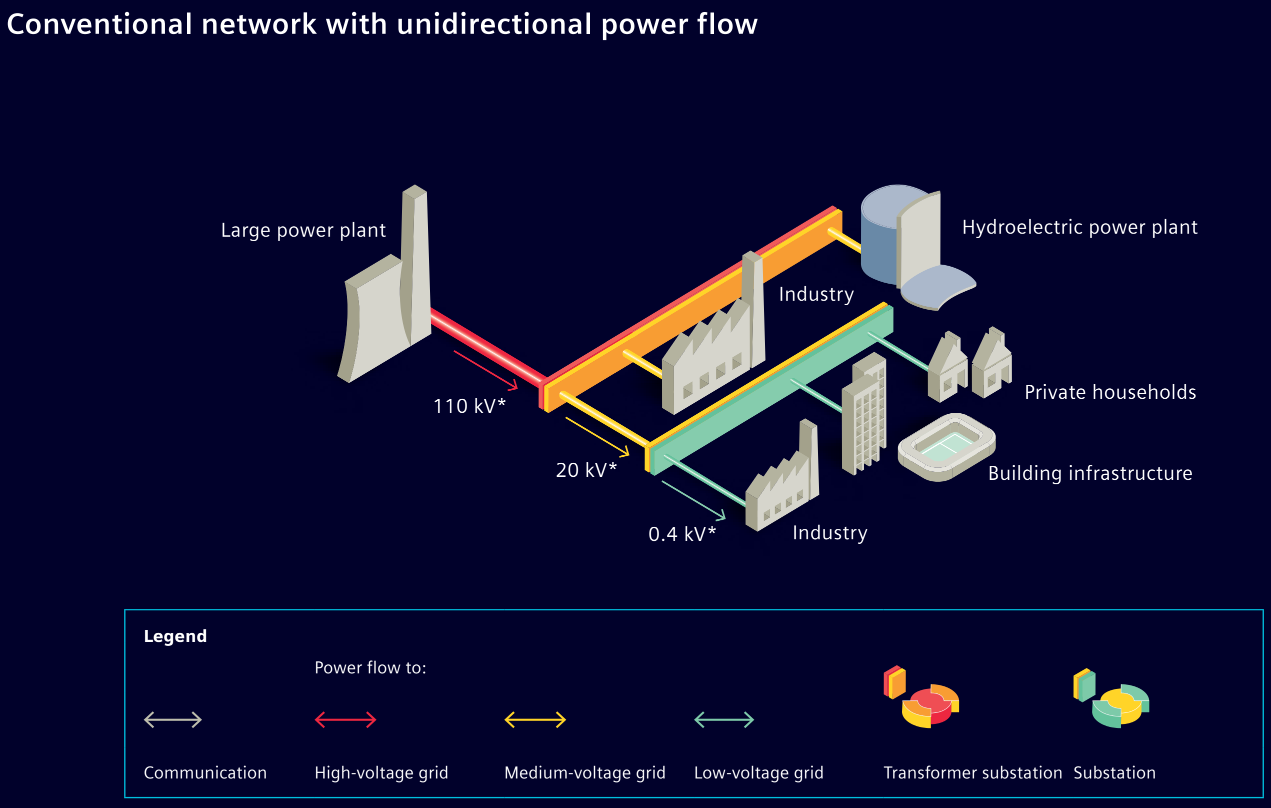
4. The importance of planning
for "Integrated intelligence"

The improvement of "energy-related performance including energy efficiency, use of energy, and energy consumption" is named as the goal of a systematic energy management in ISO 50001. Planning as the basic step in the management process (PDCA cycle: Plan – Do – Check – Act) serves to define the energetic starting point. IEC 60364-8-1 is the link for planning regarding energy efficiency and energy-related performance of electric power distribution.

The requirements and planning instructions described in the standard shall support the optimization of costs (investments, maintenance costs, and energy prices) and consumption, as well as the design of options for real-time adjustment options according to Fig. 1. Especially when it comes to system retrofit and system replacement in existing buildings, particular emphasis shall be placed on planning process that aims at the long-term improvement of energy efficiency.

For real-time adjustments in system operation, the interactions between local generation, storage, and use of electrical energy plays an increasing role. In addition to that, the participation in the power market may be taken into consideration in the case of self-generation. This shows that buildings must be a part of smart grids [2] in the future, and not only connection points for classical power distribution grids.

Fig. 4: Graphical comparison of classical power distribution grids and smart grids

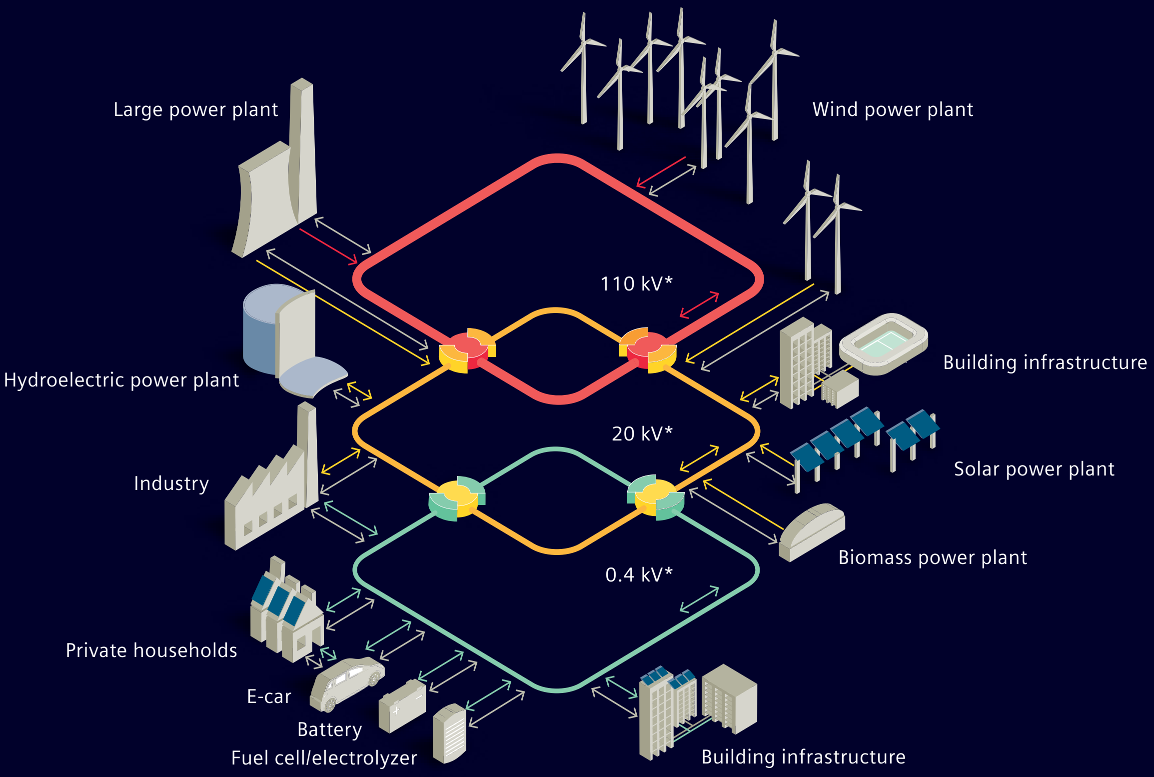

Conventional network with unidirectional power flow

* The specified voltage values are exemplary

Fig. 4 illustrates the difference between conventional grids with an unambiguous direction of the current flow and smart grids with temporally variable directions of the current flow. The electricity customer as a consumer will be increasingly rare. Due to the intermittent change of roles from an energy consumer to an energy supplier, many will take on the role of a prosumer, i.e., a combination of producer and consumer.
By bundling smaller generation and storage units, new business models are emerging with a type of energy pool manager who "operates" a virtual power plant. Background: In Europe, the participation in the electricity balancing market is only possible from a certain reserve power (5 MW).
If virtual power plants are coupled and operated with storage systems and consumer load management, this is referred to as a virtual power supply system.

The digitalization of individual components and an energy management across plants and systems are required to implement "Integrated intelligence". The prequalification of "components" for connection to a virtual power plant will be a milestone in order to avoid the costs for numerous individual acceptances and for the verifications about safe interaction of the individual components.
A platform such as MindSphere provides the required framework for that. It is therefore important for the planner and system operator to partner with a reliable solution provider.

Network with bidirectional power flow and intelligent transformer substations



Smart grids

Depending on the perspective, different definitions are given for intelligent power grids (smart grids); for example, the definition of the German Federal Network Agency [2]: *"The smart grid includes the networking and control of intelligent producers, storage systems, consumers, and grid equipment in power transmission and distribution grids with the help of information and communication technology (ICT)."*

Besides a common definition *("Smart grids are power grids which support energy-efficient and cost-efficient system operation for future requirements via a coordinated management of timely and bidirectional communication between grid components, producers, storage systems, and consumers")* the Austrian technology platform for smart grids, SMARTGRIDS Austria, defined an approach that is easy to remember [3]:

Intelligent Grid = I^3 =
Information x Interaction x Integration

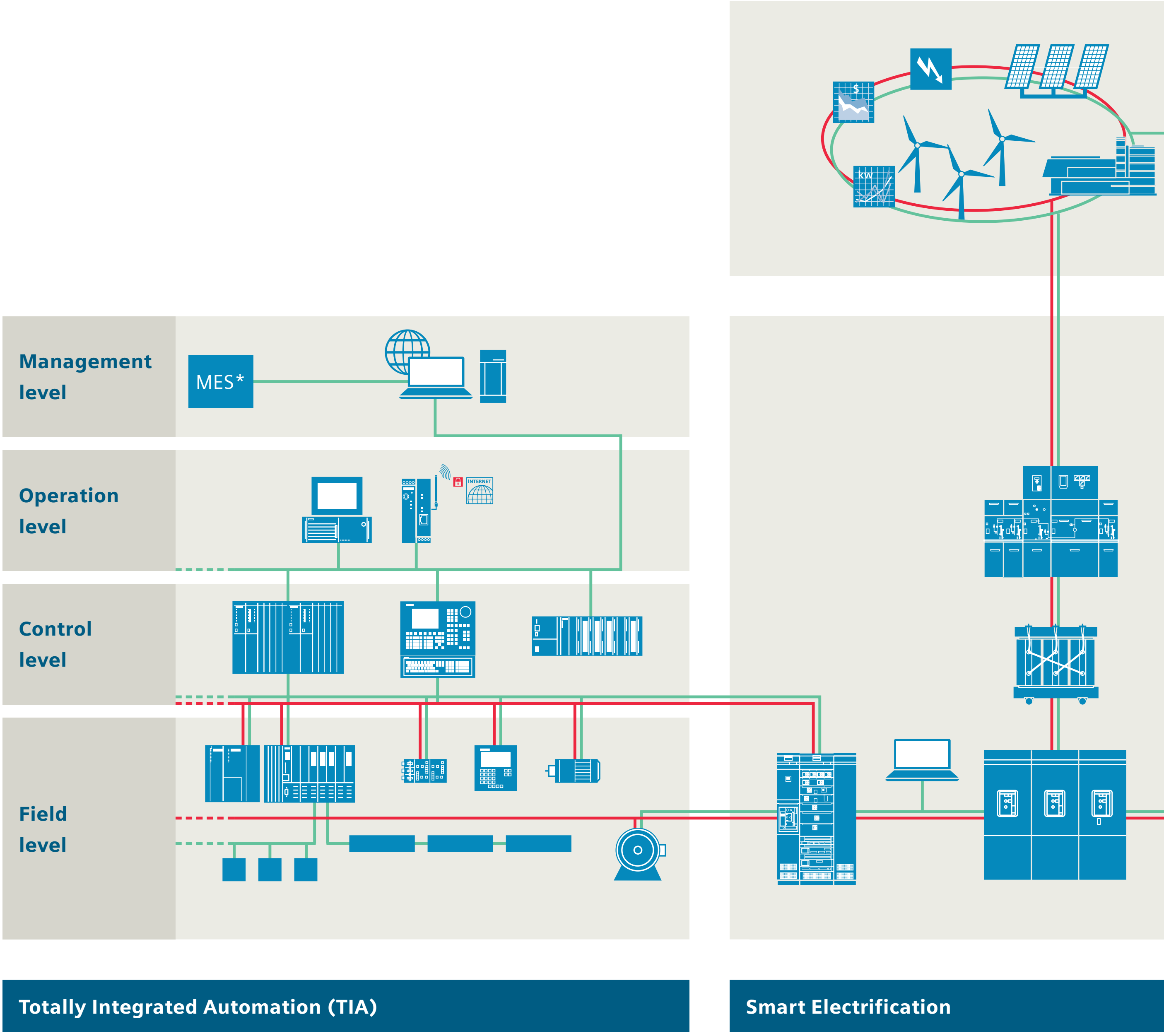


Fig. 5: Planning of conventional grids and smart grids as well as their realization with consistent Siemens power distribution solutions with TIA, Smart Electrification and Smart Buildings

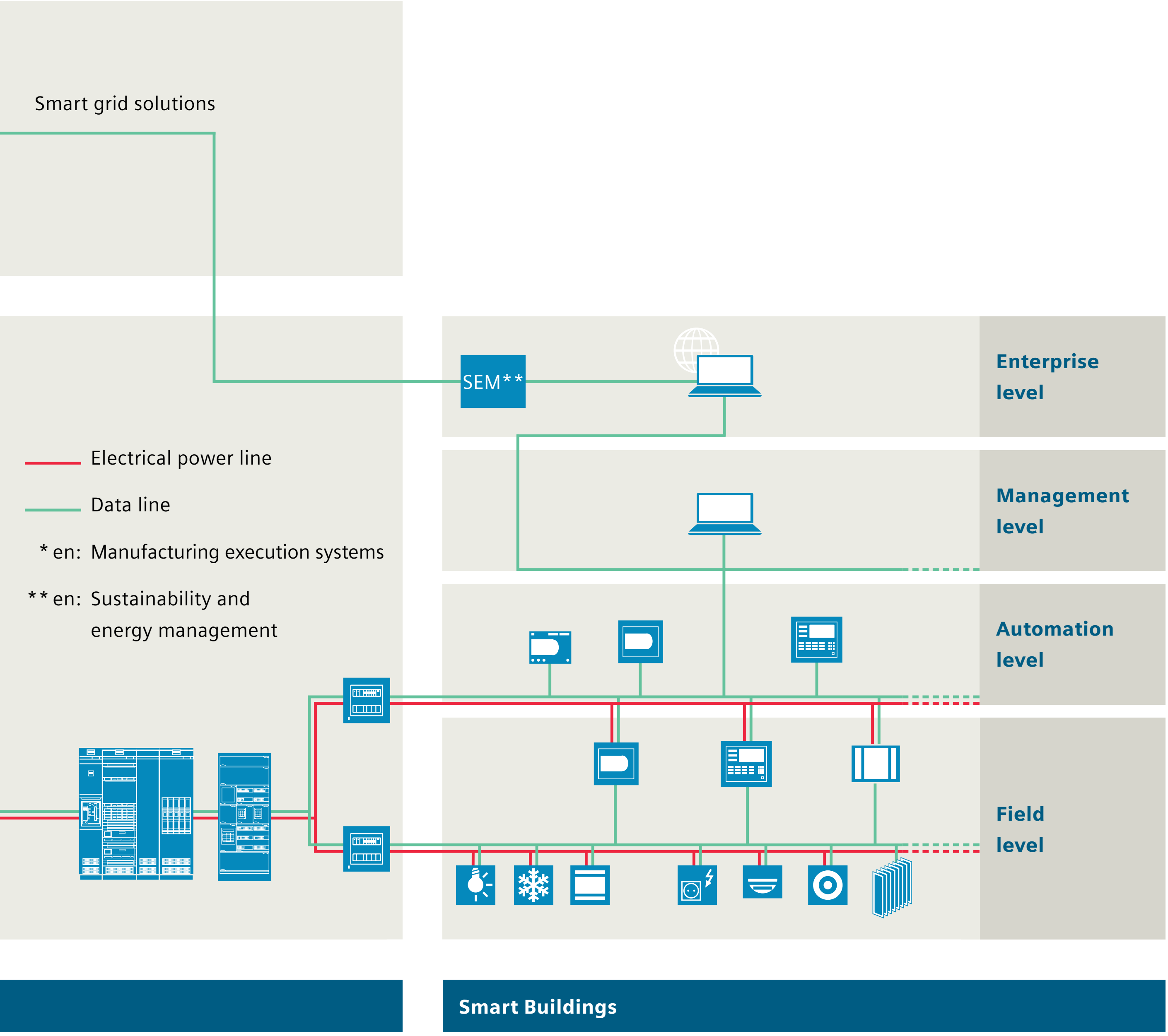
With

- "Information" for data acquisition, storage, and processing
- "Interaction" for control and regulation options
- "Integration" for the inclusion of smaller, decentralized power generation units into the distribution grid as well as for the coordination between volatile generation, flexibly usable storage systems, and time-dependent consumption control.

Usually, three steps are taken in the planning of the electric power distribution until products and systems for the chosen solution are selected [4]:

- Concept finding
- Calculation
- Dimensioning

This process is usually iterative. Electronic aids, such as those which can be integrated into the BIM, shall support and simplify the planner's work. The so far accustomed conventional power flow from the producer to the consumer allows for the consideration of stationary values, e.g., for currents and voltages (Fig. 5), at specific points of time (usually, at the time of commissioning of a system).



Planning of conventional grids

Concept for conventional grids	Calculation	Dimensioning	Product series
• Analysis of the supply task • Selection of the network configuration • Selection of the network system • Definition of technology features • …	• Power demand • Load flow, normal operation/failure • Voltage drop • Short-circuit currents prospective/influenced • …	• Transformers • Emergency generating sets • Switchgear/switchboard • Protection devices • Measuring devices • …	• GEAFOL • SIVACON • SENTRON • SIRIUS • SIPROTEC • …

Planning of smart grids

Concept for smart grids	Calculation	Dimensioning	Product series
• Analysis of supply, generation, and feedback (e.g., efficiency considerations) • Definition of load priorities • Definition of behavior patterns for the use of consumers, storage systems, and suppliers (base for control algorithms) • Selection of the network configuration • Selection of the network system • Definition of technology features; especially possibilities for manual intervention • …	• Power balance • Load flow, normal operation/failure • Voltage drop • Short-circuit currents prospective/influenced • Power demand/ generation/feedback • Load curves and environmental conditions • Power trade possibilities • …	• Transformers • Cables/busbar trunking systems • Emergency generating sets • Power generation systems • Energy storage systems • Switchgear/switchboard • Protection devices • Measuring devices • Automation systems • Energy management systems • Communication • …	• GEAFOL • RONT • SIVACON • SENTRON • SIRIUS • SIPROTEC • MindSphere • SIMATIC, SICAM • Desigo • BEMS, DEMS, MES, SEM • …

Due to the requirement for optimizing energy efficiency as a part of the Energiewende, and as a result of the influence of smart grids on power distribution of a prosumer, time must be increasingly taken into consideration as a planning parameter: Time dependencies, and thus considerations of energy, environment, and operation, play an increasing role for new structures and power flows in the planning, particularly against the background of mid-term and long-term economic and ecological aspects that are taken into account in the early planning stage.

For the digitalization of energy systems, additional product characteristics such as communication, measurement, and evaluation equipment (hardware and software) must already be included in planning. This is also what the standards and guidelines on energy management (e.g., ISO 50001), energy efficiency (e.g., Directive 2012/27/EU), energy controlling (VDI 2166-1), and energy balancing (standard series DIN V 18599) aim at in some parts.

Intelligent total energy concepts lead to energy efficiency

The new EU Directive 2018/844/EU on energy efficiency introduces the term "smart readiness of a building". This "ability" shall be described and made comparable via a "smart readiness indicator". To indicate the "Integrated intelligence" of a building, an infrastructure facility, or a production facility, a building IQ could be defined.

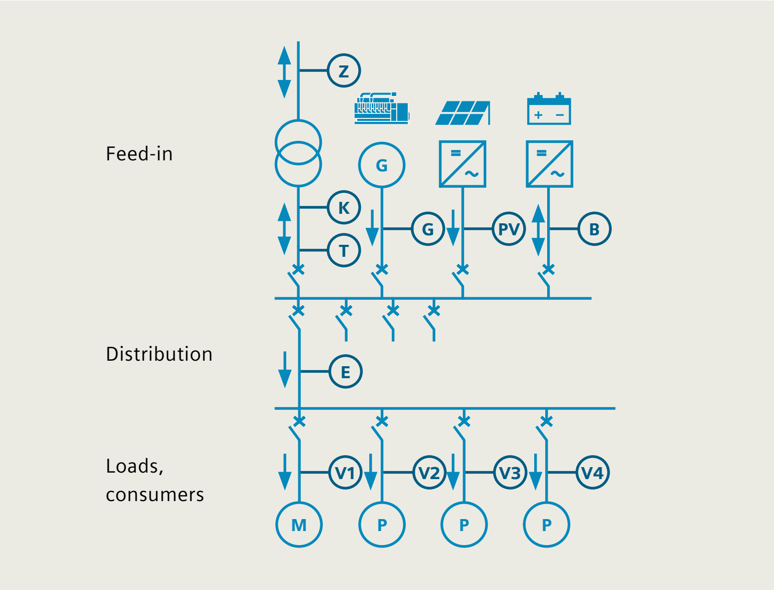
To develop the corresponding evaluation structure for a building IQ, IEC 60364-8-1 (VDE 0100-801) can be used. The standard contains "requirements, measures and recommendations for the design, erection and verification of all types of low-voltage electrical installation including local production and storage of energy for optimizing the overall efficient use of electricity".

In the standard IEC 60364-8-1 (VDE 0100-801) from 2019, efficiency classes are introduced (from low efficiency EE0 up to very high efficiency EE5). The following characteristics must be observed in electric power distribution (the parameters to be observed are in brackets):

- Initial installation (determination of energy consumption, arrangement of the main incoming feeder, voltage drop, efficiency of transformers, efficiency of consumables)
- Energy management (areas, applications, load management coverage and duration, meshes, measurement per application, coverage and recording of occupation detection for zones and rooms, energy management system, lighting control)
- Preservation of performance (introduction and follow-up of a service life methodology, frequency of performance checks, data management, work point of the transformer, continuity of monitoring)
- Power supervision (power factor, harmonic content of voltage or current)
- Use of renewable energy sources and energy storage systems as a bonus

The aim of energy efficiency improvements is the optimization of energy consumption with the output remaining unchanged: e.g., for production numbers, for working conditions in the building, for transport services (use of elevators, escalators, conveyor belts, vehicles), as well as for ICT services. Here, the entire process chain of power generation, transmission, and distribution, as well as energy storage, conversion, and utilization must be observed.

A major precondition for energy efficiency improvements is their checking and evaluation by means of measurements throughout the entire service life of the system. In case of the common star structure in electric power distribution, the scope and accuracy of measurements can be selected based on the distribution levels (Fig. 6).



Z	Supply point meter
K	Check measurement
T	Transformer feeder
G	Generator feeder
PV	Photovoltaic feeder
B	Battery storage feeder
E	Power distribution
V1	Load – 3-phase, linear symmetrical, e.g., motor
Z2	Load – linear and asymmetrical, e.g., floor distribution board
V3	Load – non-linear and asymmetrical, e.g., electronic switching device
V4	Load – cost center allocation, energy billing

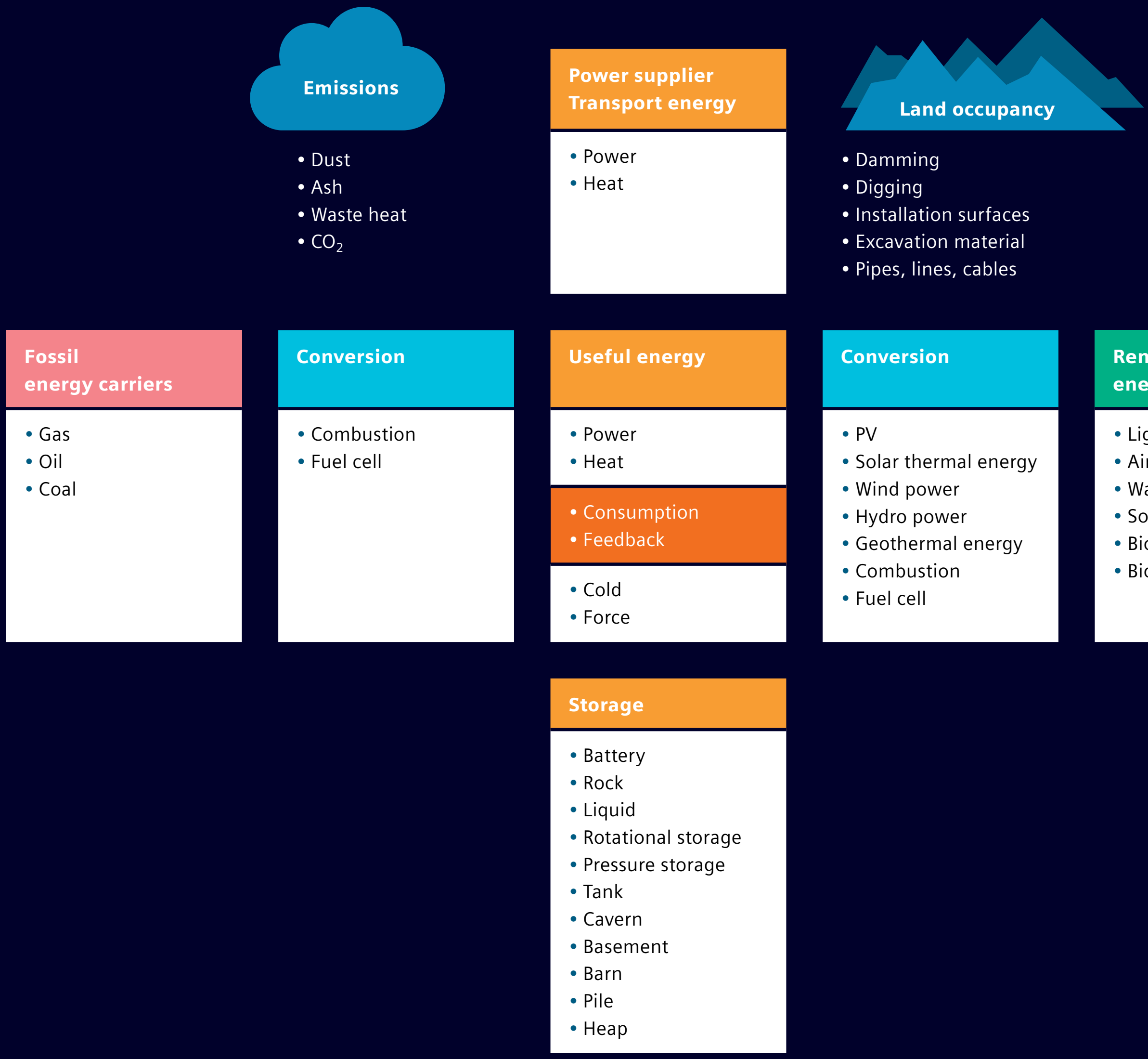
Fig. 6: Structure of measurements in the distribution grid (arrows indicate direction of power flow)

The economic and ecological integration of electric energy storage systems is a current challenge in prosumer grids. The appropriate coordination between energy storage, self-generation, the behavior of energy utilization, and network feedback will be a main task for "Integrated intelligence" – and thus a focus for the assessment of intelligent power distribution.

Presently, many self-generation plants in prosumer grids are designed in a way that the generated power can partially supply the base-load requirements, but the main portion of power demand can be covered more cost-effectively via the distribution grid than by using energy storage systems. Today, an unpredicted network feedback takes place in an uncoordinated way when the own energy demand is not sufficient at a given point of time. In the future, the planning of demand and the forecast of power provision must be coordinated more closely.

In response, distribution system operators install regulated distribution transformers and invest in additional measures such as parallel cables, other transformers, and reactive power compensation. This, however, affects the price for electricity and could make storage technologies relevant for many applications in the mid or long term. The aim of acquiring storage is to minimize the procurement of electrical energy from the grid or the use of externally procured energy sources (e.g., oil or gas) (Fig. 7 shows an example for an energy structure diagram). This will increasingly lead to users and planners having to coordinate regarding supply structures and power conversion technologies, so that the electrical planner is involved in a comprehensive total energy concept from an early stage. When connecting a so-called microgrid (which can be the subgrid of a smart grid or can be operated as an off-grid; see IEC/TS 62898-1), the electrical planner must, for example, take into consideration the monitoring of the power quality not only at the point of connection to the grid, but also for power conversion and storage options. Ultimately, the total energy concept will become more important for financial reasons, for reasons of efficiency, and from an ecological perspective (for example, heat or cold storage systems for excess electrical energy during self-generation). Digitalization can be a tremendous help for such coordination tasks.

Fig. 7: Structure of power provision as the basis for feedback and storage concepts (selection of paths; dependencies on the environment must be included in the concept, e.g., shading, supply, and disposal)



Emissions

- Dust
- Ash
- Waste heat
- CO_2

Power supplier Transport energy

- Power
- Heat

Land occupancy

- Damming
- Digging
- Installation surfaces
- Excavation material
- Pipes, lines, cables

Fossil energy carriers

- Gas
- Oil
- Coal

Conversion

- Combustion
- Fuel cell

Useful energy

- Power
- Heat

- Consumption
- Feedback

- Cold
- Force

Conversion

- PV
- Solar thermal energy
- Wind power
- Hydro power
- Geothermal energy
- Combustion
- Fuel cell

Renewable energy carriers

- Light
- Air
- Water
- Soil
- Biomass
- Biogas

Storage

- Battery
- Rock
- Liquid
- Rotational storage
- Pressure storage
- Tank
- Cavern
- Basement
- Barn
- Pile
- Heap

5. BIM as a coordination concept

The coordination and optimization between individual assembly sections is supported by BIM throughout the entire project lifecycle. However, the currently still prevalent understanding of BIM limits possible efficiency advantages. While an extensive recording of all influencing variables and their dynamics is required for smart grids and microgrids, the BIM concept today is still strongly limited to the architectural project coordination with geometric data and work flows [5]: "Implementing BIM often is understood as changing over to 3D- up to 5D-based modeling." 5D here stands for the consideration of the time sequence, use of resources, and costs. Data transfer and maintenance of project data throughout the entire lifecycle is also defined as the sixth dimension (6D planning). Finally, the BIM guideline for Germany [5] summarizes: "Not everything is possible yet, but a lot can already be done and the potential is continuously growing."

The same applies for software tools to support planning and operation with BIM. It does not make sense yet to bundle all into one single digital simulation. The definition of interfaces, data storage, and simulation routines of the manifold special programs (e.g., regarding flow behavior, material behavior, mechanics, electrical engineering) cannot be combined into one tool. One first important step would be to define the data that can and shall be recorded in BIM realistically. A realistic simulation does not have to take into account the effect of a butterfly flapping its wings on weather forecasts.

In the German guideline VDI/BS-MT 2552 Sheet 8.1 [6], the BIM methodology is defined as dynamic system which requires basic knowledge on the five basic BIM factors:

- People
- Processes
- Data
- Technology
- Framework conditions

as well as knowledge about the correlation between these factors and the environment.

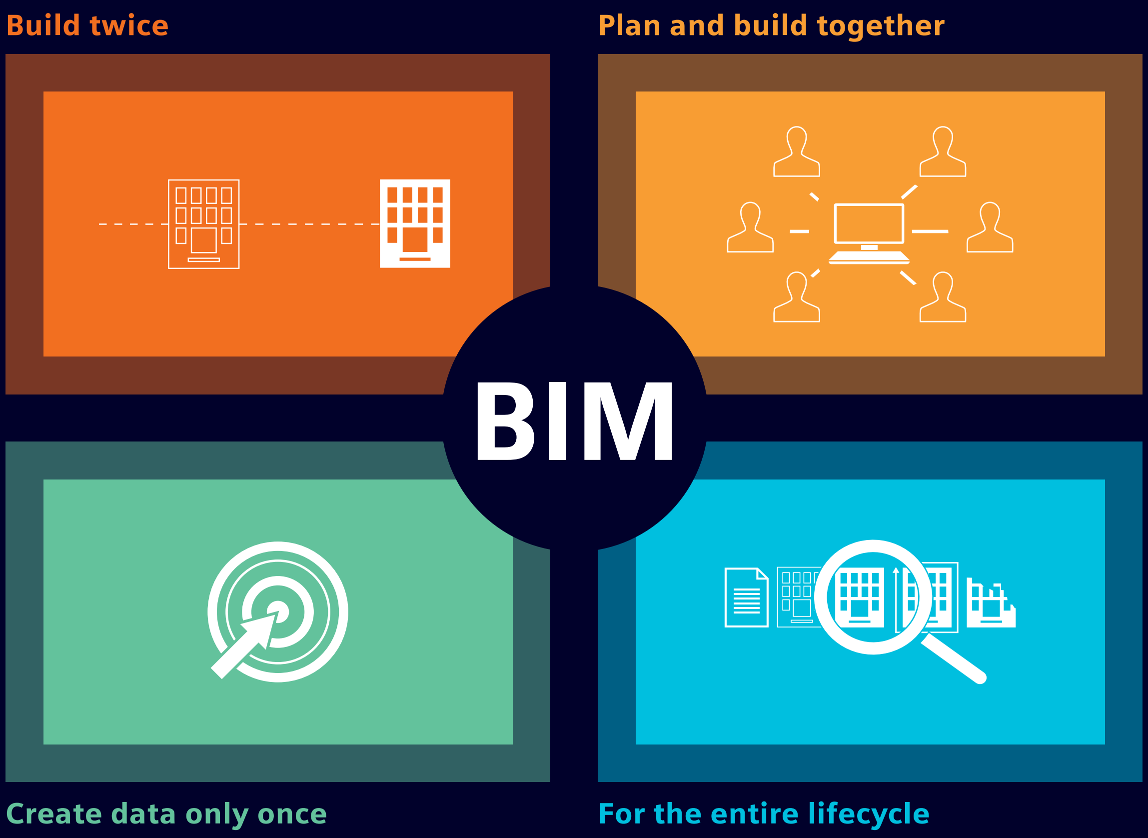


Fig. 8: Basic principles of BIM

An open BIM requires the use of internationally coordinated data formats and a corresponding information management.

The IFC data classes defined in ISO 16739 (Industry Foundation Classes) depict the building structures, characteristics, and optional geometries for modeling in the open XML format. In order to be able to process 5D model data, there have been corresponding additions to the data classes in the IFC4 standard [7] since 2014. Particular BIM software tools like REVIT are compatible with the existing standard software formats in the planning industry and allow for a quick data exchange with easily manageable file sizes at the same time. REVIT can also output data in IFC format.

Essentially, BIM is conceptually based on the principles depicted in Fig. 8. Constructing virtually for two or more times will most often be more efficient than holding on to one solution which is not adapted across the entire lifecycle.

The digital model helps to prevent errors, better coordinate cooperation, and detect defects in the possible construction process – before problems occur during practical implementation. Furthermore, the data can be used for other construction projects. Data is compiled in the model only once and is then available for all so that further new and different measurements can be avoided.

Planning with BIM offers time and cost advantages throughout the entire system lifecycle.
For this reason, the consideration of power transparency, performance check, efficiency optimization, energy management, servicing, maintenance, and disposal will be more important in the first planning phases in the future (Fig. 9). It will become increasingly important to involve the electrical planner and other technical planners at an early stage. Thanks to the modeling, complex coordination and delays in the processing of the project can be avoided so that the overall period of time up to the start of operation can be reduced by BIM. As a part of “Integrated intelligence”, BIM can promote the consideration of energy efficiency throughout the entire system lifecycle and thus improve the energetic estimation of the planned power distribution.

6. Conclusion

The changes in power distribution structures due to energy storage systems and network feedback as well as an enhanced consideration of operational efficiency during energy consumption will increasingly affect electrical planners, system operators, and maintenance companies.

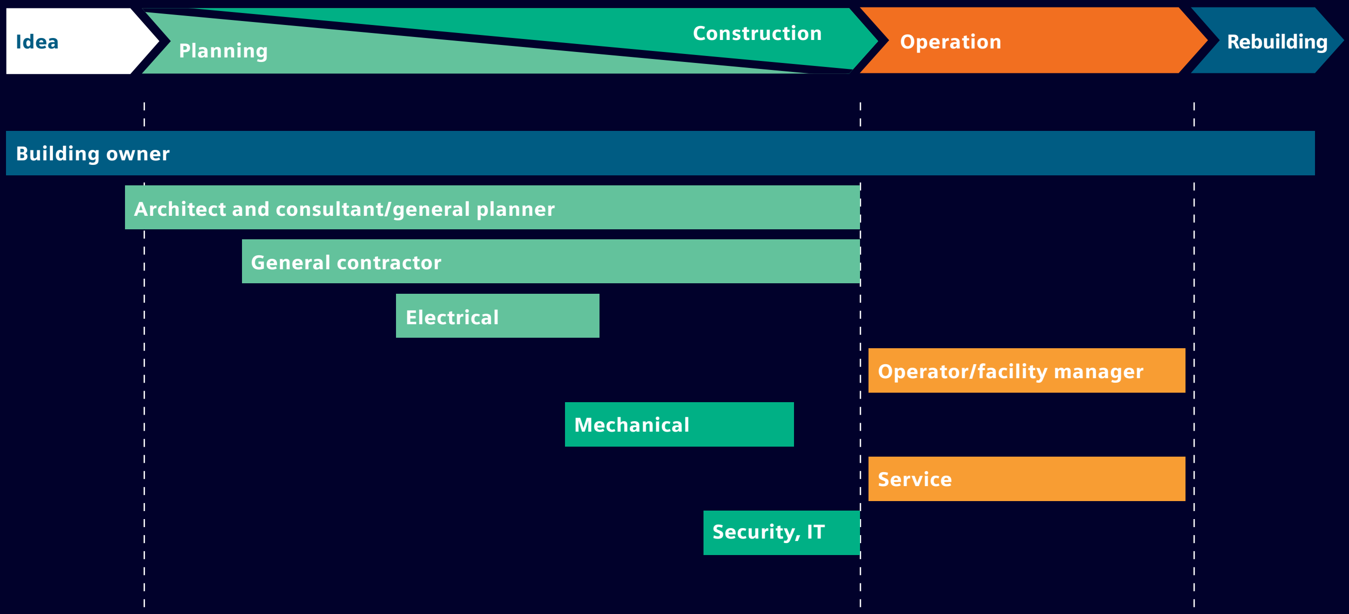
In order to implement the approach of an intelligent power distribution, the components of electric power distribution (switchgear/switchboard, transformers, distribution boards, converters and motor operating mechanisms, verification and control systems, ...) must be characterized and made assessable. A dynamic perspective will be required for this.

“It will hardly be possible to distinguish planning and operation phases”, says Jürgen Brandes in the “VDI nachrichten” [8] and adds: *“Data modeling will become dynamic: operation-dependent and environment-dependent energy consumption, load curves to describe time-dependent usage behavior, integration into intelligent management of microgrids and smart grid, as well as the development of operating costs including service, maintenance, and retrofit – i.e., “Integrated Engineering to Integrated Operations” [8].*

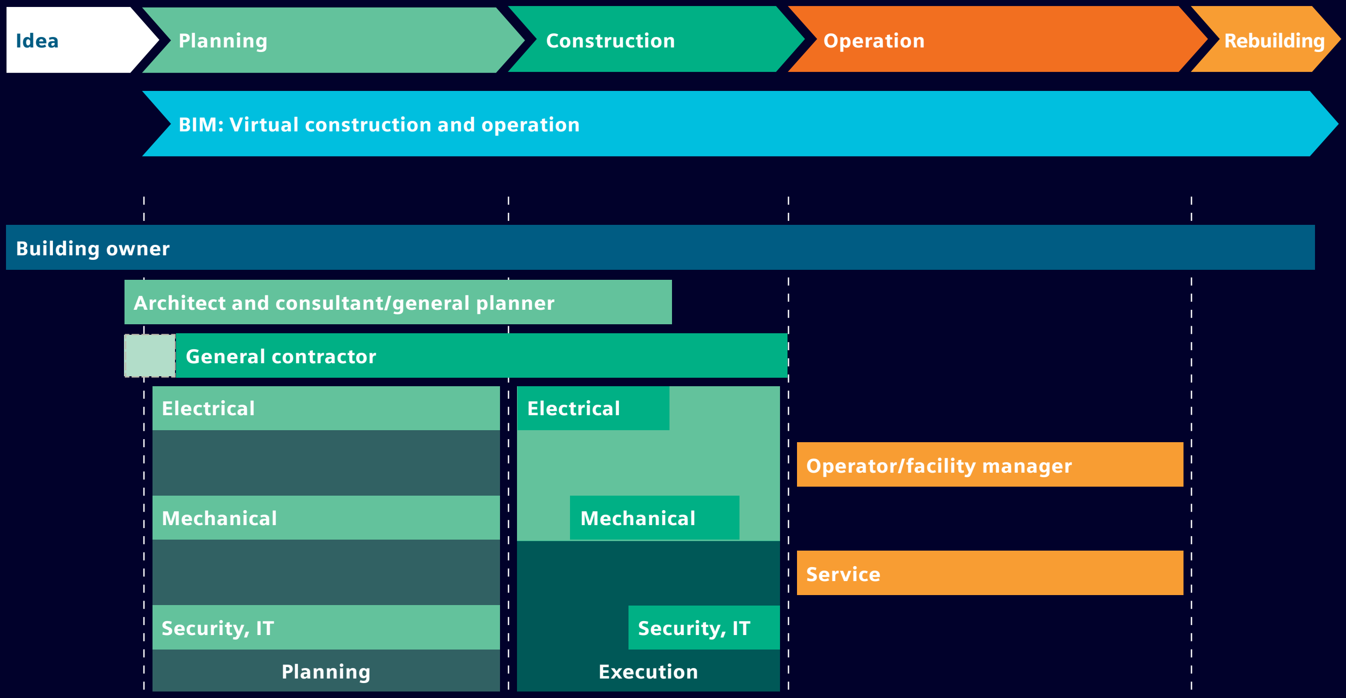
With the help of measuring technology, the PDCA cycles are updated based on realistic “life data”.
The integral implementation of operational plan changes, action plans, and requirements for rebuilding or maintenance demand a uniform system basis for the “Integrated intelligence” of electric power distribution with the corresponding networking and a partner who provides integrated support.

Fig. 9: Comparison of a schematic project timetable without (today) and with BIM (tomorrow)

Today



Tomorrow



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