

Distributed Power Generation: Requirements and Recommendations for an ICT Architecture

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Abstract: Contemporary power distribution faces various new challenges. Most of those challenges have a strong impact on the ICT-structure required and on system architecture. This contribution briefly introduces changes and requirements imposed, both for trading and distribution of power. On this basis, alternatives for ICT architectures are discussed, recommendations are made on implementation choices for a meaningful sustainable solution, and communication and security challenges are addressed.

Keywords: Information and Communication Technologies (ICT), distributed generation, energy management systems (EMS), IEC standards

1 Power Generation and Distribution

1.1 New kinds of energy

The previous kind of energy generation was based upon chemical or physical conversion of resources that will eventually expire like burning oil and coal or fission. There are two main disadvantages about this proceeding: firstly, the supply of the resources will cease so that these will get more expensive in the course of time until they are not available at all. Secondly, as it is only possible to generate energy efficiently in large-scale power plants, a complex infrastructure is needed to distribute the energy to the consumers. Besides, both the process of converting raw material as well as the final storage of the conversion products in the nuclear power case imply severe environmental problems.

In the future of energy markets, the distributed energy production through wind and hydroelectric power plants, solar cells, and combined

heat and power generation will play a major role. These energy production methods have certain characteristics. Some of these are sustainable (wind and hydroelectric power plants, solar cells), some are controllable (hydroelectric power plants, combined heat and power generation). All have in common that many small capacity power plants supply power to the grid. Also, demand side actors may be suppliers as well as consumers.

1.2 Challenges for ICT

This new situation and the emergence of energy markets [4] lead to two different challenges for ICT. On the one hand, heterogeneous power plants have to be controlled so that the supply matches the demand with regard to the stability of the energy grid. On the other hand, a platform for trading energy has to be established with requirements like high availability, currency, etc. In the following sections, various architectures and their characteristics will be discussed. Additionally, requirements of the communication infrastructure will be identified.

2 Trading

Considering electrical energy, one has to distinguish between two in principle different products: consumption power and balance power. Consumption power is considered to be the portion of the overall generated power intended for use by consumers. Its use is accounted on a quantitative basis, which means power customers, e.g. private households or industrial companies, have to pay a certain lump sum per obtained kWh including production and distribution costs [1].

Unlike consumption power, balance power is not used to operate electrical equipment, but to guarantee stability of distribution grids and to ensure a constant quality of the power provided. Disturbances in the equilibrium between power generation and consumption, e.g. due to inaccurate predictions, power plant blackouts, or power line failures, manifest themselves in deviations from the mandatory voltage frequency [11]. These deviations can be compensated by application of balance power. To ensure undisturbed operation of the power grid, transmission providers have to hold adequate generation capacities. Contrary to the accounting mechanisms of consumption power, the possibility to supply balance power is primarily reimbursed [14].

In order to establish an efficient competitive market it is appropriate that the operation of power grids and other business activities are separated.

For example, Companies and utilities in the German liberalized energy market act in different roles (see fig.1). With the exception of grid providers, each actor takes one or many of these roles. They have to offer the power grid to all other market participants as an independent platform. Grid providers are prohibited of otherwise engaging themselves in the market [6].

Consumption and balance power are provided by power plant operators. Suppliers usually buy from energy exchanges or retailers and sell consumption power to consumers. Apart from costs of purchasing the consumption power, the supplier pays a grid access fee for the connection of its customers. The consumer is charged usually for both by the supplier.

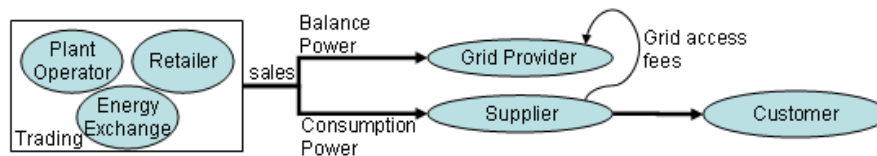


Fig. 1. Roles in the energy market

For receiving grid access fees, network carriers have to guarantee grid stability [5]. They obtain balancing power either directly from power station operators or from energy exchanges.

On the balancing power market, only few power station operators compete with each other. Strong restrictions such as high reliability and high minimum offer quantities prevent market access for many small companies [16]. Balancing power is location-dependent. In contrast to consumption power, balancing power must be fed into certain sections of the grid to ensure stability.

For proper competition it is necessary to increase the number of participants. An approach to lower the market entry barriers would be to establish co-operations between several smaller power plant operators [14]. However, the necessary organizational and technical solutions are currently not available. ICT systems have to meet the technical and legal conditions to allow common acting of several market participants.

A similar situation exists in the market for consumption power. Private households, farmers and small industries become power producers as a result of the distributed nature of the production. The quantity of power exceeding the internal demand can be marketed, provided suitable organizational and technical solutions are established. For this target group, energy

marketing is not the central activity. Therefore, suitable solutions should allow automatical trading to a large extent.

3 Power grids

In addition to trading requirements, power grids are affected by ongoing structural changes in power supplies. Grids have to deal with input from many distributed, small, and to a large extent heavily fluctuating producers. This makes scheduling, controlling and monitoring of every system from a single centralized site unattractive. Based on an anticipated, yet likely-seeming high penetration of power supplies with CHP plants, scheduling thousands of small producers from a single site would take too much time and calculating capacity, thus being inefficient. Therefore, it is reasonable to iteratively establish localized and typed clusters of plants to manage these.

Considering power grids, another requirement is guaranteed fail-safety. In order to achieve this, a grid management has to be fail-safe as well, either by means of backup plans or by avoiding a single-point-of-failure by distributing grid management functionalities. From the grid's point of view, an implementation of scheduling, controlling, and monitoring of power generators has to consider specific communication functionalities of different producers. On the one hand, there exist plants not accessible via standardized interfaces, and on the other hand the plant's autonomy poses strong restrictions on scheduling and controlling.

The power grid topologies present general conditions for grid management. Unlike traditional power plants, distributed plants feed in power at different voltage levels, including low-, medium-, and high-voltage [1]. Thus, with an increasing number of distributed power producers, the likewise growing risk [10] of current backflows damaging parts of the power infrastructure, such as voltage transformation substations or protective gear by overheating must be dealt with by means of scheduling, controlling and monitoring of power equipment at all voltage levels.

4 System architectures

The requirements mentioned above for both trading and power grid can be met using different system architectures. Figure 2 summarizes three possible architectures "centralized", "peer-to-peer" (P2P) and "super-peer"

[2]. In the following paragraphs, the architectures with regard to power distribution and trading, will be elaborated.

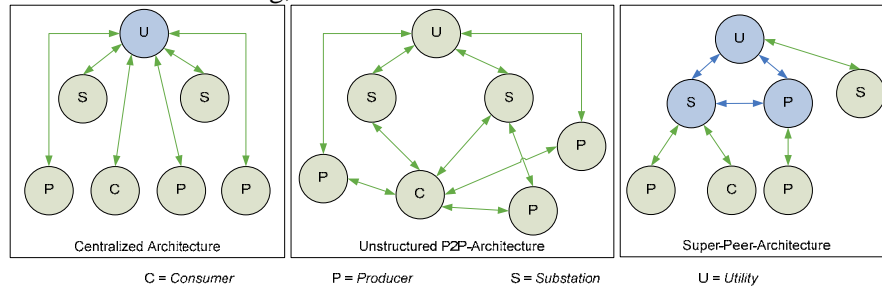


Fig. 2. System architectures

4.1 System architectures for trading

To fulfill the requirements mentioned in section 2 for both consumption power and balance power, a central trading approach or a P2P approach can be utilized.

Using a central trading platform, all information accumulates in one point for the trader in charge. A central platform provides a convenient *legal security* for all partners, as there is one responsible institution that controls and maintains the platform. Legal security can be important, when high damages – because of platform unavailability or contract violation – have to be considered. The responsible not only have to guarantee the availability of the platform, they also control the access to the platform itself, usually by means of high penalties for market entry. From the economical point of view, a better overview of the markets and hence more transparency are obtained. High costs for running systems reliably with large amounts of data can occur. Such costs are often channeled to the users in terms of high fees.

Contrary to this, there is the P2P approach, which can be fully automated (limited by market rules) for everybody to be used for trading. Also the overall amount of communication is higher than in a centralized solution, every market participant has full control over their provided data sets, and can therefore hide their internal information, with respect to legal requirements. Furthermore, real-time pricing becomes interesting because even single devices can act on the market. Low investing costs reduce the barriers to enter the markets. High availability of the overall platform services can be expected due to the sheer number of participants.

But there are also disadvantages. Every participant has to ensure all legal issues related to trading. Furthermore, due to the P2P approach, the

market does not clear and no price is achieved, leading to disadvantages for some users.

Taking the requirements from section 2 and the advantages and disadvantages of both solutions into account, it appears to be useful to implement a central market place for balance power and use the P2P approach for consumption power. A trading platform should therefore support both system architectures because both types of power are utilized by large generating companies.

4.2 System architecture for the power grid

Similar to the trading platform, the power grid management can be implemented using different system architectures. In order to identify an optimal solution, one has to take requirements from section 3 such as scalability, reliability and autonomy into account.

Grid management based on a central platform makes for easy maintainability and access control for the overall system. Furthermore, a central dispatcher can supervise the global grid security and safety. Disadvantages, such as single-point-of-failures or bottlenecks of applications, can only be avoided partly by using caching-mechanisms or backup-concepts [3]. Neglected problems so far are overall system scalability and autonomy of distributed generation plants.

Using P2P solutions, the autonomy of each individual plant can be kept. Crashes of single systems (peers) can be compensated by others and do not disturb the overall system stability. One particular disadvantage of this solution is the increased amount of communication that must be handled and kept in narrow bounds by utilizing appropriate communication strategies. One further problem is a missing global entity to maintain power grid stability and to supervise decision-making processes. One solution would be a super-peer architecture where super-peers coordinate and control lesser peers. For this case, local autonomy is suppressed by global communication signals. Individual plants do not communicate directly among each other. Instead, super-peers submit orders to their subordinate peers. Crashes of super-peers can be compensated by other super-peers.

Super-peer architectures belong to the set of hierarchical architectures. Clusters of producers are organized in a hierarchical order. The communication is routed over different hierarchical levels. Within strict hierarchical architectures, each node puts its sub-nodes at risk because a failure cannot be compensated as in super-peer architectures. For the power grid and its requirements, super-peer architectures pose the best solution. So far, the

problem of standardized interfaces has been omitted and will be discussed in the following sections.

4.3 Standards for communication

As mentioned before, communication with the distributed units must be laid out for different architecture scenarios. From a comparison of these scenarios, it is clear that though the mapping of the communication peers varies from architecture to architecture, the basic nature of the data and the necessity of data transmission are invariant among the architecture scenarios. In order to guarantee flexible and future-proof system architectures, both standards for communication and standardized data modeling are indispensable.

Currently, the norm families IEC 61968-13 and IEC 61970-XXX define the Common Information Model (CIM) [7] for the semantic description of objects and attributes for utilities. This model will be discussed in depth within the next section. Additionally, IEC 61850 defines the communication standard used for medium-voltage level substations, and the norm family IEC 60870 defines communication protocols between control center and substation. Between these norms remains an urgent need for further harmonization; the integration of the distributed units in the low-voltage grid is missing. There is a pressing need for a both vertically and horizontally integrated system with consistent data models throughout the various voltage levels in the power grid. This would serve efficiency and trading. For reasons of data privacy and efficiency, one should consider data aggregation at super-peer level in super-peer architectures: super-peers need only know the overall power demand or supply needs existing in the hierarchy below.

4.4 Domain ontologies and data models

When combining several components from different vendors in order to build a distributed system, different semantics for data exchange arise. There is a need for a common vocabulary or language [15]. One particular domain ontology for the electric utility is the Common Information Model CIM.

The CIM was originally defined the Electric Power Research Institute EPRI, a utility funded governmental institute in 1991. The CIM defines a vocabulary of relations between objects within the electric utility. Objects from different functional blocks are defined. It consists of mainly twelve packages that have a variety from contracts and legal documents to wires

and transformers. Nearly all important objects and their corresponding attributes can be used to model the data exchanged between components or systems. In order to exchange CIM-compliant data, some serializations have been defined. Serializations exist mainly as XML-conform structures [9]; the XML is used in different fashions.

XML is mainly used to define payloads utilized by EAI systems. In order to provide richer semantics for applications like net state estimation or grid model exchange [8], RDF and OWL semantics can be used on top of the ordinary XML serializations. The OWL models provide a good possibility to use ontologies in order to achieve semantic interoperability and harmonization with other standards like IEC 61850. Therefore, the CIM can be seen as the ideal data model for the semantic electric utility.

5 Security

In distributed system architectures, apart from a standardized communication for the exchange of operational and trading data, one requires security of communication for reasons of data privacy, authenticity, and for protection against sabotage [12, 13]. Security flaws are introduced accidentally due to the unavoidable interfaces between private and public (i.e. the Internet) network infrastructures. Thus, there is a necessity for firewalls and encryption both symmetrical and asymmetrical to guarantee tamper-proof operation of the system.

The problem with closed source security implementations is the danger of remaining security holes, often leading effectively to a “security-by-obscurity” situation, instead of real security. With open source implementations one has the advantage of auditing by a large community. Contrary, when security flaws are revealed, the infrastructure is temporarily at risk.

6 Conclusion

The need for different ICT-architectures used for trading and power grid management has been motivated. Taking the requirements mentioned into account, suitable architectures for trading and distribution were proposed. Additionally, one should not underestimate security challenges and implement a standardized and vertically integrated communications and systems infrastructure.

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