Siemens White Paper

Transactive Energy System

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1. Introduction

The power industry is undergoing a transition. Power grids are evolving to become smart grids. This trend is being accelerated in several regions by the further development of renewable power sources, which are increasingly penetrating the grid network in the form of distributed energy resources (DER). A growing number of these DER assets are highly intermittent energy resources. Wind turbines and solar panels in particular pose a challenge when it comes to predicting and controlling supplies[1]. Due to the merit order effect [2], this intermittent renewable power generation could decrease the market price [3, 4] of energy. However, the growing importance of volatile renewable sources in the energy mix will lead to critical situations within the power grid [5, 6]. Power markets have to be ready for smart grids so that they are capable of dealing with the grid-wide integration of DER assets while at the same time efficiently controlling decentralized power generation units as they transition to autonomous operating modes (see Figure 1). In order to do this, existing power grids will have to be updated – creating a new smart grid paradigm [7, 8].

Figure 1: Evolution of energy systems

This new smart grid paradigm with distributed energy systems will mark the emergence of intelligent power supply networks that allow energy resources to be used efficiently and reliably. It will also herald a new market structure. On the one hand, this paradigm shift requires a more active market-grid coupling [8] that allows seamless interactions and transactions between the market and the grid at different levels. On the other hand, it offers multiple opportunities for – and in some cases demands – rapid innovation and new customer-centric business models. Technical and business parameters will shift, resulting in the following major changes to the power and utility industry:

- **Redefinition of the business model:**
  From conventional top-down value creation to a customer-centric strategy for local value creation;
- **Value shift:**
  From value measured in "copper" to value created by software and rapid innovation;
- **Assets focus:**
  From utility-owned, bulk generation assets to more and more customer-owned DER assets;
- **Solution shift:**
  From highly customized solutions to more standardized, open, flexible and off-the-shelf solutions;
- **Operational changes:**
  From manual operation to automated and autonomous operation;
- **Management redistribution:**
  From central management of supply-side and unidirectional power flows to smart management of DERs and bidirectional power flows.

In this white paper, we focus on the Transactive Energy (TE) concept proposed by the U.S. Department of Energy's (DOE) Gridwise Architecture Council in 2015 [9] and build on this to address the challenges and trends mentioned above. TE is broadly defined as "a system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter." The TE approach promotes more interactions and transactions at all levels of generation and consumption, and offers a way for producers and consumers to more closely match and balance energy supply and energy demand at certain points in place and time. As such, this market-driven approach is better suited to a network with a high share of DERs than a traditional hierarchical grid. It provides a transactive coupling between the physical grid and the economic market, paving the way for enhanced interoperability. This kind of TE concept has been used for several decades in transmission networks with wholesale market coupling. Now, however, we are focusing on the distribution network.

In this white paper, we would like to reach beyond a market or trade perspective to present – in detail – a concept for what we would call a Transactive Energy system, and explain how a company such as Siemens is delivering the building blocks to realize this vision.

As we know, digitalization is a key enabler for the growing pace of electrification and automation. Reflecting widespread digitalization in the power and utility industry, Siemens invests not only in hardware components to automate, secure and control the grid, but also delivers comprehensive, innovative and open software solutions to speed up the transition to greener sources of energy ("Energiewende"). The Transactive Energy blueprint that we outline in the following will thus also be driven by software solutions. We will look at software solutions that focus on the distribution grid and enable direct transactions between various existing grid players such as TSOs, wholesale market operators, GenCos, traders, DSOs, retailers and consumers, as well as new entrants like local market operators, DER providers, DER aggregators, IPPs and prosumers.

The Transactive Energy system described in this white paper emphasizes the connection between the grid and the market, so transactions are integrated into grid control and the grid status impacts transaction pricing. It thus promises efficiency and reliability gains as we evolve towards a more intelligent and interactive grid.

The goal of this white paper is to present a possible path towards the next-generation distributed network that is easy, cost-effective and efficient thanks to greater integration of DERs. It starts by explaining our Transactive Energy vision in detail, before going on to frame an implementation proposal based on the hardware and software components offered by Siemens. We conclude with the Siemens value proposition in this area.

2. Our vision for a Transactive Energy system

In this paper, we illustrate the major building blocks of a Transactive Energy system as shown in Figure 2. These blocks primarily cover four functional components known as market trading, financial transactions, distributed resource management and grid management systems.

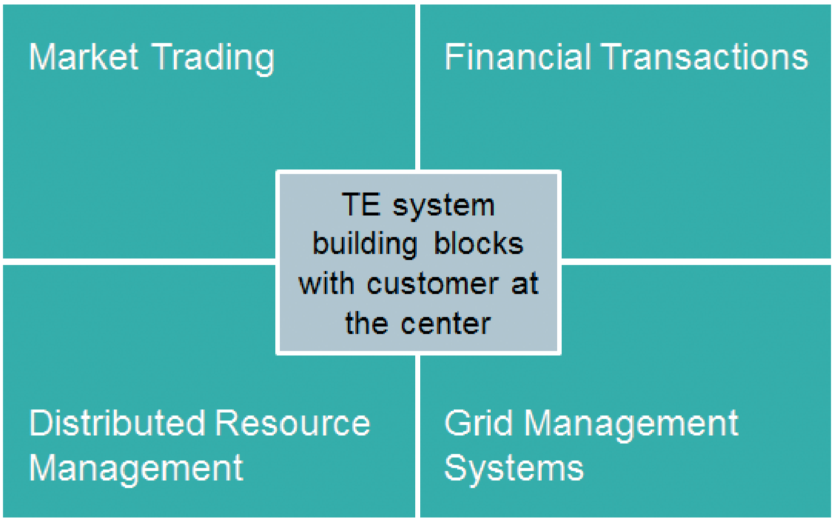

Figure 2: Transactional Grid Components

This white paper presents a detailed vision for a possible Transactive Energy system. On the one hand, this system is structured in line with the conventional definition of Transactive Energy and focuses on transactions between various market players at different grid levels, right down to the prosumer. On the other hand, it also acts as an ecosystem between the grid and the market, enabling stakeholders to proactively interact through diverse products and services. Figure 3 provides an overview of this potential Transactive Energy architecture. The ecosystem brings together different stakeholders (shown in grey rectangles) and a local trading platform with trading-related products and services (shown in teal rectangles), as well as market and grid operation modules with operation-related products and services (show in turquoise rectangles). The figure also includes a cloud services module, comprising calculation and analytic services for the grid control module and the local optimization module.

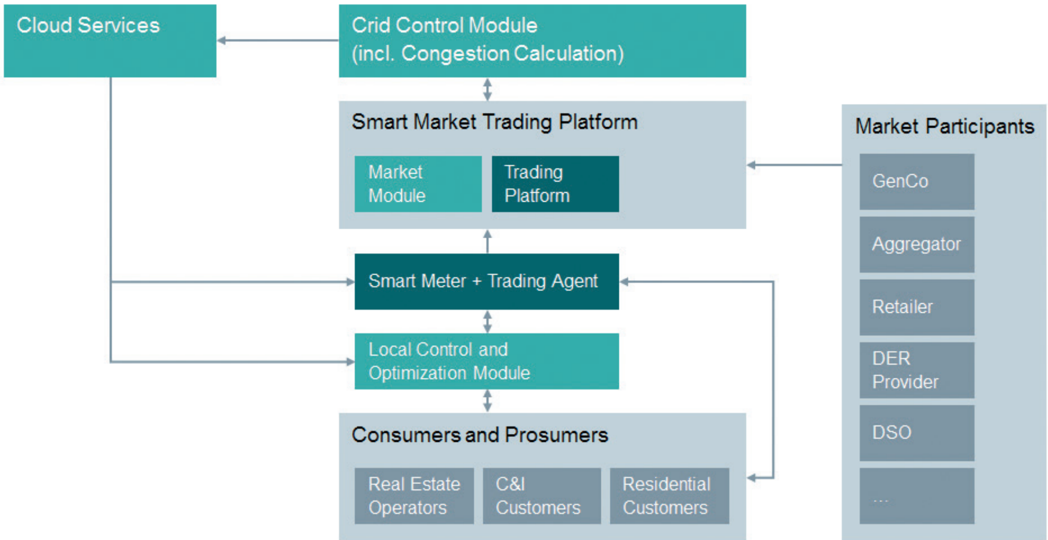

Figure 3: Architecture Overview of the Transactive Energy Ecosystem

2.1 Architecture & Players

In the architecture shown above, we aim to create more interactions, in particular transactions among all stakeholders. As mentioned in the introduction, future smart grids will be digitalized to create highly distributed energy systems that enable new market players to realize local transactions.

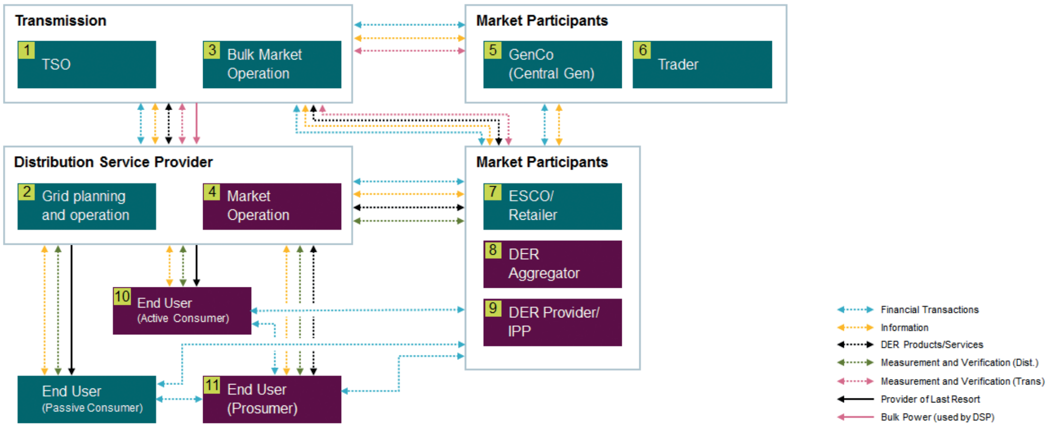

Figure 4: Overview of Existing Market Players and New Entrants

Figure 4 shows an overview of market players in the Transactive Energy system, including existing ones and new entrants. As we move away from the traditional power system, the role of these market players will change. In the following, we define the roles and requirements of individual market players.

2.1.1 End User

End users are changing and maturing. They are evolving from consumers to energy producers and prosumers. Prosumers and consumers will have to manage multiple energy devices and assets such as HVACs, heat pumps, solar panels, electric cars and batteries. To deal with these assets as efficiently as possible, prosumers and consumers will need a monitoring and control system such as a home energy management system (HEMS). These kinds of systems will also have to enable prosumers and consumers to trade automatically at local level. Local energy trading is one of the main features of Transactive Energy. This means that end users, grid operators and market operators will need to interact frequently and seamlessly. As the above architecture shows (see Figure 3), all interactions will be conducted via a local trading platform that functions as a local market in the distribution grid. In order to place offers and orders at the local market, each end user will have to have a trading agent (software agent) that works with their smart metering infrastructure. End users can also be small- to mid-sized commercial or industrial customers who decide in some regions of the world to become prosumers based on energy prices, grid stability or as part of a microgrid strategy. These commercial and industrial (C&I) producers play a critical role as they bring larger production facilities into the grid and also provide battery capacity and other means for grid optimization. They can be leveraged to keep the grid stable and may require a different management approach than that suited to residential prosumers.

2.1.2 Retailer

Traditionally, retailers have sourced power from bulk energy markets (wholesale markets) or generated their own power, selling it to consumers for a profit. With the introduction of a local market at distribution level, retailers will need to adapt their business models. Firstly, the local market requires an approach that interacts with retailers. Since prosumers and consumers now have the opportunity to buy or sell energy on a peer-to-peer basis at local level, retailers will only supply energy in the event of a shortfall or purchase excess energy in the event of a surplus (residual energy). In this case, the local market assumes a central role by matching orders and offers between prosumers and consumers with a contractual relationship with a given retailer. Instead of interacting with each end user individually, retailers can only supply or purchase the aggregated residual energy. The costs or revenues are then distributed to all end users automatically. Secondly, with their traditional business model eroding, retailers can look into new business models around energy services. This may include providing implementation, operation and service offerings for renewable generation to prosumers. Thirdly, retailers have to take into account the varying costs of supplying energy to end users as this is subject to varying grid fees that are linked to the time of delivery and the delivery location in the local market. Once they are operating at this level, retailers might take an even more active market role by acting as aggregators, offering the market battery storage or other forms of load and consumption control. Retailers can also offer risk mitigation services such as fixed costs for electric services and by doing so, shield consumer from price volatility.

2.1.3 DER Provider and Aggregator

Traditionally, DER providers own and offer all assets in distributed energy resources, while aggregators consolidate distributed energy resources (generation, storage and flexible loads) and integrate them into the grid for bulk energy markets. This business model can be broken down into two main parts. The first is technical integration, which includes communication links to the DER, and monitoring and controlling the DER. The second part focused on trading the DER. Instead of being integrated at bulk-market level, the DER will be integrated into the distribution grid at local-market level. This raises the question as to what requirements aggregators have to fulfill in order to enable the successful design and implementation of a local market concept.
In the Transactive Energy system, DER providers can either trade their own resources individually on the local market, or distribute them through an aggregator. Aggregators will aggregate surplus generation from prosumers with much smaller power ratings and flexible load options from consumers at nearly all grid levels. Aggregators will then use information and communication technologies (ICT) to more effectively steer energy consumption according to market and grid needs and the availability of renewable energy. Furthermore, aggregators should be able to sell aggregated services on both the local market and the wholesale market, as well as directly to grid operators (both TSO and DSO) and retailers. Similar to retailers, aggregators also have to take into account the varying costs of purchasing energy from the DER as this is also subject to varying grid fees linked to the time of supply and the supply location.

2.1.4 Grid Operators

Transactive energy is an emerging, market-based concept aimed at balancing the grid and will therefore enhance interactions between grid operators and market operators. At transmission level, the role of transmission system operators (TSOs) will change slightly. Currently, they are mainly responsible for traded surplus energy and demand at transmission level or between neighboring distribution cells. To ensure grid operations are optimized globally, the TSO needs access to the wholesale market and the local markets. At distribution level, the role of distribution system operators (DSOs) will change dramatically. On the one hand, the DSO needs to provide real-time information on the grid status and congestion forecast to the relevant market operator. On the other hand, the DSO needs to impose utilization-based grid fees on the trading platform for the local market and also support energy exchanges between different local markets. This means that in its new role, the DSO will have to focus on optimizing local grid operations while assuming responsibility for balancing supply and demand variations at distribution level and also connecting the wholesale market with local markets. We believe that the TSO will require more transparent access to the DSO's local market as a result of this new system.

The DER production added to interconnection points in the distribution grid can reach a significant volume and therefore, affect the TSO operations and markets.

2.1.5 GenCo's

A GenCo's traditional "core business" includes unregulated energy trading and the provision of support services such as energy efficiency and demand response programs. In the new system, GenCos will have to share these services with other players, for example other DER providers. As such, the role of the GenCo is changing as Transactive Energy evolves. This change is needed to support the evolution of a flexible energy coordination ecosystem [9]. In order to achieve this coordination, the GenCo and the DER provider's value streams have to be clearly understood and ownership boundaries must be respected [9]. New business models are needed to consolidate the coexistence of the traditional GenCo and the DER provider. Ensuring the reserve power for rapid ramp-ups if wind or solar supplies are not available (duck curve) will be a critical factor here and one that will be challenging to make profitable in difficult economic conditions.

2.1.6 Market Operators

With the introduction of a local market at feeder, substation or distribution level, a three-layer market structure needs to be established that incorporates the new roles of wholesale market operators and the local market operators. Details of the requirements and responsibilities of market operators are provided in the next section.

2.2 The Market System

The concept of Transactive Energy focuses on a market-based approach aimed at monetizing the value of energy products directly at distribution level. The introduction of a local market as the trading platform in the distribution grid will change the overall market structure, moving it away from the traditional centralized system at transmission level to a hierarchical and decentralized system across different grid levels. Figure 5 shows the three-layer market structure of this proposed Transactive Energy system, comprising the existing wholesale market at transmission level and a number of local markets at distribution level. At distribution level, local markets are compartmentalized and have different trading responsibilities. In our vision, the overall structure remains hierarchical. Local markets at feeder or substation level are responsible for trading local energy sources for neighboring loads, while a higher-level local market across the distribution grid is responsible for trading excess generation or load that cannot be managed on lower-level local markets. Based on this vision, there would be three different scenarios for lower-level local markets (i.e. feeder, substation and microgrid), which vary in terms of the physical location of the DERs. Energy should be traded primarily within each local market. Transactions can also be carried out between two local markets and between a local market and the wholesale market. The wholesale market operator is responsible for the matchmaking and clearing at transmission level. The new local market operator at distribution-grid level is responsible for matchmaking, clearing and settlement on the local trading platform. They also function as a distribution service provider together with the DSO.

In this white paper, however, we aim to focus on local transactions and interactions at distribution level. Realizing this kind of local market requires either a centralized platform without interdependency on other local markets or a decentralized platform with interdependency on other local markets. As illustrated in the previous section, the typical market participants in this market system include retailers, aggregators, DER providers, grid operators (in particular DSOs) and GenCos.

The intraday and balancing markets (see Figure 6) can enable grid relief (power balance) to a certain extent to prevent the physical grid from collapsing (and causing a blackout, for example). Due to the uncertainty of demand (i.e. load volatility) and the uncertainty of forecasts for renewable feed-ins, these short-term power markets need to be more aware of real-time information about the physical grid's generation capacity and transmission constraints (incl. congestion calculation). They also have to be more flexible in order to respond effectively to increased grid uncertainties [8, 10]. As such, a trading platform implemented at local level is the key component of the market system in our Transactive Energy system.

This platform must include coupling between the grid and the market, thus enabling dynamic pricing (e.g. LMP, grid fees) that reflects the real-time grid status and ensures transactions are made in compliance with grid constraints and that the grid is regulated, including congestion management.

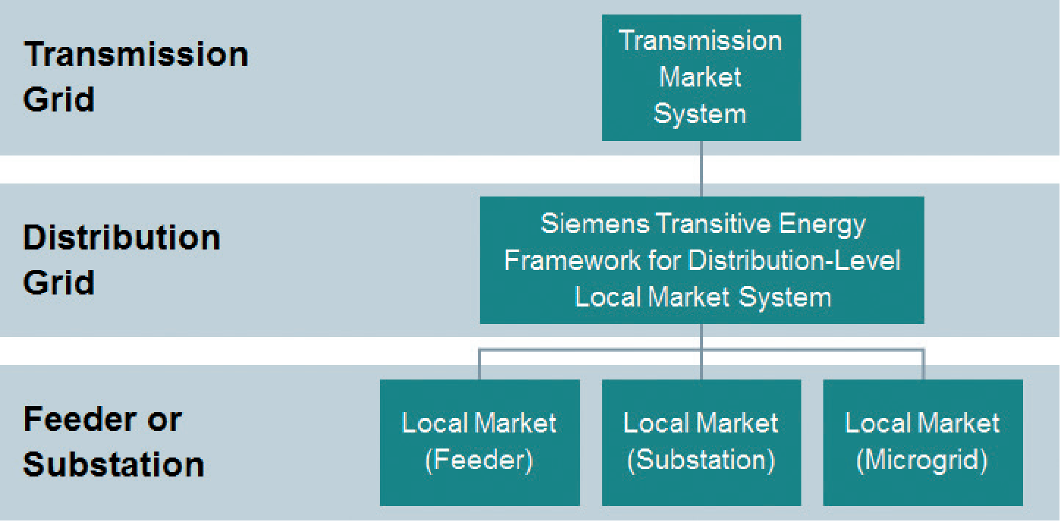

Figure 5: Three-layer, Hierarchical Market Structure

Two approaches are necessary for realizing the market system proposed above:

1. **Market coupling** [11]:
   This creates the technical conditions for optimizing the utilization of cross-border transmission capacities while complying with the physical constraints of the corresponding grids or sub-grids.

2. **Real-time market** [12]:
   This refers to a tool that allows market operators to balance power and/or congestion in transmission/distribution grids at any time in real time.

We propose this market system as a balancing option that can be linked with the intraday or balancing market. Currently in the global power market, power can be balanced through a regulating power market component that operates within the timeframe of one hour before the time of power delivery [13]. Alternatively, a power imbalance can be regulated either through intraday trading (15-minute or 30-minute contracts) before power is delivered, or by balancing reserves in different control stages after power is delivered. As such, we believe that there is a lack of real-time capability in existing power balancing options. Our proposed market system is a regulating power market option that fills the gap in the balancing timeline. Figure 6 shows how our proposed Transactive Energy system with coupled real-time markets can be integrated in the timeline among existing power markets. Each individual real-time market can be considered as an extension of the intraday market in terms of its ability to balance power with a faster response time. As the figure shows, the timescale for the real-time market is just a matter of minutes before the time of power delivery. Moreover, for a highly distributed energy system, the market coupling approach can enable a collaborative balancing service. For a detailed market model for trading, we refer to a simplified sharing economy platform developed by Gartner Industry Vision research [14]. This platform which enables individual transactions between parties and delivery cost exchanges based on congestion management.

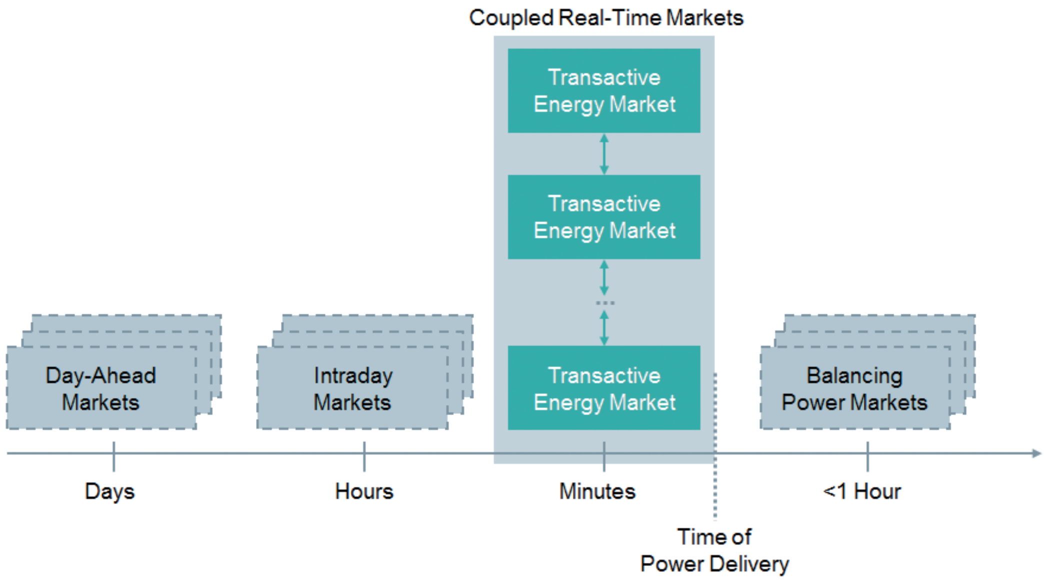

Figure 6: Integration of Transactive Energy markets as a balancing option

2.3 Regulatory and policy considerations

Building a Transactive Energy system involves contributions from market economists, power engineering specialists and policy makers. Thus, we would like to summarize regulatory and policy aspects that have to be taken into consideration when implementing the Transactive Energy system.

As stated in the DOE's framework paper for the Transactive Energy concept [9], regulatory policy is just as important as market design. Ideally, policy makers and regulators need access to case studies, best practices and model regulations that provide guidance on drawing up policies for Transactive Energy. The following are recommendations related to specific topics and challenges that could be used to guide policy makers:

- **Optimizing rate design:**
  Ideally, TE should allow market participants to respond to price signals as this would ensure that the power system is used more efficiently while maintaining reliability. This is best accomplished when prices from liquid, transparent wholesale markets are transmitted to end users or, in the case of automation, end devices. Rate design should factor in wholesale prices, while ensuring that a portion of the rate structure recovers the fixed costs incurred by providing and operating the transmission and distribution grids.
- **Addressing interoperability challenges:**
  A TE concept must enable different market participants to interact across the entire power grid to facilitate settlement, payment processing, and transparent data access.
- **Maintaining grid reliability:**
  A reliable, economically efficient power grid requires an open and transparent energy market. In addition to incentive and tariff options, further mechanisms have to be drawn up, for example, to encourage prosumers to include their assets in reliability services or to enable traditional GenCos to partner with other companies and offer new products and services.
- **Supporting and controlling the large-scale influx of DERs:**
  Regulatory policies for reviewing and approving investments in grid modernization need to be considered with regard to long-term customer benefits. This includes equitable incentive options to drive investment in the infrastructure necessary to accommodate the increased proliferation of DERs as well as new economic systems that ensure long-term financial stability for both grid and market operators.

- **Facilitating local market participation:**
  RRegulatory policy is required to establish systems for local market operators to enable the transactions of the local market participants, and allow profitable local market coordination services for customer participation. Policy is also needed to ensure the network cost recovery for DSOs regarding transactive designs in distribution grids that now involve bidirectional power flows.
- **Enabling efficient, effective implementation:**
  Technical and payment standards are crucial elements for ensuring a market can succeed. These standards include the communication of data and control signals, data formats and customer authorization procedures for data sharing and market participation.

2.4 Use Cases

Energy trading and energy balancing are currently performed at transmission level. This means that there has not been any direct trading interaction between market players in the distribution grid to date. Unlike in the transmission grid, where the market pricing mechanism based on Locational Marginal Pricing (LMP) already factors in grid status, prices for grid usage, generation feed-in and consumption are the same across the distribution grid. As described above, the concept of Transactive Energy enables direct transactive interaction between prosumers and consumers in the distribution grid. At the same time, it also factors the grid status into the pricing algorithm in order to determine locational values of energy delivery at distribution level. In his dissertation, Ding [8] theoretically proved and tested that increased communication and interaction between the market and the grid at distribution level offers huge potential for relieving the grid and stabilizing market prices. As a result, we would like to introduce two use cases to show the benefits of Transactive Energy.

2.4.1 Use Case 1: P2P energy trading in the local market at feeder or substation level

In this subsection, we illustrate first the use case of a peer-to-peer (P2P) energy trading on the lower-level local market platform at feeder or substation level. Here, the P2P concept refers to equal trading roles. We assume that this is a highly distributed energy system with networked smart meters and that the grid exhibits high transmission costs and a sparse transmission grid infrastructure. Furthermore, prosumers and consumers within the same feeder or substation prefer to sell or buy energy on the corresponding local market, enabled by smart meters (with trading agents) following smart contracts, as shown in Figure 7. Local transactions between prosumers and consumers can be conducted in a predefined time period (e.g. 15 minutes) followed by instant payment. As a result, surplus generation will be consumed locally by the nearest load. This provides transparency about energy flows, makes use of the grid infrastructure at distribution level and helps protect the transmission grid from overloads to a certain extent. In compliance with grid constraints and grid control, the DSO can then carry out dynamic grid pricing while factoring in the grid status of the respective feeder or substation (including congestion). The P2P concept here exhibits equal trading possibilities to all market participants at feeder or substation level. The resulting P2P information and energy flows will be operated in parallel either via a centralized trading platform or a decentralized one at the corresponding grid level.

There are a number of ways in which different stakeholders (market players) can benefit from Transactive Energy trading on the lower-level local market at feeder or substation level.

- Reduced costs for grid operators and retailers through improved forecast accuracy
- Reduced costs for the DSO through reduced power imbalances
- Reduced costs for grid expansions
- New business models for retailers and aggregators through the aggregation of small DERs
- Reduced administration costs (clearing, billing, etc.) for grid operators, retailers and prosumers
- Increased earnings for in-feed and reduced energy costs for producers
- Reduced energy costs for producers and consumers as well as earnings for the provision of flexibility

- Earnings for producers and consumers through the provision of balancing and ancillary services
- New business models with value-added services for the platform operator, e.g. P2P power exchange as sharing economy platform for the energy market

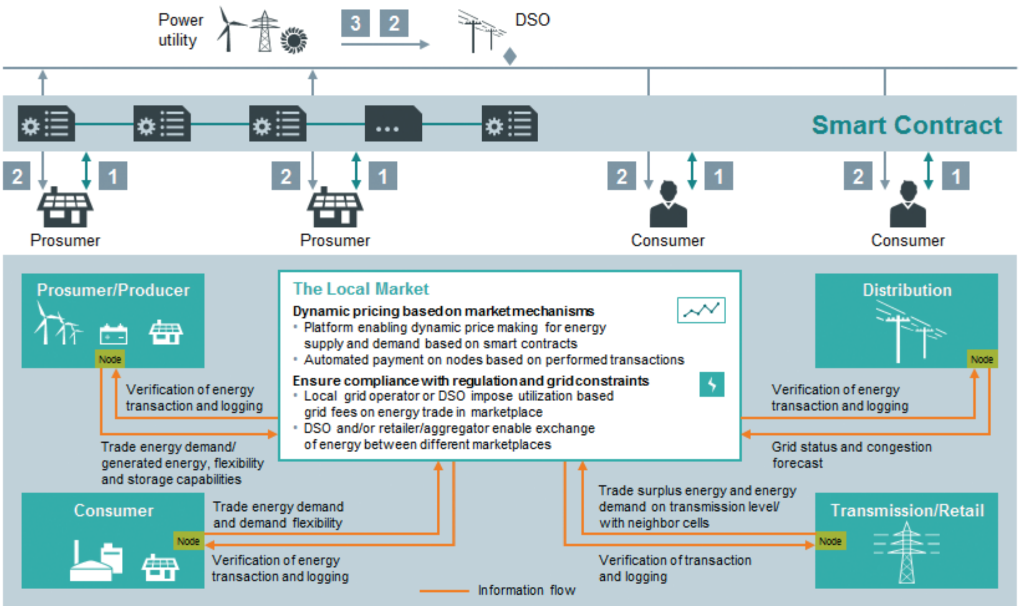

Figure 7: Use Case of P2P Energy Trading within the Lower Level Local Market

2.4.2 Use Case 2: P2P energy trading in the local market across the distribution grid

In this subsection, we demonstrate the second use case of P2P energy trading across the distribution grid. Here, we assume that the energy system is highly distributed with deregulated energy markets. There is large-scale penetration of distributed renewable resources and a possible energy system with a number of interconnected distribution sub-grids and corresponding lower-level local markets. As Figure 8 shows, there are four different distribution sub-grids. They can trade energy on their own lower-level local market as proposed in use case 1 to achieve a local optimum. Alternatively, they can trade with each other on the trading platform of the distribution market operation as depicted in Figure 8 to achieve a global optimum. The trading platform of this distribution market operation can be considered a higher-level local market at distribution level, which is a multi-tenant extension of the trading platform proposed for the lower-level local market. In this scenario, aggregators of individual distribution sub-grids as well as all types of consumers, prosumers and producers trade energy on the platform instead of local prosumers. This use case is also suited to enhancing microgrids in both islanded and grid-connected modes. A microgrid is either considered to be a distribution sub-grid, so that it has its own local market, or it is linked to the geographically nearest local market in place for its local trading.

This multi-tenant distribution market operation is also responsible for exchanging information between different distribution sub-grids. On the one hand, each local optimization problem experienced by an individual distribution sub-grid can be resolved by using a grid control module that has a certain degree of autonomy. This allows decisions to be made based on the information from other grid control modules in corresponding distribution sub-grids received via the platform. On the other hand, a collaborative approach can be promoted by sharing not only information between interconnected distribution sub-grids but also by sharing individual grid control results. Thus, the local optimization problem of each individual distribution sub-grid becomes an optimization problem in which physically interconnected distribution sub-grids can solve their own dynamic dispatch problems by collaboratively resolving certain constraint violations.

Also, this use case offers the same opportunities as those listed in use case 1, enabling different stakeholders (market players) to benefit from Transactive Energy trading based on the higher-level local market across the distribution grid.

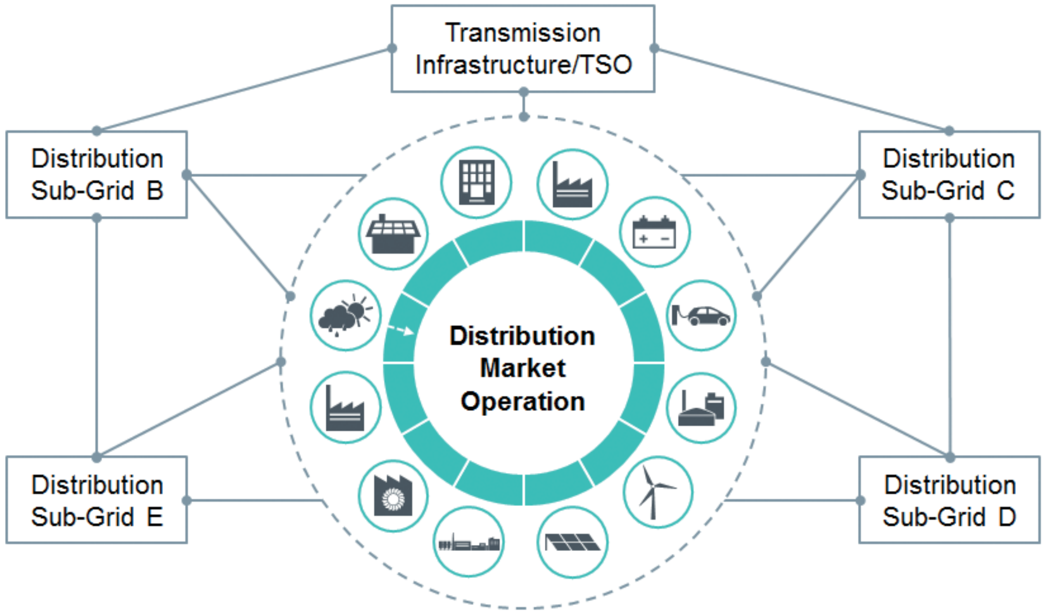

Figure 8: Use Case of P2P Energy Trading within the Higher Level Local Market across the Distribution Grid

2.5 Services

At a high level of abstraction, our proposed Transactive Energy system can be represented by an encapsulated market concept that can be applied to specific regions and, by cascading the market platform, to the European market as a whole. In a country like Germany, for example, this market platform can be applied in a top-down approach to various states and regions, and also to cities, towns and districts.

In its current stage, our proposed TE concept still assumes that utilities will retain a controlling role in energy and network operations. It can be considered a transition model, as a future model will be based on the concept of an open infrastructure, where energy is exchanged "freely" among participants in the same way as documents are shared on the Internet. In this scenario, utilities will be independent service providers (ISPs) not energy providers. The market system for Transactive Energy with our proposed P2P trading platform will then evolve further from a sharing-economy trading platform such as UBER to become a fully open and democratic operation platform. Regardless of whether we focus on the current transitional model or the future model for Transactive Energy, the following key services need to be provided on premises or in the cloud.

Market-related services

- The **P2P trading service** provides all types of consumers, prosumers, producers, retailers and aggregators with access to trade on the local market. For all end users, trading will be automated and carried out by trading agents.
- The **price settlement service** provides trading customers (transacting parties) with smart contracts to pre-determine prices and rules for local transactions.
- The **cross-platform trading service** (or local market coordination service) makes it easier for aggregators to sell aggregated services on the local market, the wholesale market and directly to grid operators and retailers.

Grid-related services

- The **balancing service** provides grid operators with a grid control module that performs power flow analyses in real time, enabling voltage and VAR to be optimized as well as phase balancing and power dispatch, and distribution and transmission operations to be coordinated with the wholesale market.
- The **reliability service** provides the DSO with voltage support and supplemental reactive power for managing two-way power flows at distribution level.

In addition, ancillary services are required to support the transmission and distribution of capacity and energy from resources to loads while at the same time ensuring that transmission and distribution systems continue to operate reliably. These services can include support services for the market platform, grid operation and for end users:

- For the market platform:
  Relevant ancillary services can include scheduling, visualization, analytics (such as forecasting) and optimization.
- For grid operation:
  Relevant ancillary services can include load forecasting, generation forecasting and weather forecasting.
- For end users (focus on local optimization):
  Relevant ancillary services can include price forecasting, load forecasting, weather forecasting and schedule optimization.
- Demand-response-based services are also relevant for transactions between end users and the DSO. The incentives for providing these services are based on real-time prices in the local market.

All of these services need service providers. This offers great opportunities for Transactive Energy vendors and other third-party service providers to start new market ventures. In order to avoid technical issues, service providers and grid operators need to harmonize their coordination in advance and in a secure way that does not compromise the manageability or reliability of the system.

3. Implementation Approach

Based on the use cases we have identified, we will focus on implementing a market structure that addresses the following relationships within the energy landscape:

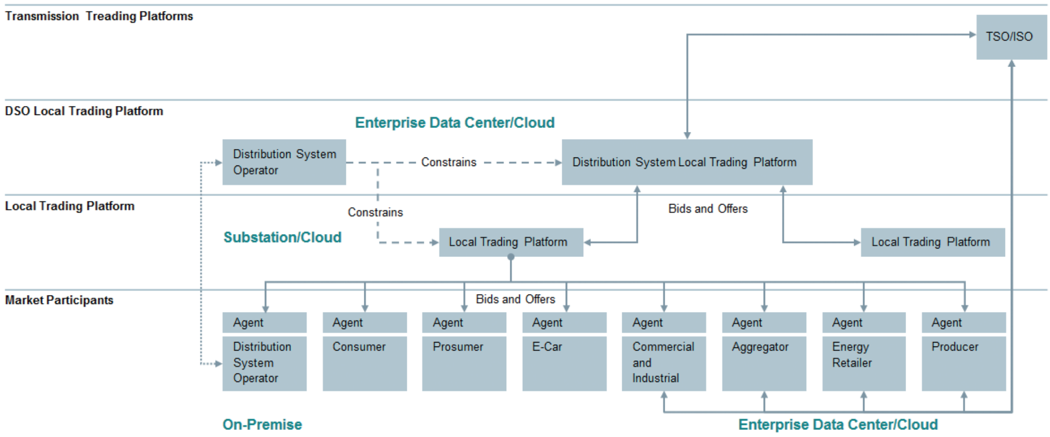

Figure 9: Energy Landscape within the Transactive Energy System

The Transactive energy system that we propose comprises highly localized trading platforms that enable energy trading at as low a level in the electric network as possible, including feeder and substation level. This will encourage maximum use of local energy sources for neighboring loads and maximum use of the distribution grid. The high level of automation across local trading platforms and participating market resources will allow all locally available sources of energy to be used efficiently, while also factoring in the variability of these sources and the loads that consume the energy.

Large numbers of local resources would be able to participate in the local trading platform. At the same time, the platform would not overburden computing capabilities and data networks as it would process trades at the lowest possible level and reduce the volume of data that needs to be processed and transmitted. A form of constrained economic dispatch is used to match load with generation from DERs on the local trading platform.

The local trading platforms would be hierarchical to ensure there is a platform for trading across the DSO's entire footprint. This would enable resources to be used as effectively as possible across the distribution grid and any localized issues to be addressed. If there is excess generation or load that cannot be addressed on the local platform, then bids and offers would be passed up to the higher-level trading platform, allowing access to additional resources across the grid. This means that load requirements at one substation could be addressed by a DER at a different substation. This would ensure maximum use of DERs connected to the local distribution network before players have to turn to the bulk electricity market for additional supplies. It also allows excess generation or load to be offered to the TSO-level markets.

In addition to the trading platform, a management system for the distribution system is another key element of this implementation. This allows the DSO to run a power flow analysis to determine the impact on grid resources as well as any constraints that may or are likely to be exceeded based on load and generation forecasts, as shown in Figure 10. The DER forecast module is responsible for the DERs themselves and also co-existing storages. The resulting constraints are provided to the local trading platforms so they can be included in the process of matching bids and offers. This is done using a form of constrained economic dispatch that harnesses as-bid prices plus the added element of the grid transmission fee, which can vary depending on the distance between the point of supply and demand and congestion in the network. As mentioned in the concept chapter (chapter 2), calculating and managing congestion play a crucial role in the concept of Transactive Energy. Congestion cost is a key element of the DERs' locational value.

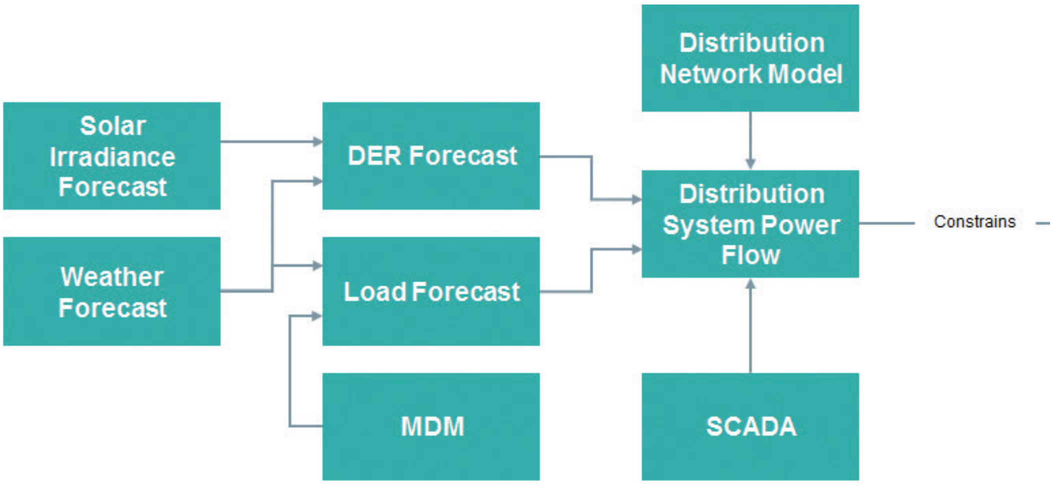

Figure 10: An Implementation Example of the DSO

We expect a variety of participants at market-participant level. Here, we provide a TE framework with a range of technological approaches and toolsets for varying degrees of interaction rather than a specific solution for energy trading. Passive participants may set high-level targets or objectives such as comfort levels, energy source choices or price ranges, while aggregators and producers may want to take a more active role, for example, to maximize profit. There may be a variety of agents that interact with the trading platform depending on the types of participants. These could range from smart meters with embedded smart agents that submit consumers or prosumers' preferences in the form of bids and offers to the trading platform through to solutions that allow users to determine bids and offers and submit them to the trading platform. Consumption and production need to be measured using a smart meter infrastructure that feeds into a meter data management (MDM) system. This may be managed by the trading platform operator or distribution system operator and used to confirm trading results. A scalable platform for data and grid management is required to cope with a broad spectrum of market participants. For interactions between trading agents and the trading platform, we focus on a distributed financial transaction system that enables peer-to-peer energy transactions without intermediaries.

The trading platforms themselves could be distributed across the distribution grid on hardware based in substations or other distributed, securable locations. Alternatively, they could be deployed in centralized data centers or stored in the cloud for ease of maintenance, with the choice based on the communication technologies available.

3.1 Portfolio Offering

Realizing the Transactive Energy system proposed above requires a comprehensive solution framework. The company Siemens offers just such a framework with existing components. The EnergyIP platform from Siemens, for example, offers multiple components that can be used for the trading platform and data and grid management. In particular, the EnergyIP DEMS offering addresses multiple requirements of the trading platform. These include:

- Registering DERs
- Monitoring and controlling DERs using the Internet of Things (IoT) and SCADA protocols
- AMI interface
- Load forecasting
- Generation forecasting
- Bid/offer interface
- Settlements
- Analytics

The Spectrum Power™ 7 platform offers a complementary set of functions that can be used by distribution system operators. The Spectrum Power Advanced Distribution Management System (ADMS) is a promising solution that includes:

- SCADA
- Distribution network model management
- Distribution network applications – power flow, state estimation, load scheduler, Volt/VAR optimization

Siemens' Spectrum Power™ Energy Market Management offers a component that can optimally match bids and offers while at the same time factoring in the constraints set out by the distribution system operator and the cost of transmission.

For a smart trading platform with a corresponding financial transaction system, Siemens can leverage technology developed in several internal and external pilot projects in Europe and the USA to provide an ecosystem that includes smart agents and enables these agents to communicate with the trading platform. This would be integrated with Siemens' EnergyIP platform, the Spectrum Power™ 7 platform and the Exergy Platform (LO3 Energy) to provide comprehensive functionality for the financial transaction platform.

We are currently investigating whether it makes more sense to use partner technologies for the trading platform or to build a dedicated solution. As trading is an established market, the primary focus is on partnering with other providers. However, if our initial investigations reveal that current trading platforms are either not flexible enough or cannot scale to the expected performance requirements, we may decide to build a platform tailored specifically to the requirements of transactional grid trading.

Overall, we can break down available solutions as follows, based on the functions they offer to different stakeholder groups:

Market operations (including trading)

- Exergy Platform (LO3 Energy):
  Enables peer-to-peer energy transactions
- DEMS 4 (EnergyIP):
  Integrates VPP and DR to enable an automated, economically-triggered control of DERs
- MTM (EnergyIP):
  Provides a central data hub where all market players can manage aggregation, tracking and the delivery of meter data for the purpose of enabling settlement transactions
- MDM (EnergyIP):
  Manages smart meter devices and associated data
- Analytics (EnergyIP):
  For load forecasting and generation forecasting
- EMM (Spectrum Power):
  Performs market clearing based on the security constrained unit commitment

Grid operations

- MGMS (Spectrum Power):
  Software solution for controlling and operating microgrids (if the grid operator owns the microgrid)
- DNA (Spectrum Power):
  Applications enabling optimized and efficient operation of distribution grids with capabilities for grid analysis, grid power flow analysis and power flow forecast
- ADMS (Spectrum Power):
  For integrating distribution SCADA, outage management and advanced fault, and distribution network analysis
- Analytics (EnergyIP):
  For load forecasting, generation forecasting and weather forecasting, as well as grid loss detection

Related to end users

- Analytics (EnergyIP):
  For load forecasting, generation forecasting, weather forecasting and price forecasting
- SICAM Microgrid Controller with cloud-based optimization
- SP7 Microgrid Management System (MGMS) with local optimization for privately owned microgrids
- EnergyIP Energy Efficiency Analysis (EEA) and Management
- EnergyIP DER Performance Analytics and Management

Figure 11 shows an example of an implementation that uses Siemens' products to enable interaction between the distribution system operator, trading platform and market participant agent. The entire implementation consists of the following processes and functional scope.

- **Balancing/matching/optimization:**
  On the trading platform, this module matches bids and offers (loads and generation). It takes into account the constraints that have been detected by the distribution system operator. This module also calculates prices for energy, taking into account any locational value determined by congestion and other factors such as the distance between the load and point of generation.
- **Publication and settlement:**
  After the matching process, contracts are established and sent to the transacting parties. Smart meters at the resources collect the performance information and transfer them to the settlement module.
- **Trading platform:**
  The trading platform provides a bid/offer portal with the definition and implementation of the API for the market participant agent. A bid/offer validation module is responsible for defining and implementing market rules. The market timeline management module is implemented using a business process engine. An interface is implemented at the AMI head end or other source of meter data for settlements. An archive module is implemented to store all data needed for audits and settlements based on the rules and charges designed on the local market. The market clearing process is implemented in compliance with power flow analysis and optimization.
- **Constraints:**
  The distribution system operator provides the constraints detected by the power flow analysis
- **Bids and offers:**
  Market participant agents use standard APIs to submit offers and bids to the trading platform. The bids/offers indicate the flexibility node that they apply to. They are validated by a rule-based bid/offer validation process to ensure they are correct. Market timeline management closes the gate for bids/offers and triggers the optimization process.

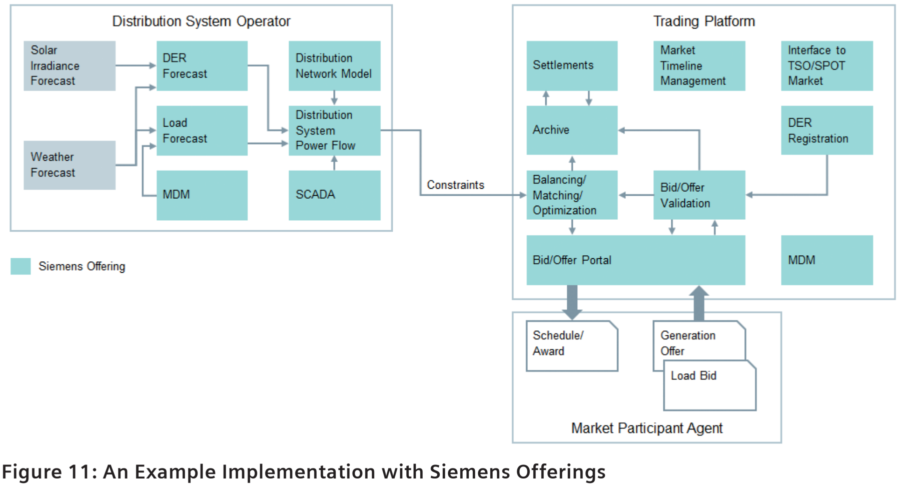

Figure 11: An Example Implementation with Siemens Offerings

Regarding the platform, Siemens can offer both on-premises and cloud solutions. As a result, Siemens provides a combination of on-premises and cloud deployments for implementing a Transactive Energy system such as the example above. The entire trading platform could be deployed in the cloud, while the functions for the distribution system operator have to be partially installed on premises (e.g. grid control and power flow analysis). Market participant agents will also be deployed locally on hardware such as smart meters.

4. Value Proposition and USP

The trade-focused approach of a Transactive Energy system can provide all market participants with a fair mechanism for assessing value based on time of use and costs. The value proposition for the related operators in a Transactive Energy system is a share of the revenue generated by the platform for the new Transactive Energy market. However, the value proposition offered by Transactive Energy is not limited to kWh. It offers multiple benefits, including:
1) energy flexibility; 2) energy efficiency and reliability; 3) a higher degree of automation and transparency in energy markets; 4) large-scale DER interconnection; 5) new business models.

The transactive coupling of the distribution grid and local markets generates **energy flexibility**. This is particularly interesting when it comes to grid operation and balancing the market. This transactive flexibility can be utilized to rapidly (re-)establish grid stability or to directly balance supply and demand locally. More transactions and interactions at distribution level can reduce strain on the transmission grid and improve the **availability** and **reliability** of power supplies in general. Local prosumers and aggregated DERs can save costs thanks to accurate demand profiles. They can also reduce costs for distribution system operators by allowing them to mitigate grid stability costs and reduce the effort required to upgrade the grid system for energy balancing. In addition, integrating grid control and congestion management into market transactions, and vice versa, improves the **efficiency** and **reliability** of the power system. Furthermore, our proposed implementation with software-driven digital transactive technology enables a higher degree of **automation** and **transparency** at market level. As we know, about 97 percent of DERs are installed in the distribution grid. If we therefore make participation in local markets easier, more and more DERs and aggregators can be **interconnected** based on the local market platform as a network of **distributed storage**.

Overall, this approach to implementing Transactive Energy not only provides individual solutions for relevant stakeholders, it also presents several holistic design ideas. It focuses more on the system-wide design, offering comprehensive software interfaces (APIs) that allow third-party software components to be easily integrated. From a system perspective, the trading component paves the way for **new business models** at local market level, but also in other parts of the Transactive Energy ecosystem, including:

- **DER Management:**
  Decentralized coordination and autonomous control mechanisms at local DER level for managing market-connected, distributed generation with highly intermittent renewables;
- **Demand-Side Management:**
  In addition to programs such as energy efficiency and demand response, more capabilities for active demand management at end-user level are needed to enable market-driven interactions between prosumers and grid operators;
- **Market-Driven Grid Control:**
  Grid operators need to control and manage medium- and low-voltage power as well as frequency – leveraging the mechanisms and opportunities of an open market;
- **Storage management:**
  Energy storage at the end-user level needs to be controlled in a decentralized, autonomous, market-driven way; in the meantime, it also has to be well coordinated in the grid management model to ensure an efficient energy balance;
- **Cyber Security:**
  Digitizing assets, integrating IT/OT and networking DERs generate potential cyber security risks. These must be addressed and managed using a holistic approach that results in a resilient Transactive Energy infrastructure..

5. Summary

In this white paper, we present a potential Transactive Energy system and explain how technology from Siemens could be deployed in order to implement this concept. The system primarily focuses on the distribution grid. In this setup, market players take on new roles and have new requirements. We also outline a trading platform for local markets. The concept we present here emphasizes the market-driven approach of Transactive Energy and shows how it can be used to monetize energy products and relieve the grid directly at distribution level. This transactive coupling between the grid and the market paves the way for dynamic pricing that factors in the real-time grid status. It also ensures that transactions comply with grid constraints and regulations. Our two use cases focus on P2P energy trading in a local market, highlighting the benefits of Transactive Energy for different market players.

In terms of market structure, we propose a hierarchical, decentralized design with a sharing economy trading platform. We see this as a transition model for the current Transactive Energy concept. We would envisage that this model would be further evolved in future to create a completely open and democratic operation platform. We illustrate how solutions from Siemens could be deployed to realize the proposed market structure by supporting the entire Transactive Energy system. In the implementation chapter (chapter 3), we listed the components from Siemens that deliver the functions needed to implement our concept. We then presented an example to show how these components could be used to realize the functions for distribution system operators, the trading platform and market participant agents and also enable these players to interact. Our approach to implementing Transactive Energy features several value propositions. These provide prospective customers with comprehensive software and services for easy integration and deployment and also pave the way for new business models.

As mentioned at the start of this paper, we believe that distribution network operators and distribution service providers will be at the core of this transition. The Transactive Energy system outlined here aligns with the process flows, experience and business models of these market operators. In the near future, the market can expect to see pilots that will demonstrate proof of concept for the Transactive Energy system presented in this paper.

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