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Contents

Summary

Traditionally, the electricity generation is mainly centralized and it's hard to manage them in a dedicated and well-organized way. The energy system relies on original structure–a large generation will come from a large utility-scale level and will be allocated to users with requirements through the existed power network. However, the old system no longer matches the requirements of the energy system to shift to a more efficient, reliable, and environmentally friendly structure in the new era. Right now increasing renewable sources of energy has increased the variability of energy supply, thus making the need for intelligent coordination of electricity assets more acute. From the technology aspect, great advances have taken place in both technologies and networks developed for distributed energy resources, which creates possibilities to manage energy assets at a micro-level of local grids. By managing energy microgrids, the supply and demand for electricity within this local area and between this local area and the larger utility-scale grid can be matched and it provides high efficiency and saving. Many researchers are working on techniques and tools for coordinating for handling the challenges of coordinating assets within microgrids. In many cases, not all of the assets within microgrids will be owned by the same people or the same organizations and therefore there arises the challenge of striking contracts between different owners of different assets in order to realize the full potential of these coordination opportunities within a microgrid.

Recently, a number of systems emphasize the potential role of blockchain technologies and or digital currencies as tokens that can be used to handle transactions and settlements. However, most of the work that has been undertaken in looking at the management of transactions within microgrids has not addressed the possibilities that are created when power demand is interoperable. When power demand is interoperable, the users of power have additional flexibility. This additional flexibility needs to be incorporated into any models of microgrid management in order to realize the full opportunities for microgrid management. For doing that, the users of the power need to be able to be aware of the price not just right at the moment that they're using power, but also at various times in the future. In other words, they need to be able to forecast future power prices and make decisions about when they will contract for power based on what future prices will be. A forward contract within the context of a microgrid is electricity contracts will be built between a supplier and a provider of power at a certain price in advance and not delivered right away but at a future time. In this study, we investigate how the integration of forward contract effects is expanding the range of opportunities for optimal management of a microgrid. New formulas and models that take into account this managerial flexibility needs to be written and developed. The use of power in the context is where much of the power is delivered from intermittent supplies like renewables.

Introduction Context

The first need for energy distribution system is to find ways to progressively shift power load in the new energy economy environment that is going to be increasingly characterized by intermittent generation resources.

Traditionally, the way that the electricity system works does not include demand-supply communication, the supply will only adjust itself to meet the people's demand in any time and of any amount. However, this technique is no longer feasible when intermittent resources come to play an important part in electricity generation because intermittent resources rely on the flowing conditions for generation(e.g. when sunsets there won't be any new generations coming out immediately to meet the demand). So there will be new challenges for matching the demand and intermittent supply. You can either use energy storage which is basically moving the supply through time to meet demand, or you can use various demand-response techniques to reach a balance between demand and supply.

And that's where we are looking at—to match the demand and supply in a better way. There are several models developed for that. The brutal way is that the utility simply cuts off the supply of some consumers or some parts of the load when the supply is not available. However, this technique is quite disruptive because denying the service of consumers independent of their needs and value of energy usage is not a well-targeted design and may cause conflicts and problems.

Looking back to the new scenario, the opportunity that arises now is to do the demand management in a more targeted and responsive way for consumers' needs and desires. We are hoping that the consumers can reduce their demand in response to the signals from utilities of insufficient supply. This kind of reactions to specific events and times when utilities are having troubles satisfying all demands and loads requested.

There is another program that is trying to solve this problem by setting negotiations between consumers and organizations. Energy companies will pay consumers money or reduce their payments to have their allows to cut off their utility energy supply when needed. However, this program is not a well-designed system for each individual user's decision. A second version of this program is to adopt time pricing. Traditionally, consumers will be charged for the same price throughout the whole time even if the actual cost of delivering that power is highly variable. So the variable signal is not sent to the end-users for them to make their decisions of purchasing and using the energy. Time pricing means that different prices will be assigned to different times of the day–when demand is higher the general average price will be higher. It is a simple technique to implement and for people to understand. But the disadvantage is that the general average price may not be accurate or reliable to represent the fluctuated energy price.

An improvement here will be providing the consumers with real-time prices so that they can have the chance to respond and make reasonable decisions about using electricity. However, implementing real-time prices can be challenging since that right now there is no mechanism in place for most electricity distribution systems to make real-time prices feasible There needs to be concrete systems for users to send out signals, receive these signals, and respond to these signals. The highly variable prices ask for smart algorithms and consumption technology to help appliances respond to these signals in an intelligent way so that they can satisfy individuals' requirements and desires.

The need for the demand to be responsible for the changing real-time prices is especially challenging and complex because real-time price differs across different times and locations and also differs from capacity constraints in particular. Moreover, because of the increasing use of distributed energy resources, such as rooftop solar, local storage and other kinds of energy assets separable from the main grid that create micro-markets for power and share energy with each other. So it's not just a problem of individual power load communicating with one central grid–individual energy generation assets need to build communication with each other in an effective way. The local prices generated from the individual market will also take parts in the wholesale market and the grid system.

There already exists lots of examples of local energy optimization among neighborhoods and communities, for examples Alabama Power Smart Neighborhood and Australian Smart Tech Home of the Future. But the upcoming challenge is how to transfer this energy optimization technology to a larger landscape. It requires not only integration of multiple energy resources and a flexible market regulatory constructs to trade the resources, but also asks for a secure communication infrastructure that helps customers and organizations planning and operating. Emerging technologies are offering great opportunities and chances to fulfill all these in the future.

A grand policy to connect different stockholders and players around the country and a nationwide infrastructure standard for communication and data are still in lack. Operation visibility and interoperability among different levels of communication are important to relieve their barriers in both policy and technology aspects. Standardization of protocols and information models can help reduce the difference and organize the whole structure in a better way. Except for setting good-enough standards and provide a readable and operable system, develop an autonomous decision-making criteria and self-control responsible system that are ready to serve all kinds of assets and aggregators will be the key issue.

Right now the energy system is becoming smarter–there are more communications through the network and more adaptable operations, so it allows the integrity of diverse distributed energy resources. The basic unit of distributed energy resources is microgrid and integrating microgrid will be great benefit to building a efficient and reliable energy system. A microgrid is a small and freestanding combination of power sources, power users, wires to connect them, and some sort of control system to operate it all. We will be focusing on managing smart distribution resources within a microgrid and between microgrids when not all of the assets are owned by the same entity. It requires a system of contracting for managing transactions between different owners (the owners can be both individuals and organizations).

A system of contracting has basic requirements of having messaging standards, a system for striking contract and a system for settling contracts and making payments. The current state of technology for managing energy resources within a microgrid is mainly based on the structure of blockchain to build a platform for users so that they can interact and make transactions with each other,

However, the contracting paradigm that everyone is talking about so far it's based on spot contracts–contracting in real-time. But scheduling for energy usage is not covered. There are lots of decisions to be made based on the flowing energy demand: how many generations will be scheduled for a certain time in a certain area and what's the price of energy? Also, which user or appliance gets the energy first needs to be decided and this decision is related to the energy price. These left problems reveal the importance of scheduling–if we could settle down the price and balance the demand and supply in advance, then the impact of intermittency and uncertainty can be greatly reduced. Here we are looking forward to developing a system of forward contract in erengy market where use of assets can be scheduled so that we are able to manage distributed energy resources effectively.

Literature Review

From the early age of 2012, some researchers are encouraged by advancements in smart grid technologies. They focus on the demand response side trying to solve the problem. They try to build a model with multiple parameters and constraints to simulate the aggregate demand and match it with the real demand to perform the load schedule. However, their strategies for contracting and modeling are different, some of them are risk-constrained and some of them are price-based. Different standard and parameters setting will lead to a huge difference in the models and results. Some models have too many parameters and are hard to implement in real life and some only emphasize certain parameters they care about. Ensuring a reliable and feasible model should be the key thing to focus on. Also, these proposed models are mainly based on spot contract and the concept of forwarding scheduling is not well-considered. Nguyen & Le (2015) Nunna & Doolla (2012)

In the early age around 2000, There are also considerations for building forward-contracts in the energy market. However, the models are mainly based on simulations and do not include implementation techniques in the real-world. The interoperability is weak due to the limitation of concepts.

The concept of aggregators and microgrids are also treated importantly. They are trying to design the load scheduling algorithm for negotiating contracts in the power system. The design tries to determine the purchase of energy in the day-ahead market based on the forecast electricity price and power demands. Parvania et al. (2013) Wu et al. (2012)

Developing a suitable charging mechanism and system is also important.

One-day ahead scheduling is a hot topic in recent research as well.

As the technologies keep developing, implementing the technologies to the real-world becomes the next step. The concept of blockchain is widely adopted since it fits well into the energy market with the assistance of internet connection and platform development. Besides, the security of the power transaction system is coming to people's sight more frequently in correspond to the digital world's attribute. Aitzhan & Svetinovic (2018) Su et al. (2019) # Existed Standards and Tools

Existed Standards

ISO

International Organization for Standardization(ISO) has a general outline of energy management standards(ISO 50001) which states the basic purposes and requirements of energy management(e.g. use data to better understand and make decisions about energy use). There are no specific details of implementation attached to this standard. It emphasizes the concepts of energy management system(Enms) and is also related to quality management systems(ISO 9001) and environmental management systems(ISO 14001).

According to a video ISO provided to describe the outcome of ISO 50001, there are 6778 energy organizations (both private and public organizations from more than 50 countries)using this standard in 2018. They are using it to improve energy management with the aim of saving money and resources. They are trying to reduce carbon emissions with the aid of an energy management system(EnMS).

The EnMS described in this document is based on the Plan-Do-Check-Act (PDCA) continual improvement framework and incorporates energy management into existing organizational practices. These four steps are based on the organization level design like requires an understanding of the concept and structure of the organization.

ISO (2020)

Tools for Messaging Problem

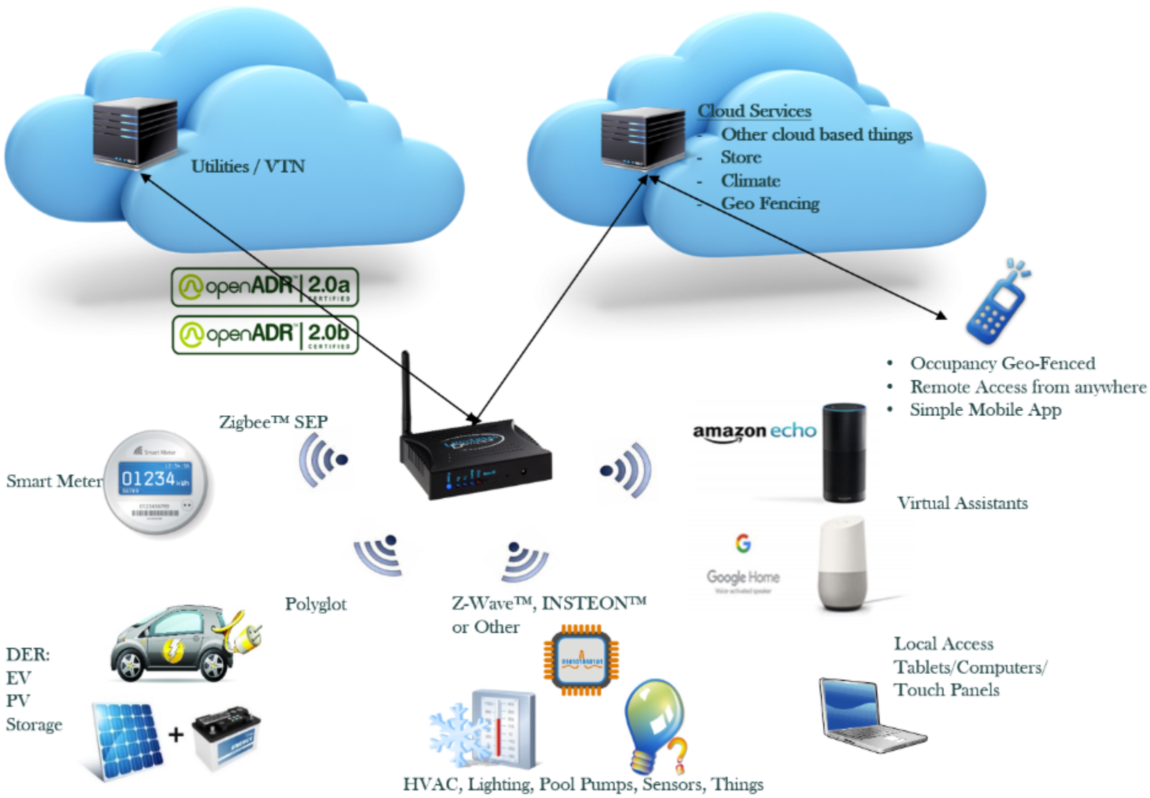
Addressing message problems, send messages and conditions, demand between different assets in the grid system.

OpenADR

Open Automated Demand Response (OpenADR) is a research and standards development effort for energy management. The goal is to solve the problem of green energy's intermittency, overgeneration, and expensive price.

It adopts cloud controls and solar operators as facilitators to manage renewables DER, energy storage, buildings and devices, EV charges and battery and smart communities. The standard combines large resources including solar farms and wind with small resources including residential solar and batteries. Three types of varibales are most important here: a static variable EV price, an active variable Bldg price which changes with equal duration, another active variable Dispatch Level which changes with different intervals.

The design is to set up a combination of conditions as basic information for decision making. In addition to the basic information of time, location, and local sunrise, it also considers electricity price and climate conditions. Normally, the appliance follows the commands given by the users(e.g. working requirements, time constraints, and price preference). It also records the device's work status and has a notification system to send information to the user when needed especially when the system supervisor mechanism finds out unusual events (e.g. extreme high temperature or load for the generator may income a warning and self-interruption).



Device (2020b)

Tools for Local Markets and Microgrids Management

Developing tools for transactions and payments management between users within a microgrid or a larger grid.

SIEMENS LO3 Energy's blockchain platform

SIMENS builds a blockchain-enabled transactive energy platform based on the potential of blockchain-based microgrids. These microgrids include network control systems, switchgear, innovative battery solutions, and smart electric meters.

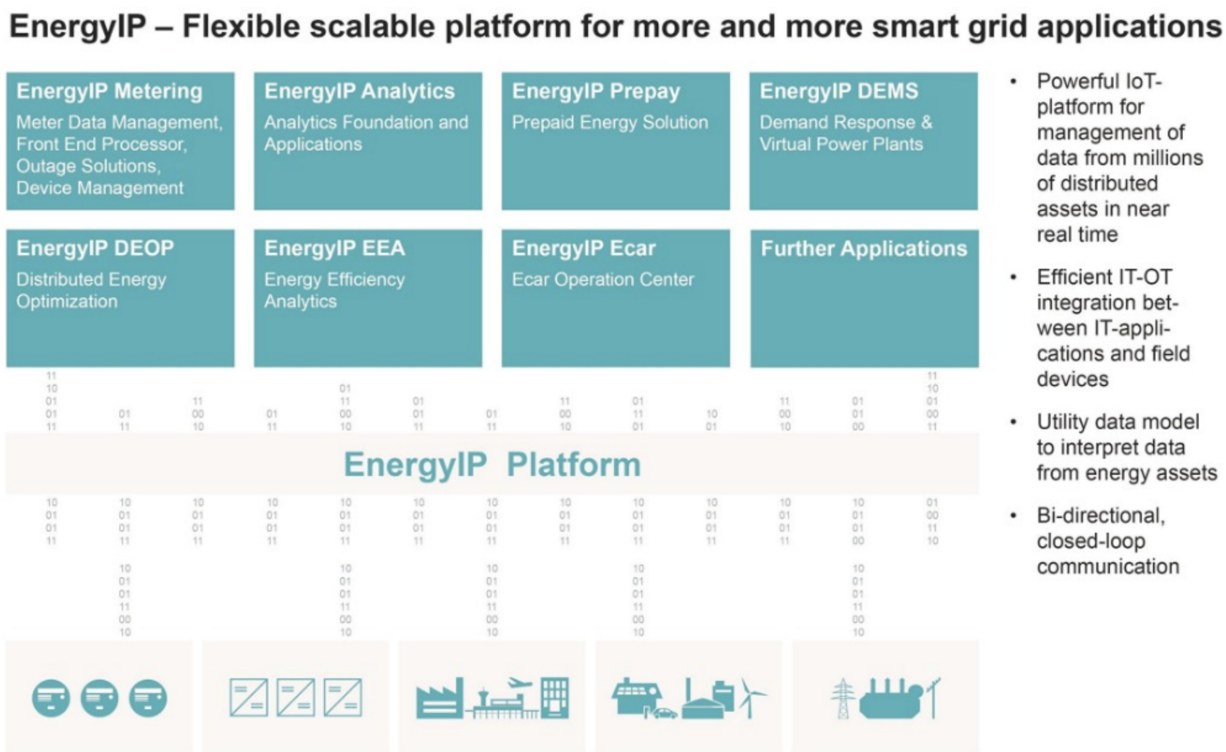
They built a LO3 Energy's blockchain platform – a technology that timestamps each transaction as a chain of secure blocks – every energy transaction was documented. Besides, Digital Grid Division and microgrid-specific technical solutions were applied.

LO3's Exergy platform is based on a decentralized ledger that uses cryptographic technology to save data in a way that is tamper-proof and enables the automated execution of contracts in a scalable manner. The platform extract data from the grid-edge and combining it with Siemens grid technology to create a comprehensive marketplace experience for participants and neighbors to make sound choices about how they intend to purchase, sell and use their energy. This will optimize the operation of electricity grids, allowing utilization to be planned ahead and opening up new servicing and maintenance models, which in the future will be implemented via apps and data transfer to the cloud.

LO3 (2018)

SIEMENS EnergyIP Platform

EnergyIP is another platform used for Distributed Energy Optimization. EnergyIP applications can process data from millions of distributed grid assets and smart devices almost in real-time, powering new approaches for grid optimization via standard communication protocol interfaces. EnergyIP can extract all data from one cloud application allowing for faster reporting and much more for energy managers, asset managers, O&M staff, and other user groups. Compare historical events with current forecasts for comprehensive insights that lead to better decision-making. Improve scheduling, implement predictive maintenance, and forecast energy purchases throw forecast algorithms for power plants. Gain a comprehensive overview of improved forecasting and performance monitoring. Improve energy production, while reducing CO2. Optimize your assets with rule-based load management. Prioritize self-consumption (load + battery + photovoltaic). Achieve optimal scheduling based on each unit's constraints and costs. And rectify errors faster for minimal downtime.



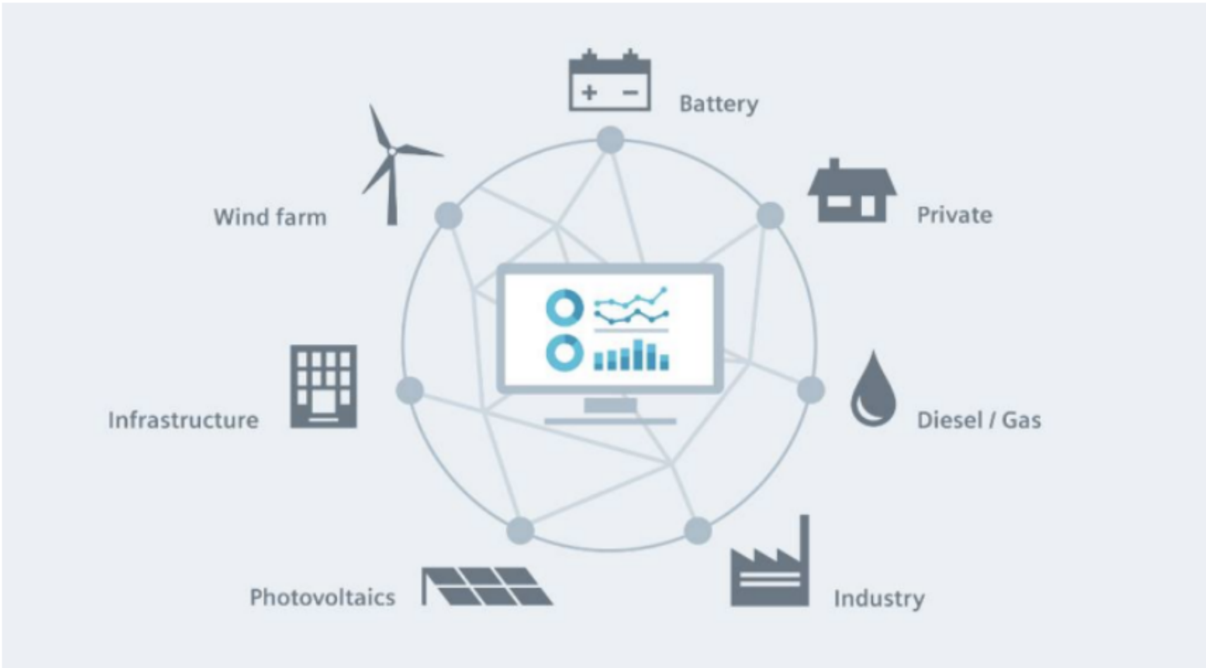
SIMENS (2020c)

They also applied similar techiniques in transformers. In addition to their primary task of transforming voltage, Sensformers will then also be able to act as information hubs for the power grid operators, who are in need of new solutions to fuel the three D's of energy supply: decarbonization, decentralization, and digitalization. The strongly fluctuating loads associated with the unpredictable generation of renewable energy influence the loads on the transformers and - if the loads are heavy - the transformers can overheat. The Sensformer can now communicate this status by measuring the oil temperature and winding current and sending the results to the cloud. Improved load distribution will help prevent damage, including blackouts. Even if a Sensformer were to break down, its location can be quickly identified. This is especially important in remote areas so that the service technicians can be immediately dispatched to carry out repairs, thereby minimizing the risk of a blackout.

They offer an idea to integrate the system - meet the demand step by step. For a place where often exists storms, the project plans to install battery storage units within the grid in order to keep the lights on at least temporarily during the next storm-related emergency. If possible, local electricity demand will eventually be adapted to solar energy generation.

Spectrum Powe MGMS

Spectrum Powe MGMS is a software solution for optimal microgrid management and control. Some of its advanced functions include seven-day load and generation forecasting, unit commitment optimization, load shed, seamless transition to and from island mode, and market participation tools. This optimal coordination allows two major functions: optimized unit dispatch, reducing energy costs and emissions production associated with onsite and imported energy, relevant to all microgrid projects. Spectrum Power MGMS has the ability to forecast site electrical and thermal loads and – while taking into account the current electric and fuel/gas utility prices – will execute a comprehensive resource optimization routine in order to find the economic optimal unit schedules for the next 24 hours. These schedules are dispatched in real-time, turning units on and off, and sending the economic optimal operating set points. This results in significantly decreased operating expenses from electricity and, in the case of thermal projects, fuel purchases.

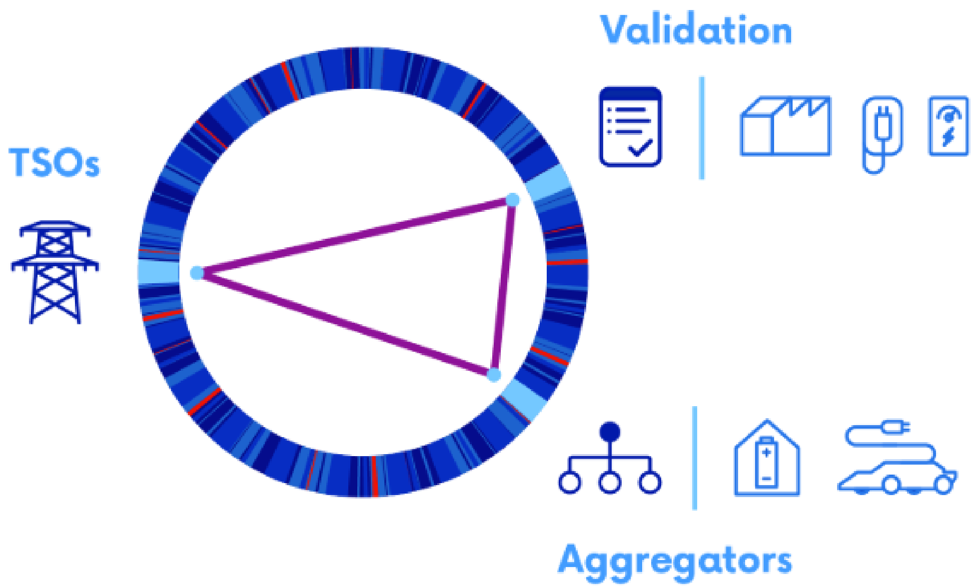


SIMENS (2020b)

IBM Equigy

IBM's idea is mainly based on blockchain technology and electricity grid management. The new Equigy platform they developed employs blockchain technology so that Consumers charging their electric vehicles (EV) or using home batteries can interact with the three transmission system operators (TSOs).

Equigy is a consortium of TenneT, Terna and Swissgrid. Y. Equigy enables owners of small-scale assets to play a key role in transforming the energy sector by optimizing their interaction with the grid. To address fundamental changes to the energy system, and to create flexibility, aggregators can now offer flexibility from small and diverse energy sources. These are gathered from electric cars, heat pumps, and other consumer-based devices. The platform facilitates data exchange between stakeholders, and brings new players and technologies into the electricity value chain. The transactions are validated based on data provided by OEMs of home batteries and electric vehicles, for example, as well as by Internet of Things devices such as smart meters and charging points, allowing consumers to be financially rewarded for their flexible battery capacity. Aggregators are key market players, facilitating this process and so helping to stabilize the electricity system.



Equigy (2020)

NREL Peer-to-Peer Blockchain

NREL researchers conducted experiments to learn what could happen when two homes were connected via a blockchain with the ability for one to sell excess solar power to another. This required two blockchain transactions: a secure transmission of data about the amount of energy generated, and a payment to the seller.

Central to this research is an NREL-developed software solution called foresee. The software uses homeowners' energy preferences—such as the temperature of their home, or their energy budget—to control connected appliances within the home. In the blockchain experiment, foresee alerted the second home when it would be cheaper to buy renewable energy from its neighbor rather than paying the utility's charges, then used a digital currency to complete the transaction. The demonstration showed the ability to automatically match energy generation and demand between these two homes.

NREL (2020)

User Interface and Experience Design

Designing user platforms and interfaces to translate human beings' preferences and desires into code for intelligent algorithms to execute

Sepapower

For sepapower, it proposes an interesting idea of Plug and Play Distributed Energy Resources. It focuses on building a system that is able to combine several technologies together to realize interoperability. The key is an open, non-proprietary interface that can apply to any DER technology with broad support from technology suppliers.

Interoperability is a keyword they are focusing on which means that a product or system whose interfaces are completely understood, that work and share data with other products or systems. Common interoperability examples include a computer mouse that plugs in and works instantly with any computer, or a smartphone that quickly and seamlessly pairs with a car's Bluetooth system. And they want to build a system that can support various energy interactions between electrical loads, storage, and generation within customer facilities and external entities.

Switching scenario back to the smart contracts, consider a household that has an electric vehicle and charger, rooftop solar panels, an energy storage system in the garage, a smart thermostat, and an advanced meter providing communication between these devices and the utility. With these devices interoperating intelligently, solar generation is directed to EV charging and storage during times of high production and low costs. When the sun sets, the stored energy is used to meet increased load, reducing stress on the grid and maintaining comfort and convenience for the customer.

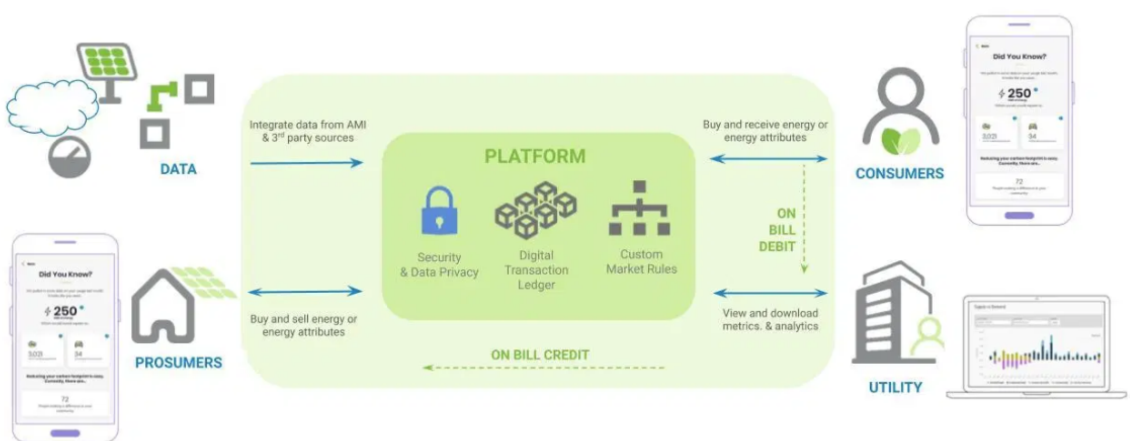
When a household has an electric vehicle and charger, rooftop solar panels, an energy storage system in the garage, a smart thermostat, and an advanced meter providing communication between these devices and the utility. These "plug and play" devices interoperating intelligently, solar generation is directed to EV charging and storage during times of high production and low costs. When the sun sets, the stored energy is used to meet increased load, reducing stress on the grid and maintaining comfort and convenience for the customer.

The target is as follows: improving grid reliability and resiliency; shaving and shifting peak load; reducing carbon emissions; deferring expensive grid and infrastructure investments; and empowering consumers to better manage their energy consumption and costs.

SEPA Power (2020)

Pando

Pando is a co-branded marketplace designed to directly connect energy companies to customers and customers to their community. It has several functions. It enables consumers to source renewables from their local community and provides powerful metrics to analyze the market with customer and trade analytics, trading dynamics, and offer subscriptions.



PANDO (2020)

NERL Community-Scale Energy Collaboration

Electricity generated from renewable resources such as solar and wind that customers cannot use can be diverted to the grid, but there are limits. Feeders—which carry voltage from a substation to transformers—were not designed for the bidirectional flow of electricity.

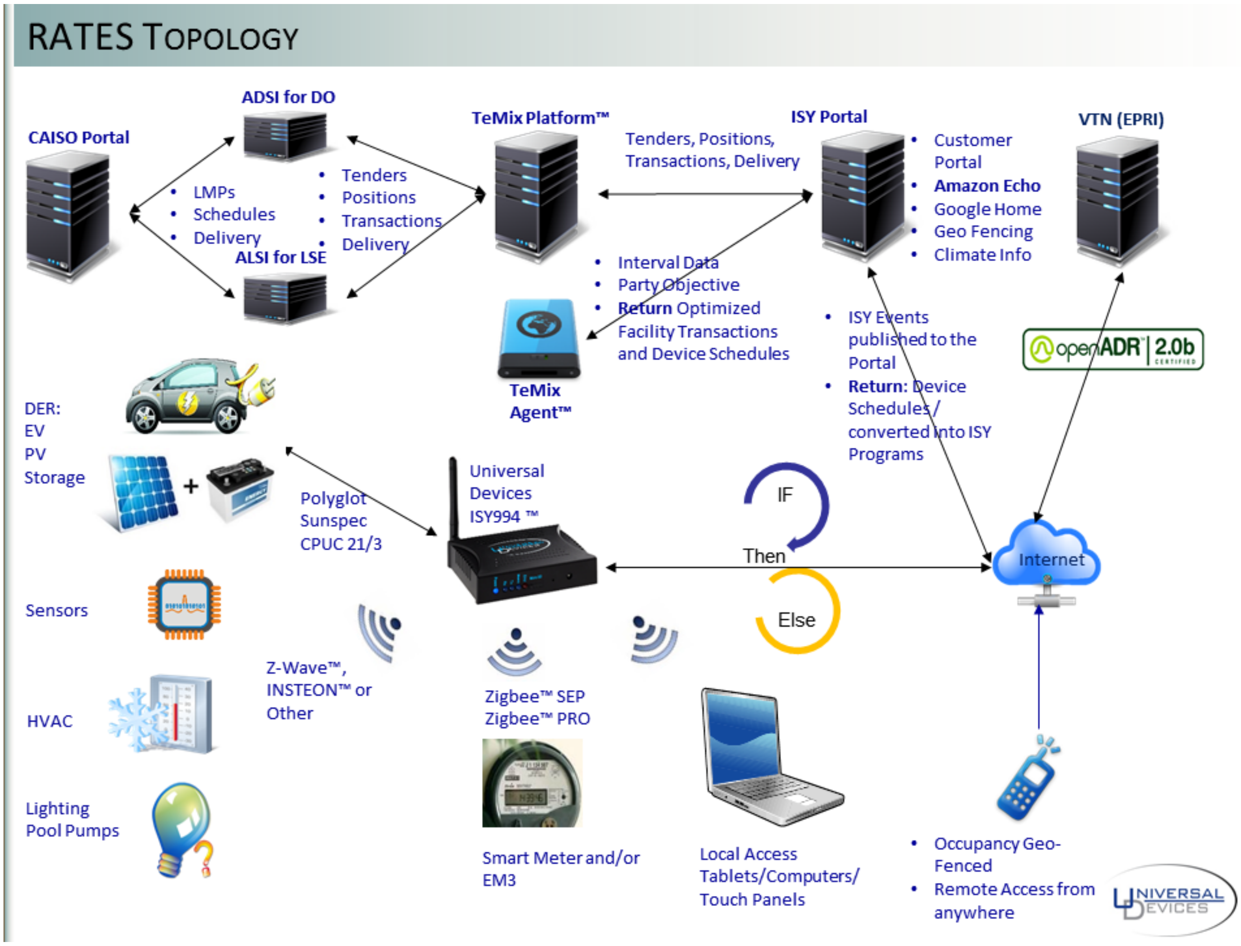
Traditionally, integrating new resources into the grid comes at a substantial cost for a utility. A large part of that cost is driven by custom and manual processes for different DER types. Every feeder is different. Every home is different. As more renewables are adopted, as more electric vehicles are adopted, continuous expert engineering has to be done.

The virtual pilot occurring at NREL is as close as possible to installation on a live grid. The project will establish customer benefits, utility cost/benefit, and help to de-risk the blockchain market solution prior to a deployment.

NREL (2020)

A platform called Retail Automated Transactive Energy System(RATES) is also developed. It allows the users to decide whether or not to do more savings or having more comfort on a per device basis through monitoring and controlling devices based on energy usage information and cost estimation. It involves almost all off-the-shelf Z-Wave or INSTEON devices, including thermostats, pool pumps, lighting, multi-sensors, energy monitors, inverters, IPSO v1 sensors, and smart meters.

It enables forward transactions and subscriptions with spot transactions which means that users can subscribe at specific costs and quantity for each interval. These transactions can also be easily automated using subscriptions, positions, and goals. Beisdes, buying or selling more at spot prices or making shed or shift in load or DER (PV/EV/Storage) can satisfy individuals' unique requirements.



Device (2020a)

Proposals

CORDIS

CORDIS provides several agenda proposals that are informative and insightful. CORDIS right now is still calling for proposals from individuals and organizations, these concepts they mentioned are mostly their requirements, and things supposed to be done in this whole energy project so they are not implemented yet.

LC-SC3-ES-1-2019 - Flexibility and retail market options for the distribution grid

This proposal aims to develop and demonstrate integrated solutions that will allow the distribution grid to function in a secure and stable manner with large shares of variable renewables. Applied Technologies (1) Flexibility measures and electricity grid services provided by storage of electricity (including batteries and vehicle to grid technologies) (2) Smart grids technologies for an optimum observability and tools for higher automation and control of the grid and distributed energy sources, for increased resilience of the electricity grid and for increased system security, including under extreme climate events; (3)Market mechanisms incentivizing flexibility or other market tools should be defined and tested, for mitigating short-term and long-term congestions or other problems in the network (e.g. dynamic network tariffs and solutions to reduce the costs of energy transition, non-frequency ancillary services). The goals (1)Enhance flexibility of distribution grids and the percentage of renewable energy production; (2)Contribute to define the conditions of a well-functioning electricity market which creates the business case for stakeholders willing to provide such flexibility and allow to sustain the necessary investments (e.g. variable price strategies); (3)Improve distribution grid operations that guarantee security of supply and the use of flexibility products while integrating large shares of variable renewables avoiding unnecessary investments by solving congestion.

CORDIS (2019)

LC-SC3-EC-3-2020 - Consumer engagement and demand response

This proposal's objective is to improve the predictability of consumption and consumer behavior (aiming to create a digital twin of the consumer). The main focus will be on households, but other types of consumers (residential, industrial, commercial and tertiary, including prosumers who are self-consuming part of the energy they produce) may be included.

target one or multiple types of loads (e.g. appliances, electric vehicles, power to heat/cool, etc.) as well as (small-scale) production (e.g. PV), include energy storage and one or several methods of aggregation (e.g. citizen energy communities). Preferably they should rely on advanced automation, advanced ICT tools, and approaches (e.g. IoT, Big Data, AI, blockchain, etc.), communication protocols, and interoperability.

Social science and humanities-related work will be closely associated with the development of technological solutions from the beginning of the project (e.g. co-creation process involving both technology/ service providers and consumers) and not as an isolated task/work-package.

Privacy, consumer, and personal data protection and cybersecurity should be addressed. Find what is the information that shall be exchanged and contribute to open platforms and market places that can be integrated with other services based on platforms.

Services, customer information, engagement strategies and contracts should be designed, tested and conclusions should be drawn to improve the predictability of consumption and consumer behavior, based on the different types of consumers (e.g. segmentation along different categories, e.g. social category, age, technology literacy, gender, etc.) on the considered location and climatic conditions and on the type and magnitude of incentives, putting the citizen at the center of the proposed approach.

CORDIS (2020)

DT-ICT-10-2018-19 - Interoperable and smart homes and grids

This proposal shall be done by developing interoperability and seamless data sharing, through aligning existing standards from the utility and ICT domains, across the devices and systems to enable innovative building energy management services, with the aim to save costs to consumers, to facilitate the integration of renewable energy from distributed intermittent sources and to support energy efficiency. The pilot needs to demonstrate plug-and-play energy management solutions within the home, by taking into account the legacy of existing smart home or building solutions, mapping their approach to common architecture models, and implementing relevant standards (such as SAREF).

SAREF means building blocks that allow separation and recombination of different parts of the ontology depending on specific needs. Integrate different parts to function at the same model.

CORDIS (2018)

Design and Formalism

The problem now comes to how to decide which asset within a microgrid to get the power and the price of power. Our focus is to develop the mechanism to build an equilibrium market where every user's desire is satisfied in a reasonable way. Right now we are only considering one moment in time without considering storage and forecast.

Our target is to build a win-win contract that provides both prosumers and consumers reliable information that can support them to make rational decisions and make the contract flexible and negotiable.

To build smart contracts, We need to build a network that allows interactions and information exchange between different kinds of stakeholders(prosumers, environment, and consumers). An integrated platform that shares information should be developed and provided to all parts of the system.

We divide the interactions of the system into four levels: Generation Interaction, Market Interaction, Grid Interaction, and User Interaction.

Generation Interaction

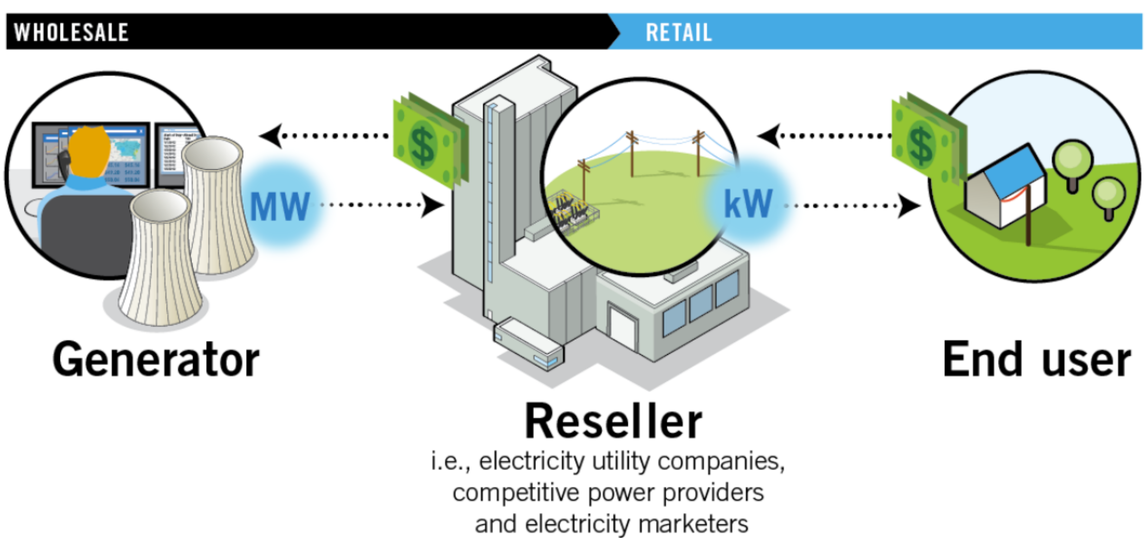
Organizations and companies which generate the electricity will receive price information from the current market and demand information from the grid and consumers, and make their production and decides the price they will offer to the market.

The electricity produced by generators is bought by an entity that will often, in turn, resell that power to meet end-user demand. These resale entities will generally buy electricity through markets or through contracts between individual buyers or sellers. In some cases, utilities may own generation and sell directly to end-use customers.

The price for wholesale electricity can be predetermined by a buyer and seller through a bilateral contract (a contract in which a mutual agreement has been made between the parties) or it can be set by organized wholesale markets. The clearing price for electricity in these wholesale markets is determined by an auction in which generation resources offer in a price at which they can supply a specific number of megawatt-hours of power.

If a resource submits a successful bid and will, therefore, be contributing its generation to meet demand, it is said to "clear" the market. The cheapest resource will "clear" the market first, followed by the next cheapest option and so forth until demand is met. When supply matches demand, the market is "cleared," and the price of the last resource to offer in (plus other market operation charges) becomes the wholesale price of power.

Many consumers have options for purchasing electricity. They can choose from their local utility or a number of competitive retailers to find the service that best fits their needs. These resellers (retail electricity providers) purchase electricity through wholesale electricity markets before they resell it to consumers (and, if they are a regulated utility, resell electricity at retail rates set by state regulators).

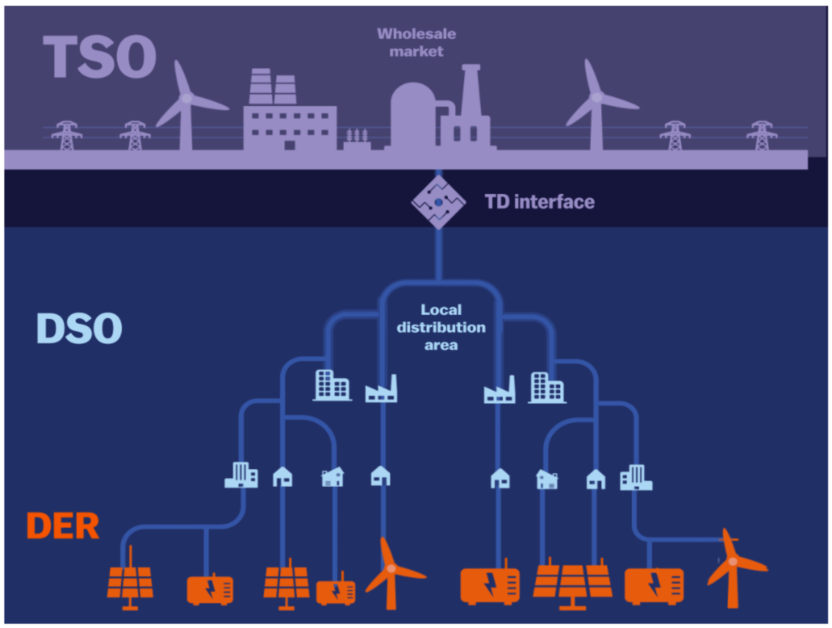


PJM (2020)

The system will predict the demand for electricity generation and try to reach a balance between the demand and production for a better market. The production should also consider time limitation of storage and choose between consuming storage energy or generating new energy according to the prediction.

Market Interaction

Build a virtual market platform that coordinates generation and consumption through a hierarchical network structure. At top, power is generated at large power plants(utility-scale resources) and managed by the transmission system operator(TSOs). Then the power is dumped from the transmission system into local distribution areas and will be managed by the distribution system operators (DSOs). At the bottom, there will be distributed energy resources(DERs) that can be aggregated as microgrid or aggregators. All these energies will be connected.



Roberts (2018c)

The contract will be based on the flowing prize of all kinds of electricity and automatically choose the minimal one to purchase. Its target is not for decarbonization which may not be everyone's interest. It is setting up a price competition for both consumers and prosumers to reach a satisfying trade price. All the data and information will be recorded during the transaction process.

Grid Interaction

A smart grid will get price data from the virtual market and follow the standard to build a contract with the generation side. Once the contract is built, the distribution of energy will be allocated to the specific grid and smart devices will start to work in the set-up time. In return, when the grid needs power, it will send requests and demand information to the virtual market to build the contract. Meanwhile, smart meters and sensors will send price information to the user side.

User Interaction

From the users' perspective, after buying a smart appliance home, the information of location will be set up in advance. This means that smart appliances can connect the local market. The needed working time and electricity demand is stationary for the smart appliance. Users only need to plug in their requirements for the appliance to do the job.

Users need convenience, flexibility (operability, to achieve their own), and benefits. Convenience and flexibility are actually contradictory. The more functions and flexible designs require more complicated operations by the user, so we need to first confirm the parts that have not been worrying about, and connect the remaining operations with the user's direct wishes. For easy understanding. Simplicity is good, this sentence applies to most areas, does not add unnecessary functions for users (but whether the functions is necessary needs to be distinguished from individuals, so set the existing mechanism as the default mode, and provide additional for users who need it), while record personal and all users' usage information.

Each user will have an individual account to log in the platform, a history rating will be recorded to measure users' behaviour(including number of transactions, transaction success rate and so on).

The working hours needed are known from users and appliance, the existing prices are known from the local market or prediction tool, three patterns for the smart appliance are developed and provided for users to choose themselves.

Parameters we will have here: H: length of the set-up given working time range
$L \leq H$ working hours needed to complete the work
$h \in (1, H)$: index of total available working hours
$l \in (1, H - L)$: index of left available starting working hours
P=<P_H $P_H - 1$ ..., P_1>: price on hours h= H,...,1

Uninterruptible Work

Uninterruptible work means that the job is required to be done continuously.

Normal pattern (default mode)

This pattern is the general mode household adopt and does not care about price. The focus here is getting the job done. The smart appliance will start working from the time the user presses the start button.

Starting from L=1, Real cost C_1 will be $P_{h=1}$.

When L>1, Real cost C'_1 will be $\sum_1^H P$.

Prediction pattern

Users will set up a time range for the smart appliance to complete the task. Users don't care about when the job will be done, they only need the job to be done within the range. Based on the prediction tools' price forecast in the given time range, the smart appliance will decide which time to start working.

The system will find which hour to start working can give the minimum cost of electricity in total for the work, That is $min_{h_{min}} \sum_h^{h+L} E[P]$. E[P] is the expectation value of the electricity price based on the prediction. The appliance will start working from h_{min}.

Starting from L=1, Real cost C_2 will be the minimum price $P_{h=h_{min}}$.

When L>1, Real cost C'_2 will be the minimum total cost $\sum_{h_{min}}^{h_{min}+L-1} P$.

Cost acceptance pattern

The user will set up a max cost C_{max} the user can afford to pay.

Starting from L=1, if $P_{h=h_a}$<C_{max},trade will be made at that hour h_a. The Real Cost C_3 will be $P_{h=h_a}$.

When L>1, if the cost is lower than the highest accepted cost (E[C]=$\sum_{h_a}^{h_a+L-1} P$<C_{max}), trade will be made at that hour h_a. The Real Cost C'_3 will be $\sum_{h_a}^{h_a+L-1} P$.

Interruptible Work

Interruptible work means that the job can be done in separate periods(segments are allowed) which offers more flexibility.

Normal pattern (default mode)

The normal pattern will stay the same.

Starting from L=1, Real cost C_1* will be $P_{h=1}$.

When L>1, Real cost C_1*' will be $\sum_1^H P$.

Prediction pattern

Since the job can be done in separate hours, we do not have to find the starting hour according to the sum of the continuous hours of electricity cost. Instead, we need to make a decision whether or not to the job in each separate hour. The optimization of minimizing cost will be based on dynamic programming.

We will introduce a binary control variables:

a_h : $a_h = 1$ iff the appliance choose to work on hour h, 0 otherwise.

$\mathbf{a} =< a_H, \dots, a_1 >$: actions chosen on dates $h = H, \dots, 1$

Now the total cost

$$C_2* = \mathbf{a} \cdot \mathbf{P} = \sum_h a_h P_h$$

.

Choose a to minimize C_2*, subject to $\sum_h a_h = L$.

Suppose an optimal decision rule $a(H, L|h)$ has been found.

Let $V(H, L)$ denote the expectation of the total cost that minimize the cost to complete the job within the time range,

$$V(H, L) = E^\pi \left[\sum_{i=L,\dots,1} a(i, L_i|s_i) \cdot P_i \right]$$

where the expectation is taken over the probability distribution of all possible sequences of forecast signals (determined by π), and where L_i denotes the number of hours remaining to complete the job on hour i when the optimal program is followed.

$V(d, f)$ called the *value function* for this problem.

Because $a(\cdot)$ is assumed to be optimal, $V(\cdot)$ must satisfy a particular recursive relationship:

$$V(H, L) = E^\pi \left[a_h^* \cdot X_h + V(H-1, L-a_h^*)\right]$$

where $a_h^* = a(H, L|s_h)$ is the optimal decision.

Once the forecast signal s_h is received, a^* will be chosen optimally:

- If $a^* = 1$, then $V(H, L|s_h) = E\left[P_h|s_h\right] + V(H-1, L-1)$.
- If $a^* = 0$, then $V(H, L|s_h) = V(H-1, L)$.

Since $V(\cdot)$ is by construction a minimum, we must have:

$$V(H, L|s_h) = \min\{E\left[P_h|s_h\right] + V(d-1, f-1), V(d-1, f)\} = \min\{P(s_h) + V(H-1, L-1), V(H-1, L)\} \quad (1)$$

This formula implies the optimal decision rule: $a^* = 1$ (“do the job in this hour”) only if

$$P(s_h) \leq V(d-1, f) - V(d-1, f-1)$$

i.e., when the expectation value of current hour's price is less than the loss in marginal cost associated with arriving hour

Call $P(s_h)$ the *hurdle price.*

The real cost

$$C_2* = \sum_h a_h P_h$$

.

Price acceptance pattern

The user will set up a max cost P_{max} the user can afford to pay. In this mode, the smart appliance will try to make a deal based on the local market's current energy price.

- If $ P_h P_{max} $, then $a^* = 1$.
- If $ P_h P_{max}$, then $a^* = 0$. The real cost

  $$C_3* = \sum_h a_h P_h$$

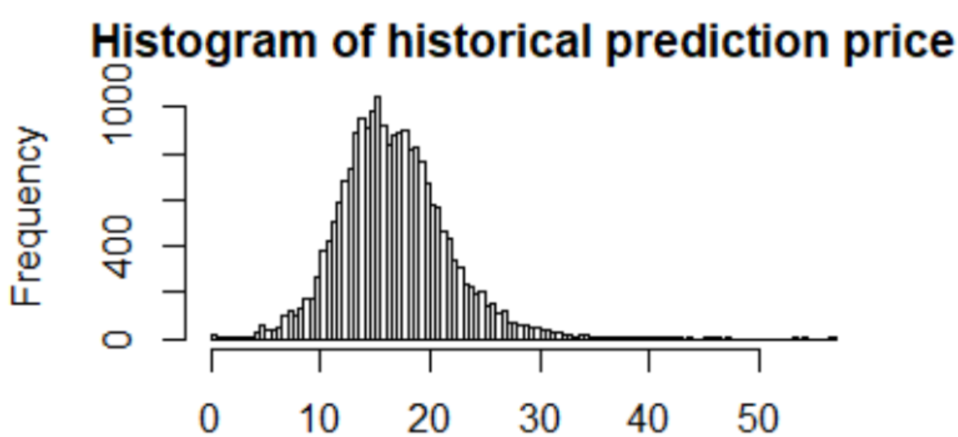
  .

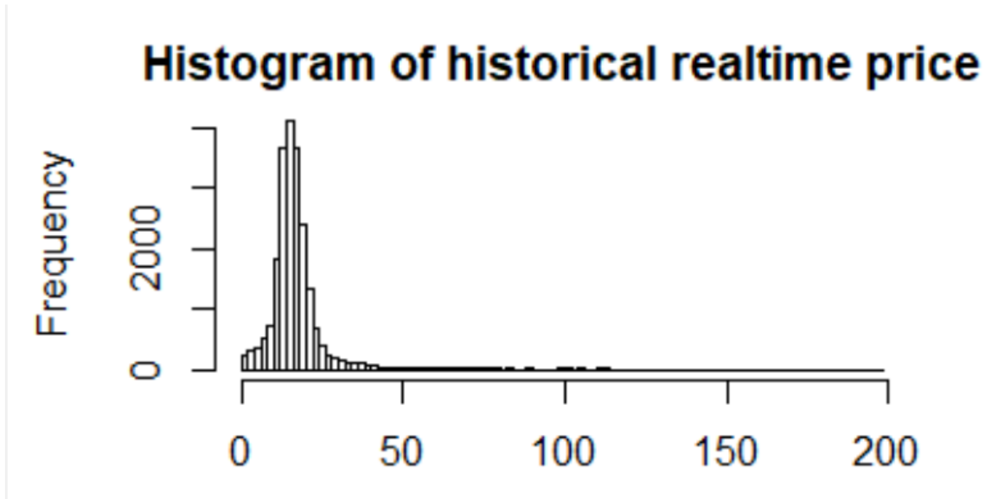
Information Updating Process and Optimal Decision Making

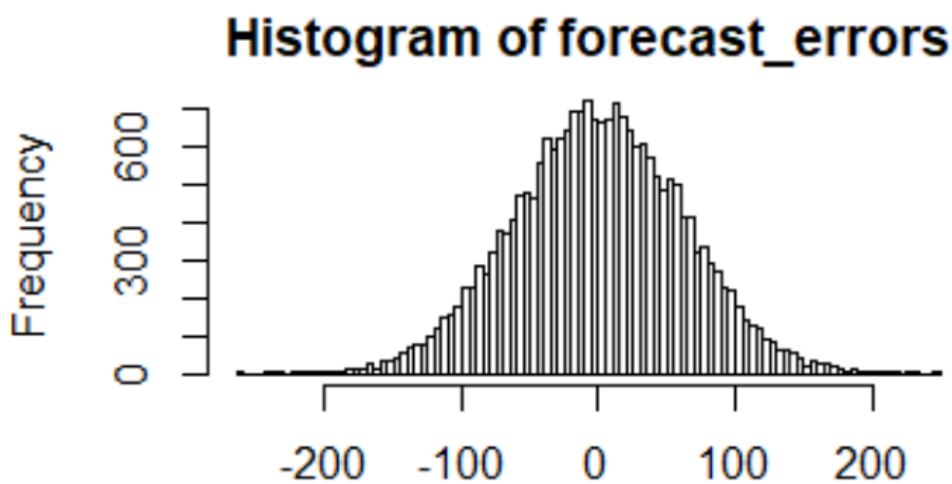
Let y_t denote realized price at time t, where $t = 1, \ldots, H$. The true value of y_t is revealed at time t without measurement error, and is known thereafter. Viewed from the perspective of an earlier period $s < t$, y_t is a random variable: in the jargon of stochastic processes, we say that the random variable y_t is {t-measurable}.

Let K denote the maximum forecast lead time, which is also the total number of forecasts issued each period for each hour and zone. Here H and K will be the same thing(forecast lead time) based on this assumption and needs. For $k = 1, \ldots, H$, let $\hat{y}_{t|t-k}$ denote the k-period-ahead forecast of y_t issued at time $t-k$. Here $\hat{y}_{t|t-k}$ is the forecaster's point-estimate of the random variable y_t, that is, of electricity demand k periods hence on the *target date* t. The forecast $\hat{y}_{t|t-k}$ is itself $t-k$-measurable. $\hat{y}_{t|t} = y_t$.

We can use histogram to show the historical distribution of prediction price and realtime price. Furthur, we get the distribution of forecast error.





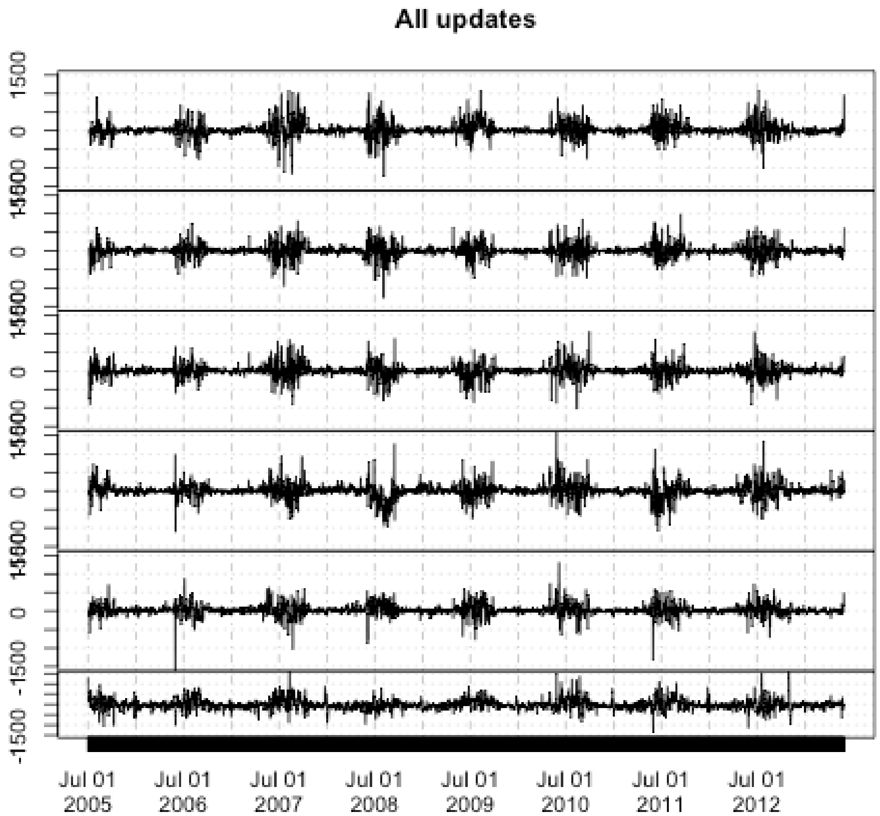


Define an *update* (or *innovation*) to be the difference between two successive forecasts of the same event. Formally, for each $k = 0, \ldots, K-1$,define the *updating process* $u_{t,k}$ by the formula $u_{t,k} = \widehat{y}_{t|t-k} - \widehat{y}_{t|t-k-1}$. In harmony with the notational convention $\widehat{y}_{t|t} = y_t$, let $u_{t,0} = y_t - \widehat{y}_{t|t-1}$.

Clearly, a forecast update is also the difference in error between two successive forecasts:

$$\begin{aligned} u_{t,k} &= \widehat{y}_{t|t-k} - \widehat{y}_{t|t-(k+1)} \\ &= (\widehat{y}_{t|t-k} - y_t) - (\widehat{y}_{t|t-(k+1)} - y_t) \\ &= e_{t,k} - e_{t,k+1}. \end{aligned} \tag{2}$$

Since we already have distribution of forecast error, after setting up different lags to the forecast. We get the distribution plot of forecast update.



Conversely, a forecast error may be expressed as the cumulative sum of all subsequent revisions to the original forecast announcement:

$$e_{t,k} = \hat{y}_{t|t-k} - y_t = \sum_{j=1}^{k} \left(\hat{y}_{t|t-j-1} - \hat{y}_{t|t-j}\right) = -\sum_{j=1}^{k} u_{t,j} \tag{3}$$

Equilibrium Price

A hierarchical network needs to be developed. From individual to one microgrid, then from one mircogrid to two mircogrids. Step by step, the wholesale market will be aggregated under the same regulations and all-accepted price.

Initial status(within one mircro-grid)

For the prosumer, the price the prosumer provides is P_P and the supply volume is S; For the consumer, the price the consumer is willing to pay is P_C and the demand volume is D. (the units for price is ct/kWh and for volume is kW)

If by chance, P_{P}=P_{C}$ and $S = D$, then the equilibrium price $P_E = P_P = P_C$ with balanced supply and demand.

If $P_P > P_C$, which means that the providing price is not acceptable to the consumer, then no deals will be made. So offers from these prosumers can be ignored for the market to reach equilibrium price.

So now we are only considering $P_P \leq P_C$, which means that at least some consumers are willing to buy the prosumers' offers.

The process for consumers to make the deal will be: buying the energy from the lowest price offers to fit the demand until the demand is fully satisfied or all available acceptable offers are sold out.

For one consumer and multiple prosumers(k prosumers). The price for the offers prosumers are providing are sort from small to large($P = P_1, ..., P_k \leq P_C$) and supply volume are accordingly matched up($S = S_1, ..., S_k$).

If the overall supply is less than the demand $S_{sum} \leq D(S_{sum} = S_1 + S_2 + ... + S_k)$, then all offers will be bought and demand is still not fully satisfied.

Else, if the overall supply is larger than the demand,

If $S_1 \geq D$, then the consumer will buy volume of D the price at P_1;

If If $S_1 \leq D$, then the consumer will buy volume of S_1 at P_1, and try to satisfy the left demand $D - S_1$. If $S_2 \geq D - S_1$, then the consumer will buy $D - S_1$ at price P_2 to satisfy demand; If $S_2 \leq D - S_1$, then the consumer will buy volume of S_2 at P_2m and still has volume of $D - S_1 - S_2$ left to satisfy.

Following the same procedure, the demand can be finally satisfied at n prosumers'offer($S_1 + S_2 + ... + S_n \geq D$ and $S_1 + S_2 + ... + S_{n-1} \leq D$), the consumer will buy volume S_1 at price P_1, volume S_2 at price P_2, ..., volume $S_{n-1} at price P_{n-1}, $volume $D - S_1 - S_2 - ... - S_{n-1}$ at price P_n.

What if 2 consumers bidding for different prices?

Price(ct/kWh)/Volume(kW) prosumers: 20/5,30/20,45/5,55/10
consumers: 50/10,60/10

Higher price gives the priority? Higher price does not mean that they should buy with higher price?

Spot Contract The electricity will be bought or sold immediately at its current price.

Forward Contract

The consumers will lock in the price of electricity by reaching an agreement with the prosumers ahead. A price formula that will adjust with condition(e.g. temperature) will be used as the locked-in price.

Option Contract

Consumers will buy the right but not the obligation to purchase the future electricity.

References

Aitzhan, N. Z., & Svetinovic, D. (2018). Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams. *IEEE Transactions on Dependable and Secure Computing*, *15*(5), 840–852.

CORDIS. (2020, February 1). *Flexible energy production, demand and storage-based virtual power plants for electricity markets and resilient DSO operation*. https://cordis.europa.eu/project/id/864537

CORDIS. (2019, May 2). *LC-SC3-EC-3-2020 - consumer engagement and demand response*. https://cordis.europa.eu/programme/id/H2020_LC-SC3-EC-3-2020

CORDIS. (2018, October 31). *DT-ICT-10-2018-19 - interoperable and smart homes and grids*. https://cordis.europa.eu/programme/id/H2020_DT-ICT-10-2018-19

Device, U. (2020a). *Retail automated transactive energy system*. https://www.universal-devices.com/green/rates/#questions

Device, U. (2020b). *Save energy, save money, and SAVE THE EARTH*. https://www.universal-devices.com/green/

enerquire. (2017, July 3). *TSO & DSO coordination – key for the integration of renewables*. https://www.enerquire.com/blog/tso-dso-coordination-key-for-the-integration-of-renewables

Equigy. (2020). *Equigy harnesses the power of small and diverse consumer-based devices*. https://equigy.com/

Erdinç, O., Taşcıkaraoğlu, A., Paterakis, N. G., Eren, Y., & Catalão, J. P. S. (2017). End-user comfort oriented day-ahead planning for responsive residential hvac demand aggregation considering weather forecasts. *IEEE Transactions on Smart Grid*, *8*(1), 362–372.

ESCO. (2018, December). *ESCO contracts energy performance contract models*. https://www.iea.org/reports/energy-service-companies-escos-2/esco-contracts

Good, N., Karangelos, E., Navarro-Espinosa, A., & Mancarella, P. (2015). Optimization under uncertainty of thermal storage-based flexible demand response with quantification of residential users' discomfort. *IEEE Transactions on Smart Grid*, *6*(5), 2333–2342.

IBM. (2020). *IBM teams with 3 european power grids to build green energy blockchain platform*. https://www.coindesk.com/ibm-teams-with-3-european-power-grids-to-build-green-energy-blockchain-platform

ISO. (2020). *ISO 50001 ENERGY MANAGEMENT*. https://www.iso.org/iso-50001-energy-management.html

Lam, A. Y. S., Leung, K., & Li, V. O. K. (2016). Capacity estimation for vehicle-to-grid frequency regulation services with smart charging mechanism. *IEEE Transactions on Smart Grid*, *7*(1), 156–166.

LO3. (2018, February 16). *A microgrid grows in brooklyn*. https://new.siemens.com/global/en/company/stories/research-technologies/energytransition/a-microgrid-grows-in-brooklyn.html

Namerikawa, T., Okubo, N., Sato, R., Okawa, Y., & Ono, M. (2015). Real-time pricing mechanism for electricity market with built-in incentive for participation. *IEEE Transactions on Smart Grid*, *6*(6), 2714–2724.

Nguyen, D. T., & Le, L. B. (2015). Risk-constrained profit maximization for microgrid aggregators with demand response. *IEEE Transactions on Smart Grid*, *6*(1), 135–146.

NOVICE. (2020, February 3). *Enhanced business organization chart for aggregators and ESCOs*. https://novice-project.eu/2020/02/03/enhanced-business-organization-chart-for-aggregators-and-escos/

NREL. (2020, May 14). *Blockchain: Not just for bitcoin*. https://www.nrel.gov/news/features/2020/blockchain-not-just-for-bitcoin-nrel-researchers-demonstrate-collaborative-energy-transactions.html

Nunna, H. S. V. S. K., & Doolla, S. (2012). Demand response in smart distribution system with multiple microgrids. *IEEE Transactions on Smart Grid*, *3*(4), 1641–1649.

PANDO. (2020). *Engage customers, enable green communities and reshape our energy future with pando, a marketplace solution*. https://lo3energy.com/pando/

Parvania, M., Fotuhi-Firuzabad, M., & Shahidehpour, M. (2013). Optimal demand response aggregation in wholesale electricity markets. *IEEE Transactions on Smart Grid*, *4*(4), 1957–1965.

PJM. (2020). *Market for electricity*. https://learn.pjm.com/electricity-basics/market-for-electricity.aspx

Qiu, J., Yang, H., Dong, Z. Y., Zhao, J. H., Meng, K., Luo, F. J., & Wong, K. P. (2016). A linear programming approach to expansion co-planning in gas and electricity markets. *IEEE Transactions on Power Systems*, *31*(5), 3594–3606.

Roberts, D. (2018a, April 27). *Batteries have a dirty secret. Vox*. https://www.vox.com/energy-and-environment/2018/4/27/17283830/batteries-energy-storage-carbon-emissions

Roberts, D. (2018b, May 18). *Solar and wind are coming. And the power sector isn't ready. Vox*. https://www.vox.com/energy-and-environment/2018/5/18/17359730/wind-solar-power-grid-electricity-managers

Roberts, D. (2016, June 29). *The simple reason most power utilities suck. Vox*. https://www.vox.com/2016/6/29/12038074/power-utilities-suck

Roberts, D. (2019a, August 7). *Using electricity at different times of day could save us billions of dollars. Vox*. https://www.vox.com/energy-and-environment/2019/8/7/20754430/renewable-energy-clean-electricity-grid-load-flexibility

Roberts, D. (2015, September 9). *Power utilities are built for the 20th century. That's why they're flailing in the 21st. Vox*. https://www.vox.com/2015/9/9/9287719/utilities-monopoly

Roberts, D. (2019b, November 25). *What happens when the humble circuit breaker becomes a computer. Vox*. https://www.vox.com/energy-and-environment/2019/11/25/20975591/climate-change-solar-panels-circuit-breaker-digital-electricity-atom-power

Roberts, D. (2018c, November 30). *Clean energy technologies threaten to overwhelm the grid. Here's how it can adapt. Vox*. https://www.vox.com/energy-and-environment/2018/11/30/17868620/renewable-energy-power-grid-architecture

Roberts, D. (2017, December 15). *Meet the microgrid, the technology poised to transform electricity. Vox*. https://www.vox.com/energy-and-environment/2017/12/15/16714146/greener-more-reliable-more-resilient-grid-microgrids

SEPA Power. (2020). *Launching plug and play distributed energy resources into the future*. https://sepapower.org/resource/launching-plug-and-play-distributed-energy-resources-into-the-future/

SIMENS. (2020a). *Real-time knowledge, real-time results – EnergyIP distributed energy optimization*. https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/grid-applications/energyip/deop.html

SIMENS. (2020b). *Spectrum power™ MGMS*. https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/microgrid/spectrum-power-mgms.html

SIMENS. (2020c). *The power of EnergyIP*. https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/grid-applications/energyip.html

SIMENS. (2017a, September 19). *Data analytics leads to grid load predictions*. https://new.siemens.com/global/en/company/stories/energy/data-analytics-konstant-net.html

SIMENS. (2017b, November 2). *Siemens and omnetric help con edison begin smart meter operation in new york*. https://press.siemens.com/global/en/pressrelease/siemens-and-omnetric-help-con-edison-begin-smart-meter-operation-new-york

Smart electrical grid clean energy institute. (2020, June 2). https://www.cei.washington.edu/education/science-of-solar/smart-electrical-grid/

Su, Z., Wang, Y., Xu, Q., Fei, M., Tian, Y., & Zhang, N. (2019). A secure charging scheme for electric vehicles with smart communities in energy blockchain. *IEEE Internet of Things Journal*, *6*(3), 4601–4613.

Wu, D., Aliprantis, D. C., & Ying, L. (2012). Load scheduling and dispatch for aggregators of plug-in electric vehicles. *IEEE Transactions on Smart Grid*, *3*(1), 368–376.