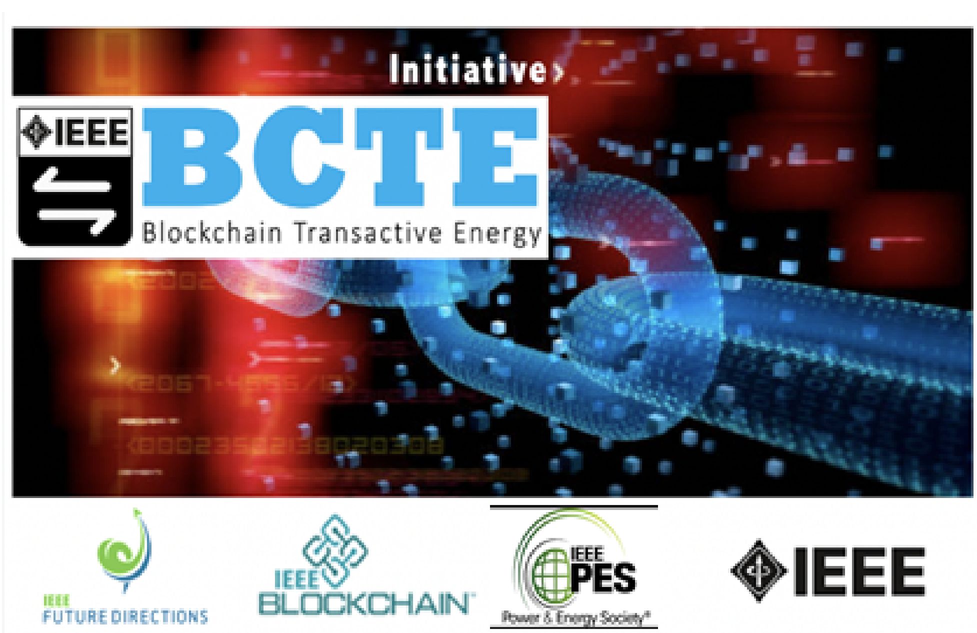
IEEE Blockchain Transactive Energy (BCTE)

A Bridge to a Democratized Energy Marketplace

Position Paper



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Abstract

IEEE has initiated a Blockchain-enabled Transactive Energy (BCTE) program which has been sponsored by the New Initiatives Committee (NIC) and is being pursued as a program under the direction of the IEEE Future Directions Committee (FDC). The work is being done in conjunction with a broader IEEE-wide initiative that can be found at https://blockchain.ieee.org.

This Position Paper describes the basic framework and principles for using blockchain technology in power and energy domains with the emerging participatory grid. A key goal is the development of the most promising global Transactive Energy use cases which can be advanced toward broader commercialization using blockchain technology.

The paper describes the IEEE initiative's goal to create a system architecture, and pursue certain real world demonstrations that will be used to inform the P2418.5 standardization efforts, and to advance other business model development activities. Furthermore, a set of selected use case demonstration projects and techno-political analyses covering the legislative and regulatory issues associated with these instantiations of blockchain technology are planned to be developed within the scope of the framework. Lastly, the initiative serves to provide a cohesive structure that can align and grow worldwide local group contributions, which will be continuously refined and distributed through formal IEEE education and certification mechanisms. It is the ongoing intention of the BCTE program to catalog the relevant initiatives that are underway worldwide to structure and deploy these energy blockchain concepts, and to help evaluate their efficacy for energy system transformation. This paper is intended to offer a path to harmonize and unify these initiatives toward a world wide standard.

Electricity systems and markets have evolved significantly over the past forty years through five distinct yet overlapping phases:

- Deregulation
- Decentralization
- Decarbonization
- Digitalization, and
- Democratization

In particular, the digitalization of power systems began more than two decades ago where modern information and communication technology (ICT) had been utilized within the energy domain actively. The first wave of digitalization activities in the power and energy domain had been carried out within the smart grid and associated frameworks when these initiatives began. The use of artificial intelligence and blockchain technology triggered the recent wave of digitalization of energy systems. With more recent advances in cryptography, local compute power, and higher bandwidth network services, Blockchain appears to be a promising technology that opens up disruptive new paths toward cost-effective, ultra-efficient, and innovative service offers for various business and industrial domains including logistics, finance, health, and energy. Within the power and energy sector, Blockchain technology also provides new and overwhelmingly undiscovered perspectives to enable the democratization phase of power systems and markets.

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Background and Intended Use

This IEEE Position Paper describes potential Blockchain-Enabled Transactive Energy (BCTE) methods that can enable an economically driven, democratized, efficient energy production and market process for highly transparent yet secure distributed energy trading. While not exclusively required to implement Transactive Energy based solutions, the use of Blockchain removes some of the fragility and market domination of the traditional central generation and radial distribution grid paradigm.

The 2020 approval of a program (Blockchain Technology Engagement at the Community Level) by the New Initiative Committee (NIC) of IEEE positions the IEEE to become a global thought and action leader in the field of blockchain-enabled Transactive Energy. This effort will be aligned with, and implemented through, regional IEEE community groups, delivered through structured education and credentialing channels, to help solve real worldwide problems regarding fair access to reliable renewable energy with a true Humanitarian focus. Beyond the core Power and Energy focus, sponsorship support from other IEEE societies and organizations includes, among others, IEEE Blockchain Initiative, IEEE Smart Grid Technical Community, IEEE Future Directions, and IEEE Standards (SA).

Blockchain-enabled transactive energy (BCTE) is a technology with the potential to lower the cost of renewable energy investments, improve the ability to combat climate change, encourage broader participation in the distributed energy resource (DER) market, and increase the pace of innovation through transparent standards which lower barriers for access to the grid. The IEEE is well-positioned to lead this work by leveraging institutional knowledge from well over a hundred years of experience in the Power and Energy domain, and through its leadership in establishing best practices, architectures, frameworks, and standards that are critical to the design and development of this global technology.

The paper is intended to inform a wide audience (not only technical) about definitions, use cases, regulations, and implementation of the use of blockchain technology in energy trading and transactive energy systems (wholesale and retail). It is also intended to present a global view of this topic. The paper's purpose is:

> *To create a common foundational understanding of blockchain-enabled transactive energy, that enables global collaboration among regional groups to develop and launch innovative projects and initiatives.*

This position paper is a component deliverable of the current BCTE project as led by IEEE's Future Directions Committee's Blockchain Initiative, and is the starting ground in a three-year effort (2020 to 2022 inclusive) to move this vision forward and to promote this subject and serve to clarify and define this technology space.

Project Objectives

The knowledge domains for both Transactive Energy and Blockchain are intersecting and rapidly evolving. Accordingly, the underlying project (BCTE Initiative) that is launched with this paper should be intentionally pursued using a "Lean Design" methodology, where core architectural framework requirements are established and applied early to select high-value use case development and demonstration which, in turn, informs refinement and expansion of the core requirement set based on outcome data. The intention is to quickly validate and consolidate those core requirements that support all (or at least most) blockchain applications for Transactive Energy that will lead to a formal IEEE Standards development Project.

The BCTE Initiative welcomes global participation and collaboration along these lines to open bulk power and distribution system operations to include grid-edge participation through peer-to-peer and community aggregation and microgrids in these ecosystem value exchanges. Moreover, by incorporating blockchain methodologies, the initiative seeks to reduce barriers to entry and transaction costs for these markets and to ensure open, secure access to introduce AI and automation to continually improve efficiency.

There are three primary anticipated results of pursuing this project using this recursive and iterative methodology. The program is intended as a globally deployed and facilitated one, with regional clusters of organized participants each contributing to the common definition and application of blockchain-based transactive energy solutions. The selected demonstrations and corresponding fast track architectural development, along with a highly focused Communication strategy, advanced from the framework of this paper will serve to quickly and efficiently:

1. Document existing practices for and develop improvements for the most efficient, scalable, and secure design of incremental energy systems and markets that can operate primarily through decentralized participant transactions.

2. Lower the barriers to, and improve the efficacy and security of, data access on energy demand elasticity, forward price offers, and the valuation and monetization of environmental and resilience attributes.

3. Create an effective outreach and education capability to influence the adoption of the emerging standard, to pave the way for consistent and efficient regulatory reform options where needed.

4. Ultimately leading to a formal certification path for assuring the performance and quality of compliant solutions that are built from the emerging standard.

Each of the objectives is intended to reinforce the advancement of practical applications of blockchain in energy transactions, as a foundational technology that enables more efficient, secure, and resilient market-driven value exchange processes in the production, transport, and consumption of electric power. The primary work streams of architectural framework development, rapid demonstration and expansion of user profiles, global outreach, and engagement will create an actionable roadmap to accelerate the adoption of BCTE.

Introduction

The energy industry is undergoing unprecedented transformation due to a number of factors including environmental regulations, new technologies, and active prosumer participation in decentralized generation, storage, and smart load management at the grid edge. The proliferation of Distributed Energy Resources (DER) has caused operational issues for grid operators due to their variability, and unpredictability of the impact of DERs on the grid. Properly designed incentive-compatible local energy markets can help align prosumer incentives with grid operator objectives. The existing centralized markets cannot handle large volumes of small quantity transactions involved for such a realization. A Transactive Energy platform providing for both peer-to-peer and peer-to-market transactions provides a natural solution turning the DERs around from being a problem into a solution for grid management based on market mechanisms. Another issue with the current energy markets is the relatively high transaction costs for market participation, delivery verification, and settlements. This is where Blockchain technology comes to the rescue. Thus a Blockchain-enabled Transactive Energy (BCTE) system is proposed in this position paper as an enhancement of existing or emerging transactive energy systems that support incentive-compatible local energy markets for the mutual benefit of the prosumers, the grid operators, and the passive consumers, and to pave the way for consistent and efficient regulatory reform options where needed

The position paper touches upon functional, architectural, performance, scalability, and security considerations, as well as the needed supporting regulatory provisions. Sample use cases are laid out to motivate and illustrate the findings and recommendations. Future updates to this document will highlight ongoing worldwide regulatory reform activities (ie. FERC Order 2222 in the US, DER Registry in process in Australia, or the Tenant Electricity Law in Germany) that are attempting to evolve past restrictive legacy market structures, to allow efficient aggregation and participation of flexible, highly decentralized DER elements through platforms such as Blockchain Enabled Transactive Energy.

BCTE Proposal Summary

Blockchain-Enabled Transactive Energy (BCTE) proposes the development of a platform for a decentralized energy marketplace that also supports grid stability and load balancing. Fundamentally, transactive energy posits a new model for the grid that supports the decentralization of production and local management of energy and includes requirement for record keeping and transaction execution that may be most efficiently implemented using blockchain-based DLT and associated smart contracts. Customers who produce surplus energy beyond self-consumption are able to transact with each other and the grid distribution provider to trade in real-time in an energy market based on local prices. Control of the marketplace rests with the participants in the market. To date, no comprehensive set of architectures, frameworks, and standards exists for a globally accepted integration of blockchain and transactive energy methods.

The transactive energy marketplace has particular applicability in developing areas of the world where reliable electric power is not available or in all areas where energy is often disrupted due to natural disasters such as wildfire or extreme storm events. It can also help to foster the prosumer's participation in the marketplace for renewable energy, allowing residential, commercial, and industrial producers of distributed renewable energy to be compensated for their excess generation above their energy use.

This BCTE initiative draws upon the industry and academic experts who have been pursuing transactive energy and want to develop a more coherent framework and applications leading to standardized methodologies. This paper and the subsequent BCTE project positions the IEEE as a thought leader in enabling economically driven, decentralized, renewable energy production, and in the construction of a marketplace paradigm for local energy trading. Building upon IEEE's core competencies in power and energy technologies, and in information and communication technologies, IEEE seeks to facilitate the development of core standards and application methods for rapidly scaling practical solutions to both developed and developing world energy ecosystems.

Context-Setting Framework

This section describes three main context-setting components that help define the framework needed for the successful development of a viable and commercially scalable BCTE platform. The three components, as further described below, are:

1. Transactive Energy Framework

2. Blockchain Technology

3. Regulation and Governance

Potential Users of BCTE

The Blockchain-Enabled Transactive Energy (BCTE) paradigm enables efficient transactions for energy and energy services that take place on behalf of numerous parties to these transactions. Some are active participants in the **physical** generation, storing, and consumption of electric power and others have a more **indirect** role in maintaining the system reliability, establishing market signals and incentives, or performing post-transaction audits and data analysis. The concept of where and when these *actors* are involved differ by their physical intensity of involvement, and also the time horizons that their involvement typically occurs over.

Below are the typical actors (and their roles) in a functioning electric power ecosystem running transactive energy protocols:

- Grid-**Centric** Actors
  - Power Generators (as specialized large central power generation)
  - Transmission Systems Operators (as specialized long haul power transfer)
  - Distribution Network Operators / Distribution System Operators
  - Load Serving Entities/Utilities (as governing entities and primary energy generators and/or distributors)

- Grid-**Edge** Actors
  - Consumers (residential and industrial end-users/loads)
  - Prosumers (consumers with the partial or full ability to self-power)
  - Aggregators (of grid-edge participant assets)

- Market Participants and Monitors

- Bi-lateral traders
- Governing bodies
- Auditors
- Market forecasters

Transactive Energy Framework

The Transactive Energy framework provides the principles, elements, common features, and conceptual models for integration and monetization of distributed energy resources (DER) in the emerging electric power system. The term Transactive energy (TE) refers to the use of a combination of economic and control techniques to improve grid reliability and efficiency and to open paths to broader participation and investment in distributed energy resources.

There are several global development activities currently exploring frameworks that could enable Transactive Energy, for example, a TE Framework was developed by the GridWise® Architecture Council (GWAC) with support from the U.S. Department of Energy, which defines TE as "*A system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using market mechanisms, with value as a key operational parameter.*" Other organizations across Europe, Asia, Australia, and Latin America are advancing this work as well.

Blockchain Technology

Blockchain technology, a Distributed Ledger Technology (DLT), enables the creation of a shared decentralized database of transactions (i.e. any sort and form of data) which are chronologically recorded, cryptographically signed with the private key of the parties that contributed to the transaction and stored in a tamper-proof digital ledger with a timestamp. These transactions are organized in blocks that are then chained together by recording a cryptographic hash of the previous block in a new block, upon reaching consensus between all nodes in the blockchain network. The blockchain records are visible to all parties with permission to access the ledger, thereby providing transparency, and are designed to preserve the verifiability and persistence of this unalterable record. Blockchain thus offers immutability, transparency, verifiability, and security superior to other existing technologies.

A blockchain or DLT is append-only – new blocks can only be added at the open end of the chain by participating nodes that adhere to the consensus model and follow other rules set in the consensus protocol – thus eliminating the need for any central authority to control.

In addition, blockchain also supports Smart Contracts and Decentralized Applications (DAaps), integration with other technologies (such as IoT and cloud) for multifaceted applications in many other domains including transactive energy.

Consensus protocols

“Consensus” plays a vital role in blockchain architecture. It is extensively used to get the transactions verified and validated as well as then concatenating them in a new block for chaining with the existing ledger. Consensus is required at each stage of verification and validation, however, it plays the most significant role in the final step - calculating the hash to padlock a newly constructed block, and providing the decentralized authority for assembling some or all verified-but-unconfirmed transactions from a waiting pool and “sealing” it as an append to the existing chain. This hashed padlock creates the extra layer of security that blockchain offers, and makes the chain immutable and verifiable in the future.

There are several classes of consensus algorithms, such as Proof-of-Work (PoW), Proof-of-Stake (PoS), Proof-of-Authority (PoA), etc. The voting-based consensus algorithms are built on Byzantine Fault Tolerance (BFT) architecture, round-robin models, etc. Ultimately, the consensus mechanisms are used to reduce or remove the role of a central administrator in authenticating the transaction. While PoW is the most commonly used algorithm for running public (permissionless) blockchain ecosystems, it brings a high overhead cost with its excessive consumption of electric energy, computational power, and time (i.e., high latency). Consequently, a private/permissioned blockchain could be more appropriate for transactive energy applications; therefore, the PoA or voting-based consensus should be preferentially developed in the BCTE project.

Smart contract for energy

A smart contract is simply a digitally signed computer “handshake” protocol (contracts) between two parties or more ‘delineating’, ‘representing’, and replacing a traditional legal contract. Smart contracts can be executed both with and without adopting blockchain or other Distributed Ledger Technologies (DLT). The main difference between a blockchain-based smart contract and a traditional digital contract is that the former is embedded in (and runs on) blockchain or DLT ecosystems, where enforceability or execution of the terms and conditions of the contract is automated – without the need for trusted third-party intermediaries.

Depending on the degree of automation required, smart contracts can also be attributed as “shallow” as well as “deep”. Shallow smart contracts are limited to perform very basic operations such as token-based transactions. On the contrary, deep smart contracts can perform complex (multiple) operations depending on the nature of the input(s) or trigger(s). Since most transactive energy applications require a complex interactive system, a deep smart contact, specific to the energy market is needed. Potentially both classes may be utilized together for certain use cases or applications where a token may become an integrated value exchange mechanism within the broader solution.

Access Control Consideration

Below are typical Access Control considerations being developed in the BCTE project. These are needed for the blockchain to securely enable the above-described roles while maintaining privacy and trust:

- Permissionless architecture using Proof-of-Work (PoW) is unsuitable considering the nature of the BCTE project. Therefore, a permissioned platform using PoA or voting-based consensus algorithms need to be implemented.

- Developing a customized consensus algorithm, based on the required write access, may be considered.

- Off-chain recording and storing of Personally Identifiable Information (PII) and/or Potential Personally Identifiable Information (PPII) can be considered to avoid conflicts with data privacy acts. Some of the private/enterprise blockchains use membership service providers (MSP) to validate the transacting nodes without sharing the PII with any peer nodes. In that process, the peer nodes may have a unique identifier (UUID) to represent them in the network.

- Read access to the data stored in the ledger or off-chain also needs to be controlled.

- Latency shall be considered when designing almost real-time grid transactions.

- Need to have smart contracts designed to facilitate and automate the energy trade.

- Read/write/execute based on need-to-know and least-privilege.

- Role-based access controls (RBAC) could be implemented using private/enterprise "blockchains".

Regulatory and Legislative Framework Associated with BCTE (Energy-Financial-Legal-Privacy)

Energy Market Regulation

Energy policymakers and legislative authorities are responsible to determine the rules of the game for the energy marketTherefore, for any type of initial market and product design, it is essential to execute a comprehensive techno-political analysis that double-checks the boundaries of the proposed framework for compliance with a given (or aspirational) set of energy policies and regulatory conditions. Energy policymakers have begun to promote, support, and control the use of blockchain technology in various domains such as utility tokens, smart contracts, and privacy-related issues in a systematic way. For example, the European Union (EU), China, Germany, Estonia, Italy, Malta, Liechtenstein, and the United Arab Emirates have developed various blockchain-related legislative frameworks since 2015 and have made considerable "crypto-political" efforts in different industries. Although lagging in the

US, there are major clean energy programs lining up for post-pandemic 2020 that may begin to legislatively direct the allowable use of blockchain-enabled transactive energy to revive the economy and expand the adoption of decentralized, digitized, and democratized DER.

While energy consumption and, increasingly, generation and storage may be hyper-local, the derived monetary transactions in exchange for the energy could cross borders and legal systems, making them harder to monitor and regulate by the governments and their supervisory agencies. While the specific area of cryptocurrency blockchain may prove important to the ultimate transaction clearing, it is considered beyond the scope of this paper. Some form of blockchain based utility token specifically targeted for energy transactions may be helpful to implement a blockchain based energy transaction system as a logical first step.

Legal/Contract Constructs

Acceptability and validity of smart contracts thus differ in different legal jurisdictions. While one school of thought is of the opinion that smart contracts are a digital representation of legacy contracts, some do not consider smart contracts as contracts at all. Smart contracts being self-executing makes dispute resolutions even harder, should anything go wrong in the performance and execution phase(s) of the contract.

In fact, differences in contract law, with regards to common law and civil law, also need to be considered, particularly in dispute resolutions. Within the Software Development Life Cycle Models (SDLCs), blockchain-enabled smart energy legal contracts (SLEC) need to be carefully designed to consider all energy transactions, legal aspects, and limitations brought about by the immutability nature of blockchain..

Cyber Security and Privacy

While the definition of Personally Identifiable Information (PII) and Potential Personally Identifiable Information (PPII) is almost similar in various worldwide jurisdictions, legislation on *protecting* PII (e.g. data protection act) highly varies. For instance, EU's General Data Protection Regulation (GDPR) and Hong Kong's Personal Data (Privacy) Ordinance (PDPO) are very strict with regards to handling PII, the California Consumer Privacy Act (CCPA) of USA is somewhat lenient compared to the former two, and the US does not have a uniform federal data privacy act for its individual states. Many countries in the world do not have any data protection act at all.

When it comes to digitalization of power systems and markets, the legislative framework is becoming more complicated since it is expected to cover the overlapping and interdisciplinary domains of energy and digital technologies such as blockchain and AI. Germany is one of the leading countries which released a comprehensive Blockchain Strategy Document that covers the energy-related use cases of blockchain beside other fundamental components. Other countries are predicted to follow Germany's previous transition to green energy (Energgiewende) strategy and release their national digitalization documentation which covers sector-specific components such as energy, logistics, and health-related legislative activities in the coming years.

Proposed Architecture

Transactive Energy Systems

The basic premise behind transactive energy is that by more directly coupling high-resolution fine-grained measurement and control of power supply and demand, with matching precision for associated payments, additional economic efficiencies can be realized. This can coincidentally satisfy broader societal goals such as increasing grid stability and resilience while avoiding large rate based cost increases, empowering local community economic advancement, and reducing the carbon emission and cost of generated power. This combination of objectives constitutes a multi-objective optimization problem both in forwarding and real-time transactive markets. Solving such a problem using traditional centralized and unidirectional power flow control approaches becomes increasingly difficult and expensive, and as the penetration of renewable distributed energy resources (DERs) increases, this accelerates the opportunity at the grid edge for a steeper reduction in the carbon content of power and enables far more efficient direct coordination and balance between producing and consuming parties.

Blockchain-enabled Transactive Energy proposes applying a blockchain based DLT to both existing and emerging Transactive Energy systems to more efficiently solve the traditional grid balancing, DER integration, and market clearing problems where:

1. Agents managing the power generation and load demand engage in multi-agent communication to improve the real-time optimization problem for grid management as well as the longer term asset investment productivity optimization.

2. A blockchain-based ledger records the results of the solution along with data about grid operation in a distributed, transparent, non-reputable data store for regulatory purposes and dispute resolution, as well as informing capital flow to the highest efficiency future infrastructure investment.

While blockchain will not replace existing power flow control communications, it may play an important adjunct role in coordinating a tighter integration of assets and their services to improve the effectiveness of the data management and communications networks. Figure 1 below illustrates a proposed blockchain-enabled transactive energy architecture for the distribution grid with three stacked layers annotated on the left side of the figure.

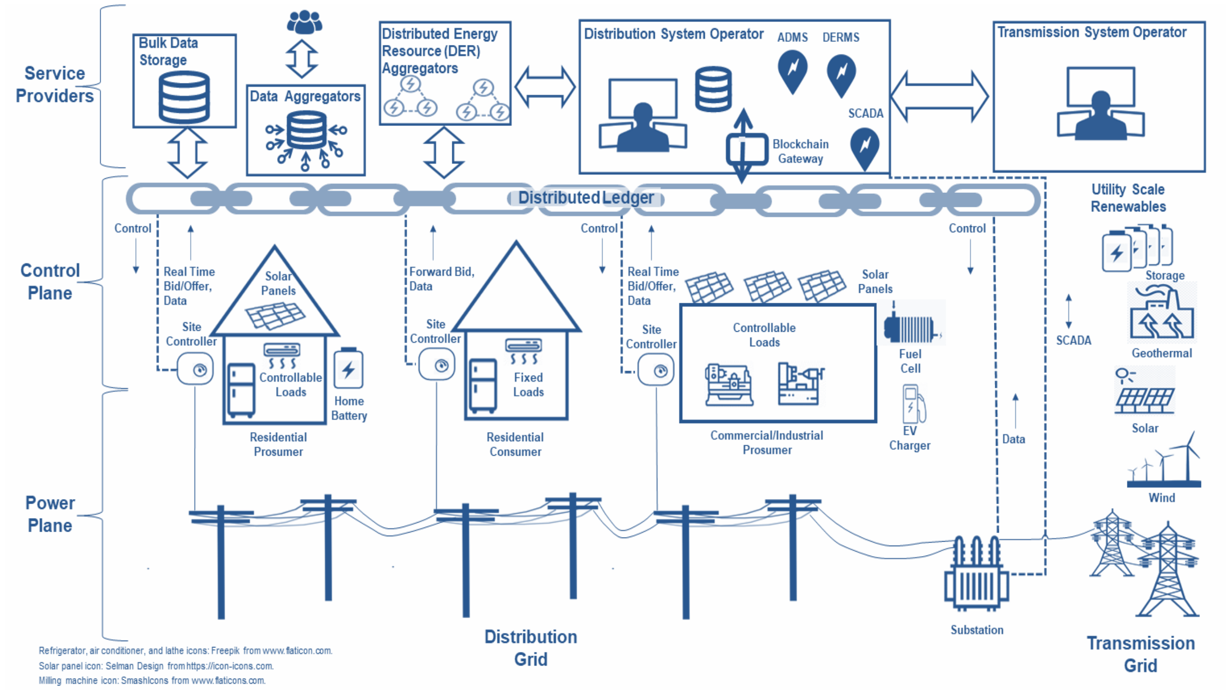

Fig. 1 – Proposed High-Level Architecture for Transactive Distribution Grid

The following are the layers considered:

- The **power plane**, through which electrical power is delivered to customers. Currently, one-directional, flowing from central large power producers to diverse consuming load, power flow is becoming more two-directional as more local DER generation and storage is deployed at the grid edge. Along with smart load control power electronics and increasing use of AI, this is providing flexible and valuable load-serving and balancing options. The equipment on the power plane consists of front of the meter devices such as transformers, substations, and storage clusters, and this equipment is owned and controlled by the distribution system operator (DSO).

- The **control plane**, which includes traditional utility control systems such as supervisory control and data acquisition (SCADA) systems for centralized control as well as the proposed blockchain transactive energy network for distributed control using utility Distributed Energy Resource Management System (DERMS) in conjunction with an aggregator's management tools. Behind the meter (BTM), customer-owned power production devices such as solar photovoltaic (PV) systems and fuel cells, as well as controllable load devices such as an electric vehicle (EV) charging stations, which are typically not seen by the DSO's SCADA systems, participate in the blockchain-enabled transactive energy control system. Control may thus be achieved through compensation provided for a response to a combination of direct load command (hard) and/or market incentive (soft) signals to these BTM assets.

- **Service providers**, who offer some service on top of the control and power planes. Chief among them is the DSO, which maintains control over their equipment in the distribution network and is responsible for the stability and smooth operation of the grid. Newer service providers include bulk data storage providers that offer storage for volumes of data too large to fit on the blockchain, data aggregators that aggregate and anonymize data and sell it for various uses, and demand response (DR) and DER aggregators (sometimes called virtual power plant operators) who aggregate controllable loads DR and DERs, and offer their aggregate flexibility to the DSO for various purposes. In some cases, the DSO may perform the DER aggregation itself. DER aggregators and the DSO participate in the blockchain transactive energy protocol to control power flow to customers and ensure grid stability through providing and consuming ancillary services.

In addition to the three layers, shown on the right-hand side of the figure is the transmission system operator (TSO). While the TSO does not participate directly in the distribution network transactive energy blockchain protocol, the DSO control systems must coordinate with the TSO to ensure that the power needs of customer loads are covered beyond what can be supplied by DERs in the distribution network. In addition, the TSO may provide for market participation of some DERs or Virtual Power Plants that may be increasingly provided by third party aggregators where allowed by regulation. TSO-DSO coordination is important in both operations planning and real-time operation to ensure DER/VPP participation in bulk power markets does not result in unintended consequences in the distribution grid such as phase unbalances, excessive reverse flows, or voltage violations.

The blockchain-enabled transactive energy system in the central part of the figure enables smooth integration of DERs into the grid while enabling residential and commercial/industrial prosumers to be compensated for providing energy and grid flexibility and resilience services. The following hypothetical and anecdotal example helps illustrate operation of transactive energy systems:

- Agents associated with individual distributed energy resource at a site engage in automated price (or other surrogate market signals) responsive device control based on the device's capabilities and the device owner's preferences.

- The prosumer's (producer-consumer) site controller aggregates the responses into an overall price flexibility curve and sends the resulting curve to its DER aggregator as a real-time bid, along with performance data about the load and power generation. Residential consumers on traditional utility rate plans without any power production or controllable load who want to exercise some compensated demand choice have forward bids that correspond to their response to the rate plan for which they signed up. These may include opting in Time of Use (TOU) rates or response to energy supply offers from non-utility energy service providers.

- The DER aggregator further consolidates the price flexibility curves from different site controllers into an aggregated demand curve, a VPP supply curve, or a combination, as the case may be.

- The DER aggregators and the DSO jointly solve the multi-objective optimization problem to perform price discovery, including grid objectives such as capacity management, frequency control, and volt-VAR control, and societal objectives such as maximizing carbon-free power generation along with the aggregated demand curve, to determine the price at which the grid and societal objectives can be achieved, or transactionally “cleared”.

- The DER aggregators and DSO broadcast the solution to the site controllers.

- Devices at the site adjust their power consumption and generation accordingly, and measurements are recorded to verify the delivery of the committed response.

- If any power needs to be imported, the DSO’s control plane participates in either the TSO’s day ahead or real-time auction, to ensure a balance between supply and demand on the distribution grid.

- The transaction is “cleared” and payments are digitally made, possibly on a side chain DLT handling energy based tokens or/and fiat currency coupled.

An important component of the blockchain transactive energy protocol is collecting fine-grained site/device data on power supply and demand, correlated with its clearing price, as well as collecting data for the price vs load aggregate demand curve. While the amount of data storage needed may exceed what can be reasonably stored on a blockchain, the blockchain provides a place to record verifiable records (cryptographic hashes) of the data and links to the data itself stored by a block-data storage service provider. In turn, this larger logical data set maintained by the blockchain can serve as the basis for decision making and analysis.

Several examples can help highlight the derived value streams that a blockchain-enabled Transactive Energy data set could bring:

- One example might be for the DSO’s planners to decide if and when grid infrastructure needs upgrading, and in what priority order.

- Another example could be an automated DSO control plane system providing input into the TSO wholesale market day-ahead pricing auctions.

- As a tertiary ecosystem player in a growing value market segment, a data aggregation service provider may also want to mine, assemble, anonymize, and sell the data to third-party service providers.

- Finally, the transparency and immutability of blockchain transactions provide regulators with a verifiable record of the energy market should monitoring or data collection for rule-making be required.

This transactive energy architecture solves a particularly difficult problem involving DERs, namely how to compensate DER owners for their contribution to grid stability and the achievement of social objectives. The most common way for owners of DERs to receive compensation today is through feed-in tariffs and net energy metering (NEM). Both schemes couple a financial return to the amount of *energy* created and fed back into the grid. But with increasing deployment of DERs, grid stability requiring both real and reactive power injection and absorption become increasingly important as well, which may not require any actual energy export. Recent advances in power electronics for smart inverters, compliant with the latest IEEE 1547 interconnection standards, and economically viable battery storage now enable DER owners to provide these non-energy-based grid services as well. By taking into account grid stability and social objectives when solving the multi-objective optimization problem, the local aggregator can incentivize DER assets to contribute more than simple power generation, and the blockchain-enabled Transactive Energy protocol allows them to be properly compensated.

While the above architecture is primarily focused on transactive energy for the distribution grid, transactive energy may also have a role to play in the transmission grid and wholesale market. In that case, the agents are associated with the larger generation and consumption entities, such as utility-scale solar and wind farms, industrial facilities that buy their power in the wholesale market, and utilities. Coupling pricing mechanisms such as locational marginal prices at distribution feeders together with real-time measurement and control of wholesale customer demand can be used to support growing load or relieve congestion points with a non-wires alternative (NWA), allowing TSOs to avoid the costs of installing expensive equipment upgrades, and leading to a higher risk of future stranded assets. NWA auctions may also take place at the distribution grid level to eliminate or defer costly upgrade of distribution circuits. Smart contracts can be used to govern the interactions between the participants in the wholesale market as well as DSO facilitated local markets.

Blockchain technology can also be used to a couple of wholesale markets to distribution markets in a more fine-grained fashion. Blockchain can also be considered as a wholesale marketplace platform for incorporating multiple DERs into the transmission grid. The inherently decentralized nature of blockchain technology solutions enables the kind of scalable integration of smaller DERs that is difficult for centralized systems to accommodate.

Referring to the high-level architecture of Fig. 2, and following the classic OSI model used widely in IT, a basic “stack” structure for transactive architecture design is envisaged here building on interoperable layers that may each be applied toward full local market solutions. Foundational lower layers that are physical, computational, or logical network in nature can be developed toward reaching global standardization goals leading to certification, while those that require jurisdictional tailoring and disambiguation at the upper layers, such as business models, market structures, regulation, and policy, maybe left more flexible while documenting best practices.

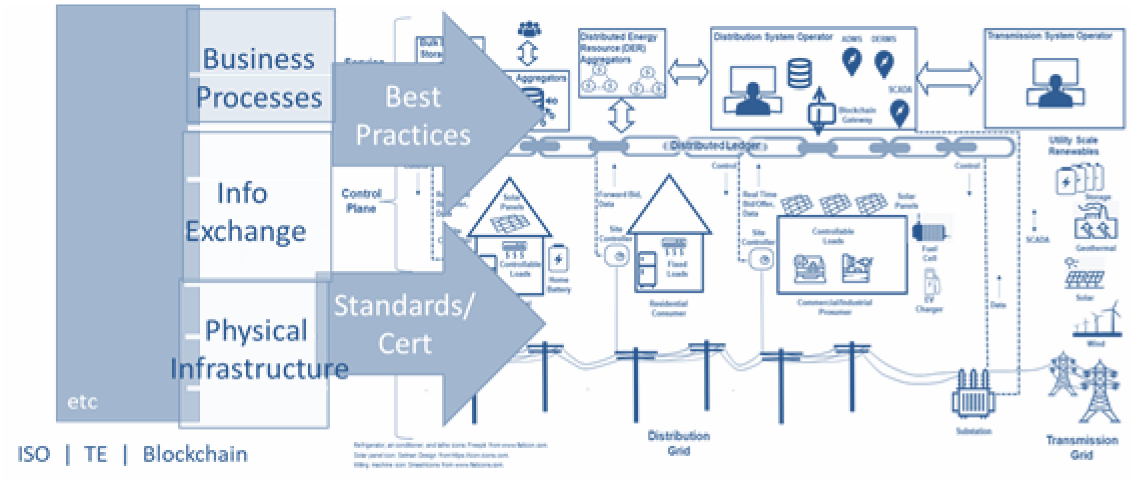

Fig. 2 – Mapping High-Level Interoperable StackLayers onto Blockchain Transactive Distribution Grid

Inter-DLT Connections

A transactive energy system spanning a distribution grid is likely to consist of many traditional consumers and many small DER and DR suppliers - commercial/industrial and residential prosumers - in addition to a few relatively large participants, including the DSO and DER aggregators. A common blockchain platform allowing all participants to communicate is the most likely deployment model for efficiency and performance reasons. Other applications, such as blockchain-based supply chain management systems, may require interconnection with the transactive energy blockchain, to ensure that the records of installed equipment and software are up to date. In addition, some social media and marketing applications may run on their own blockchain platforms, to allow participants in the transactive energy network the ability to opt-in for participation in social media campaigns. Finally, the conversion of energy transaction value created and earned may need to link the transactive energy blockchain to an energy based token application for monetization.

As transaction energy blockchain platforms achieve wider deployment, there may be a need for connecting two blockchain run distribution grids managed by separate organizations, especially in the case where a microgrid connects into the larger grid, or when a municipal utility grid connects into the larger regional utility. Connections between TSOs and DSOs may also require interconnection between separately deployed blockchain platforms. In these cases, an inter-DLT interface may be required if power and control actions are necessary between the two interacting systems.

Connections Between DLTs and Existing Systems Applications

Today utility information technology and control systems are by and large centrally controlled, either directly where the utility switches devices on and off without any local information or where the optimization and control are performed from a central point to which information must be communicated. With the increasing penetration of renewable DERs and fine-grained device load DR, central control becomes more and more difficult. Solar power generation changes quickly in response to clouds and shade, and customer loads can also fluctuate. In addition, the sheer number and interconnectivity of devices are likely to overwhelm a centralized architecture. Yet some central control is still required, to ensure that power purchases from the wholesale market are coordinated with fluctuating local generation and load profile. Also, for billing purposes, transactive energy charging systems need to be integrated with legacy utility billing applications. These considerations suggest the need for a local to the central control interface, where further aggregation to a timescale appropriate for the utility's central control plane, is performed, and an interface between the blockchain distributed ledger and the utility's centralized billing and settlement systems. Blockchain gateways are emerging for the latter purpose.

Impact of Blockchain Energy Standards

Blockchain is still an emerging technology. Blockchain in transactive energy activities started around 2017-18. In September 2018 the IEEE officially launched the first global blockchain in energy standards, the IEEE Blockchain in Energy P2418.5 WG, with the goal to create the framework, reference architecture, defined use cases, and basic definitions and terminologies for this space. In the early work of P2418.5, an industry survey was conducted to map all potential use cases around the world, and the transactive energy and energy trading using blockchain was identified as the major use cases being considered and developed by the industry. It is expected that more standards in this area will be developed as this technology becomes mature, and BCTE will be a major influence for standardizing these blockchain-based, energy-related applications.

Importance of Standards for the BCTE Adoption

Transactive energy is not a new topic. Its concept has been defined and piloted by government, industry consortiums, utilities, and energy companies in the past years. However, there have not been sufficient standards yet to fully inform a complete BCTE framework, functional requirements, and reference model. Standards are therefore an important milestone for the technology adoption and this may take from 3-5 years for this technology to achieve full maturity and become more broadly adopted by the industry.

Areas of Standardization for BCTE

BCTE is a common framework for blockchain usage, implementation, and interaction in blockchain transactive energy. BCTE is a complex topic with different modules and intersection points with other verticals and technologies. The IEEE Standards Association is developing an overarching blockchain standards series within which a specific focus area on the Energy domain is being pursued under its “dot 5” extension. Within the P2418.5 effort there has been a Task Force established for Transactive Energy that will be informed by this BCTE Project work.

The following are the main functional areas where BCTE requires standardization:

- Data formats
- Consensus algorithms
- Governance models
- Cybersecurity
- Smart legal energy contracts framework
- Reference framework
- Interoperability

Challenges of BCTE Interoperability

There will likely be multiple BCTE technology platform solutions in the near future, ranging from those developed by technology industry associations, industry consortiums, and proprietary business models. The most ambitious goal (but highest benefit) for any standardization process is therefore to define and create an ***interoperability framework*** for these diverse BCTE platforms to share a common core platform, and to the greatest extent be enabled to interoperate without extensive and customized system integration work needed. This is critical to wide industry adoption by the energy industry. However, before any interoperability model is created, a reference framework and an understanding of all different technology is needed. It is premature to start any interoperability model without fully understanding how the technology works, how it is defined, and what segments are most suited to standardization. It is expected that these interoperability models will be addressed by 2022-23 when the industry and the technology reaches a more mature level with the right reference architectures, and several of the planned demonstration pilots will begin to validate the design performance.

Types of BCTE and the Challenges for a Single Unified Model

Another important challenge for BCTE standardization is the definitions, applications, and use cases of BCTE technology. BCTE is a broad concept and can be categorized into different areas, with different customer needs and models. Among the models available the most popular is the peer-to-peer energy transactions between grid prosumer/consumers, focusing on retail energy markets. However, there are also BCTE models that address wholesale and bulk energy transactions that can be defined under these standards.

Defining Domains of BCTE Interoperability

Before any model is created, it is important first to classify the BCTE models according to an energy system, or utility grid operation, and its evolution. It helps to better understand how the traditional regional electricity grid is being disrupted by the following trends:

- Overall Load in Developed Regions is Stable or Dropping, driven by higher efficiency power electronics, more efficient buildings, and grid defection.

- Inefficient and expensive Central Power generation, along with losses in transmission and distribution lines, is rapidly losing share to cleaner and more efficient local (or at least proximate) Distributed Generation.

- Energy storage was minimal and co-located at central generation in the electric system (mostly as pumped hydro) and dramatic cost reduction of battery storage is driving the proliferation of capacity scattered at the grid edge, with some larger utility or community-run systems being placed locally as well.

- Lack of fast, reliable, and secure IT platforms caused utilities to self-invest in major control and billing systems with little integration or flexibility. IoT, blockchain, cloud computing, and open standards changing that model.

- Residential, Commercial, and (to a lesser extent) Industrial load was held captive with no competitive alternative energy provider. The energy market was first deregulated as wholesale markets developed, and now this flexible DER is enabling Retail level alternatives.
- The regulatory utility franchise model is under huge pressure to allow cost- and resilience-effective prosumer involvement and to push NWA alternatives for utility cost avoidance.

The above are forcing an evolution from a centralized to a more distributed energy model, where private investment in distributed energy resources (DER) can be connected, coordinated, and compensated. This enables the bi-directional flow of energy, which can create consumer and community empowerment in generating their own local energy. While these changes are happening, the traditional utility is looking at evolving its business model to remain efficient, economic, and in some cases even relevant, value-adding participants. This is the area BCTE is expected to grow. Most standardization efforts will be focused on enabling this evolution over the next few years.
Note that the discussion below considers the electric grid to be a conduit for both energies (i.e. the total volumetric kWh generated and transferred) as well as power (which is the instantaneous flow rate in kW at which that energy is transferred). The distinction is more than semantic, as these have different drivers of valuation, and therefore corresponding prosumer compensation, may be handled differently on the energy blockchain.

Classes of Standards that Inform a BCTE Standards Framework

There are four main classes of standards that are important for the BCTE standardization, they are:

1. Electric Power/Energy grid standards
2. Transactive energy standards
3. Blockchain standards (in general)
4. Technology specific standards

The electric power/energy grid standards are the ones driving BCTE adoption. These are traditional industry standards that are already mature and being widely used and adopted by the industry. These existing non-blockchain-based legacy standards are the first ones to be examined for an extension with components of BCTE in their frameworks. This is considered an addendum, or update of existing grid standards to make them compatible and updated.

In addition to legacy grid standards, there are also definitions of transactive energy (TE) standards, methods, and reference models that have been developed for domain interoperability by the industry for quite some time. However, for these existing TE definitions, there is the missing link of adding the blockchain layer to complement this interoperability and reduce the amount of “friction” in the transaction. That is the purpose of a standards-based BCTE framework.

There *are* some blockchain standards currently being addressed by the Standards Development Organizations (SDO), industry consortiums and associations, and others. These are more generic frameworks that do not cover BCTE standards, but in fact, are the groundwork to define some important blockchain concepts that are applicable to the BCTE reference model construct. Most of these definitions will be re-used, referenced, and incorporated in future BCTE standards.

Finally, the technology-specific standards, that cover data formats, cybersecurity, privacy, performance, interoperability, and other technical aspects are complementary concepts to the development of BCTE standards.

An intersection between these areas is expected when fully designing a BCTE framework, and eventually the standardization process to create a system-of-systems BCTE model. Figure **x** below shows the BCTE intersection areas where blockchain/DLT, transactive energy (TE), power/energy grid system, and other important topics, define the interaction between these important segments. BCTE is an emerging technology and the overlapping of existing and new areas will create this new foundation layer.

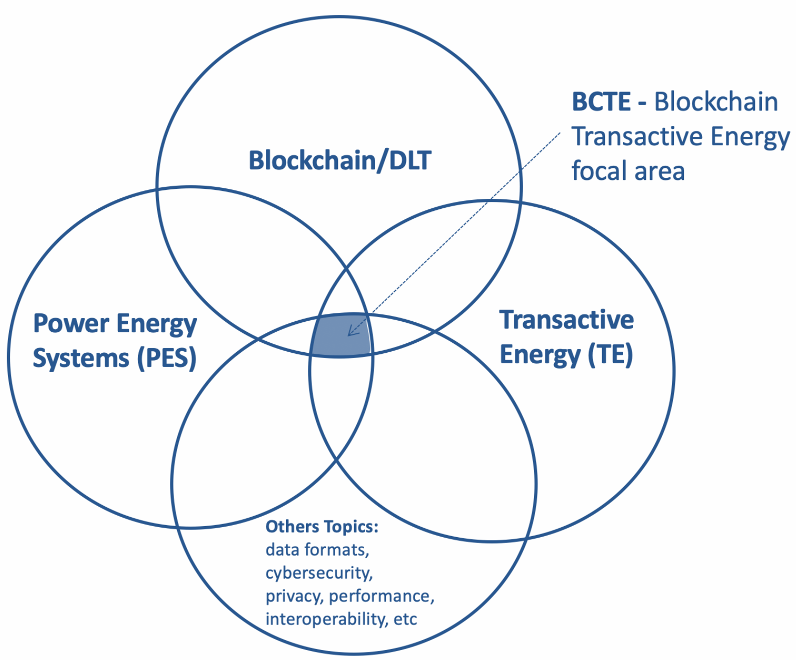

Fig. 3 – BCTE Intersection Areas

Use Case Examples of Applied Technologies and Demonstrations

Early application of blockchain technologies that loosely conform to (or at least do not conflict with) portions of the emerging BCTE architectural framework can demonstrate the efficiency, security, and functional capability of blockchain to enable various user profiles for Transactive Energy. The program envisions parallel development of these more practical demonstrations which are guided and prioritized by the following criteria:

- The blockchain portion of the application is mostly self-contained and independent of many complex functional interfaces within the energy system.
- Underlying energy systems are not overly constrained by immutable regulatory barriers.
- Potential for rapid commercial scaling of resulting business solutions.
- Demonstrations should be largely completed by 6 months.
- Demonstrations may be led by utilities, communities, regulators, or third-party solution vendors.
- Proposed demonstrations must identify the resources (people, processes, and HW/SW).
- Demos can originate within the BCTE committee or be sponsored from outside

The envisioned demonstrations meeting these criteria are considered starting concepts to be more fully designed and developed by a dedicated sub-committee, whose charter is to assure compliance with the program goals and to recruit the participants to fill the key actor roles. Each is briefly described below in terms of how BCTE can be implemented and tested to advance the goals of that specific application. In general, the following superordinate benefits of utilizing blockchain in transactive energy systems are expected for each case; process efficiency gains, artificial intelligence control, participant interoperation barrier reduction, and commercial market scalability. This work will commence in 2021.

Demos of Hardware or Software and Hardware-Software integrated applied technologies

Basic assembly of core processors, power electronic devices, communication systems, and controller software will be made with the specific goal of baselining performance characteristics of the "platform" needed for the subsequently applied models identified in the Proposed Architecture section above. Specifically, the following characteristics will be studied and documented for this baseline:

- Performance
    - Data throughput (Bandwidth)
    - Communication Latency
    - Scalability

- Security
    - Access Security
    - Data Privacy

- Cross-Functional
    - Chain Protocol Adherence
    - Immutability
    - Interoperability

Potential Demos of Rural and Urban Applied Models

Demonstrating the common functions that could be used within and across multiple domain interfaces would show the functional utility of blockchain support in process integration, including the potential use of Smart Contracts. The following transactional paths would be demonstrated

- DSO to DER
    - Directly through DERMS
    - Through an Aggregator

- DER to DER
    - Classic peer to peer direct value exchange
    - With adjacent energy based tokens or fiat currency conversion

- DSO to DSO
    - Balancing service offer and purchase
    - Microgrid Exchange? Federated Microgrids (see below)

A fourth category “blockchain-based DSO / TSO transactive exchanges” is also envisaged as a future demonstration project.

The distinction will be clearly made between the Transactive Energy portion and the Blockchain-Enabled for these demonstrations, and in some cases, it may be useful to demonstrate the identical transaction process being executed first through legacy systems and protocols, and subsequently on the blockchain. This will reveal quantifiable benefits as well as potential issues and barriers to wider adoption.

Mini-Grid

Many regions of the world are only now developing their electric grids and therefore have the option to advance their electrification with “always-islanded” community microgrids (mini-grids) that host highly decentralized generation. Demonstrating the use of blockchain-based local energy market mechanisms for the activation, permissioning, and operational participation of privately owned assets (generation, storage, and load control) will show how the mini-grid can be used as the platform for market-driven self-scaling. In many areas, the economic benefits of this model will provide exceptional returns on community education, health, and security. Community solar may be an excellent application for this use case.

The humanitarian demonstration specifically identified in the IEEE NIC approved a proposal for this BCTE project will most likely fall under this class of demonstration.

Electric Vehicle (EV) Battery Backup and Charging

Blockchain DLT can be used to incentivize and reward cost-effective and “(micro)grid-friendly” electric vehicle refueling strategies. Timestamped records from interval meters recording energy and power draw can be collected and used for transaction clearing purposes - for example, an EV owner could have a Smart Contract negotiate and execute their vehicle battery recharge strategy against a differently priced option for either a slow or fast recharge (ie varying power flow) that may also be informed by data taken from a calendar that shows when and where the next destination will be. An optimal and customized participation in the charging service can be achieved and the transaction clears with all appropriate factors applied prior to the financial reconciliation (ie payment) step.

Over the longer term, the data collected, aggregated, and archived off-chain could serve to stimulate the participation of different energy service participants in this basic recharging process. For example, if there are frequently points where the high coincident load is triggering high prices from demand charges, there may be a market signal to incent investment in a storage battery (with or without local generation attached) to buffer and flatten these peak loads, thus avoiding these higher charges or even deferring an expensive grid infrastructure upgrade. The investment signal, as well as the monetization of investment return, would be simplified because of the blockchain application.

Beyond this, the charging profile data can be utilized by artificial intelligence (AI) to optimize future charging infrastructure placement, recharging strategies, and even fleet vehicle selection and route planning based on the related energy market, community behavior, and weather data models.

Microgrid Use Case/Demo

Grid-tied, normally connected, but island-capable microgrids running under the latest IEEE 1547 smart inverter certification offers operational flexibility and resiliency with clean energy hosting capacity. This provides an extremely valuable service to both the electric utility as well as the proximate commercial or community owner/operator. The systems and technology of the microgrid are common to the utility run distribution system (albeit at a smaller scale with a lower inertia and tighter balancing needs), while the primary distinction centers on asset ownership and operating mission, namely utility, community, or prosumer ownership/control.

A quick comparison of characteristics or attributes between these ownership alternatives helps to differentiate the purpose, while perhaps exposing some common functionality that blockchain can support for all.

	Utility Controlled	**Community**	**Peer to Peer**
Ownership	Utility	Community	Prosumer
Governance (Policy-Regulatory-Legal)	Regulatory AHJ	Local Authority	Shared Oversight
Data Transparency	Low (Opaque)	High (Clear)	High (Clear)
Governance (blockchain)	Consensus, private/hybrid	Consensus, public/hybrid	Consensus, public/hybrid
Permission Control	Tight control	Broader API	Broader API
Accountability	Shareholder	Citizen	Citizen
Auditability	Rate Case or PUC Request	City Council Ordinance	Ability to track transactions
Coordination Reqd (between distributed resource elements)	Low	High	High
Decentralization	LowModerate	ModerateHigh	High
Off-Chain Extensibility /Resilience?	LowModerate	ModerateHigh	High
Unintended Consequences	Low	Moderate	High

Table 1 – BCTE Design Functionalities

The full demonstration aims at running a blockchain managed microgrid transitioning between three states: grid-connected normal, grid-connected alert, and fully islanded.

Islanded Operation (Emergency Operated Grey Sky)

It is useful to focus on a single circumstance for islanding; mitigation of the impact from public safety power shutoff as issued by the utility. This case has a much more directly aligned interest between utility and community: ensuring resilient delivery of power in a crisis such as a wildfire or a storm. As such, there are three distinctive microgrid island activation and operation modes proposed under this part of the demonstration based on different microgrid ownership and control structures.

(1) as a tightly coupled utility-owned and/or operated asset.
(2) as a loosely coupled utility control of community energy aggregation.
(3) exclusively as a privately-owned asset and Behind-the-Meter (BTM) peer-driven.

It is hoped that a common platform, with simple configuration options, can be demonstrated which supports all three operating modes. With that established, a standard proven solution may simply be tailored to each regulatory jurisdiction**.**

Grid-Tied (Alert)

This is a state where the microgrid is connected to the grid, but must be vigilant to disconnect and transition to the Gray Sky.

There are still the same three distinctive microgrid island activation and operation modes proposed under this part of the demonstration based on different microgrid ownership and control structures. However, the transactive exchanges, price signals, and underlying smart contracts differ vastly based on the microgrid control and ownership model.

Grid-Tied (Normally Operated Blue Sky)

In this state, the microgrid may be viewed differently for prioritization of its value elements based on many economic functions it can provide while tied to the distribution grid. Perhaps the best approach to determining suitable demonstration objectives for this portion may come from a simple comparison of primary objectives for individual specific functions exercised.

A cursory example is shown below in Table 2, to guide the development conversation.

Table 2 –BCTE Microgrid Transactive Services

Microgrid Services	**Utility Controlled**	**Community**	**Peer to Peer**
Backup Power	Improve SAIDI, SAIFI, and CAIDI metrics	Preserve EMS response capabilities	Individual arbitrage and ROI
Reactive Power Inject/Withdraw	Volt/Var Regulation	Improved power quality	Improved power quality
Real Power	Frequency	Arbitrage potential	Arbitrage potential

Inject/Withdraw	Regulation, Contingency Reserves		
Black Start Generation	Improved resilience	Reduced duration of service outage	Reduced duration of service outage
Wholesale Market Ramping (Flexibility Service)	Ramp product market participation	Market Participation	Market Participation

Microgrid Federations

Microgrids federations, or networks integrate neighboring microgrids through a distributed digital and power network as a way to more reliably and economically distribute electric power among members of the network who can also be optionally coupled to a larger grid. This type of interoperability was briefly mentioned as a DSO to DSO type of coordination in the previous demonstration section above Potential Demos of Rural and Urban applied models.

The coordination interfaces required for this (TSO/DSO>Microgrid, DSO>Microgrid>DER, etc) bring high complexity for this use case so this will be schematically depicted here for future reference purpose only, and further development of this user profile will be deferred until the project matures and these types of configurations become more mainstream. Of particular interest is the rapid advancement of DC Microgrid concepts, which would simplify the interconnection of these advanced configurations and perhaps make them more manageable through BCTE platforms.

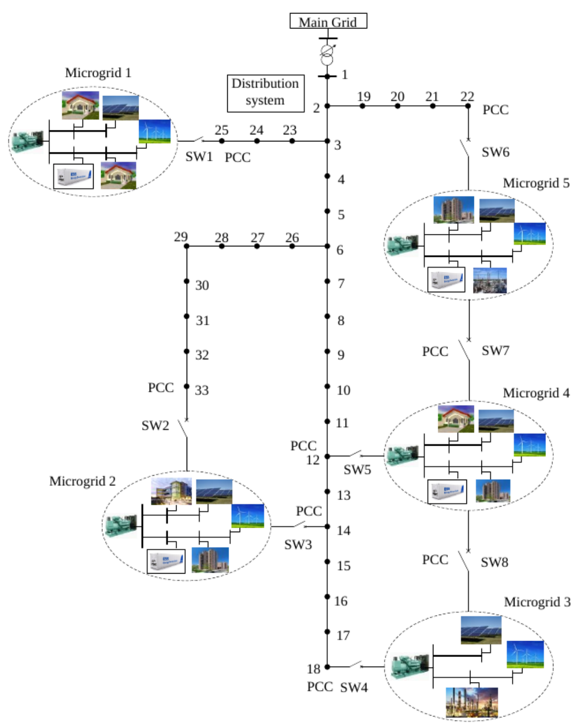

Fig. 4 – Example of a Typical Networked Microgrid

Conclusions and Key Points

This position paper serves the goal of framing and initiating the IEEE Blockchain Initiative's purpose to create a system architecture that can be used to pursue formal IEEE build standardization, and to advance other business model development types of activities, in the domain of Electric Power and Energy.

Electricity systems and markets have evolved significantly over the past forty years through five distinct yet overlapping phases: **deregulation, decentralization, decarbonization, digitalization, and democratization**. In particular, digitalization of the power systems and markets started a couple of years back when the industry and academia started to leverage the advantage of information and communication technologies to develop the products and services of the first wave of digitalization such as the Smart Grid framework, use of IoT SCADA, DERMS and similar advanced platforms to govern and control the power systems, and many other similar implementations. Digitalization of power systems has evolved over the past two decades to the point where artificial intelligence and blockchain technology has become possible to introduce to these digital ledger technologies (DLT) platforms. With more recent advances in cryptography, local compute power, and higher bandwidth network services, Blockchain technology appears to be a promising technology which opens up disruptive new paths toward cost-effective, ultra-efficient, and innovative service offers from various prosumer, commercial, and industrial domains to make, distribute, or consume electric power. This is the emerging world of Transactive Energy. It is expected to influence the development of the next-generation energy systems and the creation of new power markets for their enablement of future Transactive Energy use cases. The resulting stretch of the boundaries of existing market rules with novel forms of sharing and self-reinforcing digital economic models, all in search of ever cleaner and less wasteful energy production and consumption, will be strongly supported by blockchain technology.

This Position Paper aimed to elaborate a basic framework for principles of that blockchain technology, and its associated contextual use through distributed ledger technology within the power and energy domain. In doing so it laid out the roadmap for defining and developing standard blockchain-based mechanisms to deploy common processes, which can support the secure and efficient operation of Transactive Energy applications within a multi-party marketplace.

The paper introduced and articulated some of the more promising global Transactive Energy use cases which might be advanced through broader commercialization demonstrations using this blockchain technology, and also touched on a broad techno-political analysis covering the legislative and regulatory issues associated with these instantiations of blockchain technology.

Lastly, the initiative as structured serves to build a cohesive structure and organization around this Position paper that can align and grow worldwide local group contribution, which will be continuously refined and distributed through formal IEEE education and certification mechanisms.

Paths for Engagement

If you have been motivated to join the team developing these capabilities, please see below for paths to engagement. The BCTE steering committee is designing this program and members of this Committee can be found on the program website at https://attend.ieee.org/bcte

The BCTE Steering Committee Responsibility

The BCTE Steering Committee shall be responsible for the BCTE Program Design and shall convene four specific subcommittees that are specifically designed to include participation from communities of stakeholders with diverse backgrounds and interests. This is shown in the figure below.

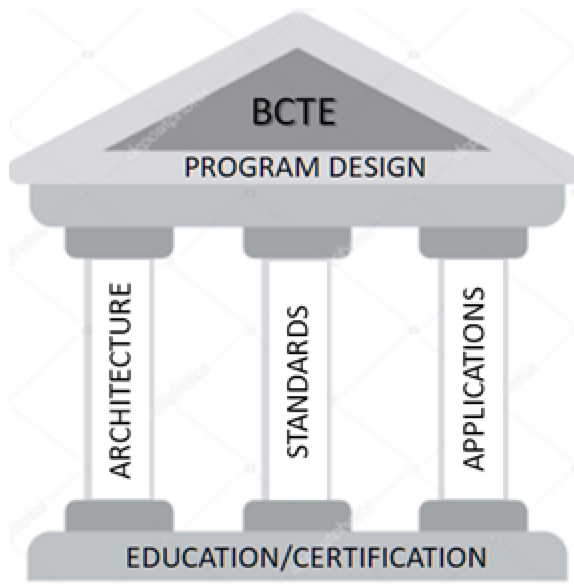

Fig. 6 – The BCTE Program Pillars

Developing the four structural elements of the initiative (Architecture, Standards, Platforms, Outreach/Education) will be assigned through subcommittees that are currently under formation as follows:

Pillar 1 - Systems and Architecture (responsible for the Architecture Plan and Blockchain-based platform(s) design)

Pillar 2 - Standards (Responsible for the coordination with overall IEEE standards and certification services)

Pillar 3 - Solutions and Applications (Responsible for the Use Case development and Demonstration)

Foundation - Outreach (Responsible for the Collaboration and Engagement Tools, Event Coordination, Training, and Compliance Certification)

There is an open call for participation on these subcommittees. The program is looking for participants that are experienced with blockchain, power and energy technologies, business and operational processes that are suitable for integrating and optimizing these technologies in a drive toward standardization.

To get involved, please visit **https://attend.ieee.org/bcte** to learn more and start with an interest survey to best align your interests.