Developing a blockchain-based prototype for wind turbine fasteners

Andrei Ionita[1], Kristoffer Holm[2], René Chester Goduscheit[2], Per Hessellund Lauritsen[3], Wolfgang Prinz[1], Kim Nedergaard Jacobsen[4], Kristoffer Isbak Thomsen[5]

[1]Fraunhofer FIT, Schloss Birlinghoven 1, 53757 Sankt Augustin, Germany

[2]Aarhus University, Birk Centerpark 15, 7400 Herning, Denmark

[3]Siemens Gamesa Renewable Energy A/S, SGRE OF TE, Borupvej 16, 7330 Brande, Denmark

[4]APQP4Wind, Lysbrohøjen 24, DK-8600 Silkeborg, Denmark

[5]Vestas Wind Systems, A/S, Hedeager 428200 Aarhus N, Denmark

The wind energy sector is undergoing digitalization processes that span multi-tier supply chains of turbine components and wind farm maintenance, amongst others. In an industrial use case that includes Siemens Gamesa Renewable Energy, Vestas and APQP4Wind, the processes of producing, fastening, and servicing bolts in turbines are mapped to a digital model. The model follows the lifetime of turbine bolts from the manufacturing phase, to fastening in turbines and maintenance, until their replacement and recycling. The development of the digital model is iteratively addressed in a design science research approach, as the authors actively contribute to the project. Distributed ledgers (DLs) support the notary documentation of the bolts and turbines, from their registration phase to the assembly-, technical service verification- and recycling phases. The immutable and decentralized nature of DLs secures the data against tampering and prevents any changes taken unilaterally by engaging the service stakeholders and component providers in a blockchain consortium.

1. Introduction

The wind turbine industry contributes increasingly higher amounts of energy into the network grid and is a key pillar amongst renewable energy sources. As an example, in Denmark almost half of the power in 2019 was produced from wind [1]. At the same time, the wind industry is in a process of digitalization. The wind industry supply chain is going through a substantial consolidation in terms of reduction of the number of suppliers for the wind turbine manufacturers. Vertical, digital integration within the supply chain is instrumental in this consolidation process.

Blockchain, on the other hand, is amongst the technologies that are advancing digitalization and digital transformation alongside Internet of Things, Big Data, 3D printing, etc.

The contributions of this paper are as follows:

- A mapping of the bolt fastening use case to a digital model is developed by identifying the data and processes involved.
- A blockchain network with the focus on smart contracts that implement the established process functionality and manipulate the identified data records is conceptualized.
- Access roles for the users in the network that regulate the access permission to the various data resources are elaborated.
- The designed smart contracts are implemented in a test Ethereum-based blockchain network.

The structure of the paper is as follows. Following the introduction, the current research on related use cases is summarized; next, the use case investigated in the paper is described in detail and a digital model mapping is elaborated; following is a description of the blockchain concept alongside the reasons for which the technology was selected; next, the proof of concept implementation of the blockchain solution is being presented; the conclusion summarizes the digital transformation process and points out further possible improvements.

2. Related Work

The presented use case is part of the UnWind project that is funded by the Danish Industry Foundation [2]. The overarching goal of the project is to increase innovation in the wind turbine industry and its supply chain while strengthening cooperation between the involved parties, both wind turbine manufacturers and subcontractors. By using the blockchain technology, which has properties such as decentralization and transparency at its core, the collaboration between the network participants will increase by the implicit sharing of resources and participation in the network governance. Holm [3] elaborates on the maturity of the blockchain as technology and its adoption in the wind industry in the context of the UnWind project.

Some of the applications of the technology have been targeted at energy use cases and the smart grid [4][5] or digitalization in the wind industry as a whole [6]. Other studies have investigated adjacent topics to the one that this paper addresses, such as the quality control in the supply chain of wind turbine blades and its traceability wins [7]. Worth mentioning is also the blockchain application to manage large amounts of data produced by offshore wind energy supply chains that achieves traceability and visibility [8].

3. Digital Model

The use case discussed in this paper follows the lifetime of bolts, from the creation- to recycling phase, as well as the maintenance process of fastening and replacing bolts in turbines.

3.1. Use Case

In the following section, the data and processes involved in this use case are described in detail.

A turbine bolt, or fastener, is designed to hold the turbine parts together and is a key element in the security of the turbine. We will further refer to a turbine-purposed bolt simply as bolt. Bolts are produced in batches of hundreds of pieces. The suppliers strive to maintain the same production quality for every bolt in a batch and provide quality documentation when delivering the bolts. Bolts are made from alloys such as brass and have a model identification. Typically used models are under the ISO 4014 standard [9].

The assembling of a turbine is performed both at the production site and at the wind farm site where it is commissioned. In the context of this use case, assembling refers to fastening of the bolts in the turbine parts, i.e., the rotor, nacelle, and tower. The turbine is commissioned to a customer, on whose site it is afterwards installed. The turbine assembling plan includes the required bolts and their respective positions in the turbine. The turbine model used is typically SG 14 [10].

Fig. 1: The SG 14-222 turbine model

The fastening of the bolts is performed by the service technicians. For one turbine, bolts from complete batches are used, if possible. The bolts are fastened by fixing them to a predefined pretension level. Documentation of the bolts used, their position in the turbine, pretension level, etc. is made by the service technicians. The maintenance and care of the fastened bolts is performed in samples at regular intervals, e.g., about 10% of the bolts 1-2 times per year, and consists of verifying the bolt pretension levels. If bolts have become loose, they are fastened at the initial pretension level. If they are found to be defect, the bolts are replaced with new ones that are taken from a different batch. As bolts from a batch are guaranteed by the suppliers to be of the same quality, further verifications of the bolts originating from the same batch is required. The risk of defects in other bolts from the same batch needs to be considered, as defect bolts may lead to accidents. When bolts reach the end of their lifetime, typically 25-30 years due to corrosion, they are replaced with new bolts and are recycled based on their material.

In the next section, the processes and data belonging to use case are identified. The process steps we identified are as follows: bolt and turbine registration, bolt fastening, maintenance, bolt replacement and recycling (cf. Figure 3).

3.2. Process Phases

When registering a bolt, its properties are entered and saved into the system, with the bolt getting assigned a unique identifier. To be able to identify and retrieve the bolt's id, a QR code is generated that encodes the necessary information, i.e., an URL, to retrieve the bolt from the system. The generated QR code is engraved on the head of the bolt in sufficiently large resolution (cf. Fig. 2), to include redundant information and compensate for the possible damages to the QR code.

Fig. 2: QR Code engraved on bolt

The turbine registration process is very similar to the bolt registration. The turbine is assigned an identifier by the system once its properties have been entered and saved in the system.

The action of fastening bolts is documented into the system by the service technicians, i.e., the bolt id, turbine id and turbine position are stored.

At regular time intervals, the service technicians will check the status of bolts samples and document the findings into the system, i.e., the found pretension levels and the new pretension levels after refastening.

When a bolt is found as defect during maintenance, the bolt is removed from the turbine and replaced with a new bolt from another batch that is appropriate to be fastened in that respective position in the turbine. The action is documented into the system, i.e., the faulty bolt id and its condition, together with the new bolt id. The old bolt is marked as defect and is set for recycling.

The replacement action is performed too when bolts have reached their service lifetime. The system notifies the responsible service technicians, which then retrieve the bold data records, climb on the respective turbine and replace the bolts. The condition and reason for the bolt replacement are documented and saved into the system.

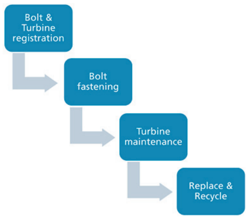

Fig. 3: The identified process phases

4. Blockchain Concept

The system that supports the above-described operations and stores the respective data needs to fulfill a series of properties:

- Store data in a database that all parties involved, e.g., bolt suppliers, turbine assembly, service technicians, traceability engineers, have access to.
- System implements functions that retrieve and locate bolts in turbines.

Moreover, all the parties involved would like to trust that:

- the data stored is not altered or deleted by any other party;
- the implemented functionality is correct, works the same for everyone and does not contain any bugs.

A traditional centralized client-server system with cloud storage would fulfill the first set of conditions, but would fail to offer hard guarantees for the second set of statements. The trust in the system is equivalent to trusting a central authority that offers the named services and stores the respective data. While having contractual agreements on the second set of statements may be a approach, the blockchain solution has a completely different approach.

A blockchain network is decentralized by nature and provides its members with the same rights of contributing to it. There are no parties that solely decide about the data or functionality in the system. In fact, the data cannot be altered or deleted by design, hence the risk of unilaterally manipulating the data is excluded from the start. Moreover, the functionality units in the blockchain, the smart contracts, are visible to all participants and can be checked for correctness and fairness prior to using the system. The blockchain satisfies the basic conditions from above as well. Data is stored in a hash-linked ledger that cannot be tampered with or, if appropriate, in designated databases. In terms of functionality, there is nothing that cannot be automated in smart contracts, as these use Turning-complete programming languages.

A suitable blockchain network would be public-permissioned, i.e., allows anyone to read, while only network members are allowed to write. The blockchain may use of the following types of consensus algorithms:

- a Byzantine Fault Tolerance consensus, e.g., Istanbul BFT [11], that guarantees the network survival even if 1/3 of the member nodes are dishonest;
- a Crash Fault Tolerance consensus, e.g., Raft [12], that guarantees protection against N/2 -1 offline nodes;
- a Proof of Authority consensus, e.g., Clique [13] or AuRa [14], that ensures that the network continues to operate as long as the majority of nodes are honest; it provides a better performance than BFT algorithms.

All of the above algorithms offer finality, i.e., there cannot be any forks in the ledger. The validator nodes participating in the consensus would be the parties involved in the process, e.g., bolt suppliers, turbine assembly, service technicians, traceability engineers. The network governance is to be agreed upon by the members. The governance regulates decisions when formulating and deciding on proposals, e.g., member eligibility criteria, addresses accountability of members for their actions, and introduces incentives to motivate members to act according to the network philosophy.

An addition to the described model is the introduction of access roles. Every participating party needs to have access to a certain amount of information in order to do its job, but seeing all the available information may have detrimental effects to company privacy and affect competition. Therefore, access roles have been established where read and write permissions are defined for all participants that match a certain role, e.g., bolt supplier, turbine assembly, service technicians, traceability engineers, etc. For example, bolt suppliers have full read and write access to the bolts that they own, while having no access whatsoever to other bolts that don't belong to them. Likewise, the turbine assembly on site has full access for turbines records that they own and to the bolts fastened in the respective turbines. The service technicians have read access to the bolts and turbines that they service and limited access to the bolts of the rest of the turbines. They also have full read and write access to the maintenance data for the respective turbines. For the engineers responsible for tracing back bolts, the read access extends to all turbines that contain bolts from the batches used on-site.

5. Proof of Concept

The developed concept is implemented as a prototype decentralized application (dApp) that offers a web interface to the user. The dApp is written in Node.js and uses Express to set up a REST API that answers user requests.

The dApp communicates with a blockchain instance in the backend, where the smart contracts are deployed. There is one smart contract for bolt management, turbine management and maintenance management respectively. We use the Truffle framework to compile and deploy the smart contracts into the blockchain. The smart contracts are written in Solidity. The blockchain node is run with Ganache as test blockchain instance, which simulates an Ethereum-based blockchain node [14]. Additionally, an Interplanetary File System (IPFS) node is used to save the larger content, e.g., PDF documents or images, with the resulting IPFS CID, i.e., the SHA-256 content identifier hash [15], being anchored in the blockchain via the smart contracts.

6. Conclusion and Future Work

The processes surrounding the fastening of the bolts in turbines can be mapped to a digital model. The manufacturing and the fastening of bolts in turbines, as well as their maintenance until the end of the service lifetime can be specified as successive phases. The necessary data recorded in the respective phases has been identified as well. The blockchain technology suits the set requirements, as it offers a decentralized network designed for collaboration, an immutable data ledger that promotes transparency and offers traceability and is easily auditable. Additional access roles have been defined that protect company privacy and preserve competition amongst the parties involved.

An extension to the model would consist of adding self-sovereign identities to the actors involved. Bolts, turbines, bolt and turbine suppliers, and the service staff would receive decentralized identifiers (DIDs), which wrap around respective private/public key pairs generated for this purpose. The bolt documentation can be represented as verifiable credentials (VCs), where the issuers are the bolt suppliers. When fastened in the turbine, the bolts receive VCs that certify their successful fastening, whereas when they are verified by the service staff, VCs with technical reports are being issued. The DID data is to be stored on the ledger, while the VCs are be stored by agents representing the individual entities. This adds an extra layer of security to the entities that need to digitally sign their actions using their private keys. By outsourcing the VC data, the access roles will not rely solely on the smart contract logic, as the data is not on the blockchain and needs to be expressly shared by its owners.

Acknowledgements

This paper is based on the findings from the UnWind project, which is funded by the Danish Industrial Foundation.

References

[1] 'Denmark sources record 47% of power from wind in 2019 | Reuters'. https://www.reuters.com/article/us-climate-change-denmark-windpower-i-dUSKBN1Z10KE (accessed Sep. 22, 2021).

[2] 'UnWind - Blockchain i Vindmølleindustrien | Industriens Fond'. https://www.industriens-fond.dk/unwind (accessed Sep. 20, 2021).

[3] HOLM, Kristoffer. Application of Blockchain in the Wind Industry. In: BPM (PhD/Demos). 2020. S. 61-66.

[4] Wang, Haitao, and Bin Wu. "Design of Wind Farm Information System Based on Blockchain Technology." IOP Conference Series: Earth and Environmental Science. Vol. 647. No. 1. IOP Publishing, 2021.

[5] Chartron, Sylvain, et al. "Digitalization potentials in supporting offshore wind logistics." Logistics 4.0 and Sustainable Supply Chain Management: Innovative Solutions for Logistics and Sustainable Supply Chain Management in the Context of Industry 4.0. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 26. Berlin: epubli GmbH, 2018.

[6] 'UiS Brage: Digitalization of Offshore Wind Farm Systems'. https://uis.brage.unit.no/uis-xmlui/handle/11250/2460309 (accessed Sep. 20, 2021).

[7] Yu, Hang, Senlai Zhu, and Jie Yang. "The Quality Control System of Green Composite Wind Turbine Blade Supply Chain Based on Blockchain Technology." Sustainability 13.15 (2021): 8331.

[8] Keivanpour, S., A. Ramudhin, and D. A. Kadi. "Towards the blockchain-enabled offshore wind energy supply chain." Proceedings of the Future Technologies Conference. 2018.

[9] 'ISO 4014 - Hexagon head bolts with shank'. https://www.fasteners.eu/standards/ISO/4014/ (accessed Sep. 22, 2021).

[10] 'Offshore Wind Turbine SG 14-222 DD I Siemens Gamesa'. https://www.siemensgamesa.com/products-and-services/offshore/wind-turbine-sg-14-222-dd (accessed Sep. 24, 2021).

[11] Moniz, Henrique. "The Istanbul BFT consensus algorithm." arXiv preprint arXiv:2002.03613 (2020).

[12] Ongaro, Diego, and John Ousterhout. "In search of an understandable consensus algorithm." 2014 {USENIX} Annual Technical Conference ({USENIX}{ATC} 14). 2014.

[13] 'EIP-225: Clique proof-of-authority consensus protocol'. https://eips.ethereum.org/EIPS/eip-225 (accessed Sep. 24, 2021).

[13] 'Aura Consensus Protocol Audit · poanetwork/wiki Wiki · GitHub'. https://github.com/poanetwork/wiki/wiki/Aura-Consensus-Protocol-Audit (accessed Sep. 24, 2021).

[14] 'GitHub - trufflesuite/ganache: A tool for creating a local blockchain for fast Ethereum development.' https://github.com/trufflesuite/ganache (accessed Sep. 24, 2021).

[15] 'Content addressing | IPFS Docs'. https://docs.ipfs.io/concepts/content-addressing/ (accessed Sep. 24, 2021).

[16] W. Prinz and A. T. Schulte, "Blockchain and Smart Contracts: Technologies, research issues and applications." (2018)