Smart Grid Management Modeling using Blockchain and Machine Learning Technologies

Roberto Alexandre Dias
Federal Institute of Santa Catarina (IFSC)
950, Av. Mauro Ramos
Florianópolis – SC, Brazil

Rafaela Oliveira de Azevedo
Federal Institute of Santa Catarina (IFSC)
950, Av. Mauro Ramos
Florianópolis – SC, Brazil

Lucas Moino Armada
Federal Institute of Santa Catarina (IFSC)
608, José Lino Kretzer Street
São José – SC, Brazil

ABSTRACT
The present work consists of modeling a system for the maintenance of an infrastructure focused on the generation of electricity integrated into a management system for the sale of energy on the free market.

Through this system, companies that provide micro grid generation infrastructure management services will be able to implement virtual power plants by aggregating microgrids implemented in their own or third-party physical spaces. In this way, the service provider will be able to manage the remote maintenance of its assets, aiming at the maintenance of the project specifications, the predictive maintenance of failures and verification of the loss of performance in components of the generation system.

The system provides intelligence on contract management in a dynamic way, from data collected as well as computational cloud from consumers and aggregate generating units. Environmental parameters such as insulation, atmospheric and climatological conditions from weather forecast services, available in an open database, can be crossed with information from microgrids for capacity planning, in order to subsidize the sales contract management system of energy on the free market.

By implementing the proposed system, it will be possible to define business models to commercially enable the adoption of the system. An example would be the model in which energy consumers act as service subscribers. In this way, the remuneration to the service provider can be made through a monthly fee or a portion of the energy generated in surplus. Acting in an aggregated way, the service provider will be able to carry out the best negotiation possible on the free market. Another example of a business model could be the remuneration of the owner of leased areas for the installation of energy generation microgrids, or power plants on land owned by the service provider.

General Terms
Smart grids, Block chain, Machine Learning

Keywords
Smart networks, Demand side management, Virtual Power Plant, Energy Market, Internet of Things, Predictive Maintenance

1. INTRODUCTION
The growth in electricity production from alternative sources, due to the reduction in the cost of its assets along with the prospect of expanding the opening of the free market in Brazil, creates a need for development of intelligent solutions for the remote management of these assets. The possibility of aggregating distributed power generation systems constituting virtual power plants still has several open research challenges. Based on this scenario, the present work consists of the research and development of an infrastructure management system for electric energy generation microgrids through alternative sources, with emphasis, initially, on photovoltaic generation.

According to the UBS Group (Swiss Investment Bank), the cost of solar and wind energy could be zero by 2030 in Europe. In the state of California (USA), a law already requires the installation of photovoltaic panels in new properties. In addition, many companies that need carbon credits are installing free solar panels in the homes of low-income people (2).

A literature review (5) on Virtual Power Plants (Virtual Power Plants – VPP) is presented, in this work the authors present fundamental concepts about the technology of virtual power plants and its taxonomy. Among the types presented in the article, Commercial VPP is described as an aggregation of geographically dispersed power generation units that can be implemented and managed by an energy trading service provider. In accordance with this literature, the challenges from the point of view of communication infrastructure for the implementation of this service are emphasized.

In (6) the need to use cloud computing solutions and large-scale data analysis to manage smart power grids of continental scope is discussed. In this model, the management of energy sale contracts is presented as a software service, where the infrastructure used in the management is presented as a commodity through the Internet. This model not only suggests the establishment of secure channels of communication but also describes the infrastructure components of cloud computing services necessary for the development of applications in a smart grid environment.

Reference (7) shows a series of characteristics of a smart grid, among which two stand out: (a), a large number of sensors and monitors and (b), a vast amount of data. The need for this comes from the potential that information about such systems has on improving their operational characteristics. On the other hand, when discussing the future of electrical energy, one repeatedly reads that in a few years electricity will predominantly be processed by static converters in its final use, that is, the vast majority of electrical equipment will have either switched sources in its connection with the distribution networks, or rectifiers and inverters to control electric motors. This is already the case with distributed generation technologies, where photovoltaic solar generation is processed by static converters (DC-DC converters and inverters), wind generation (rectifiers and inverters), as well as storage applications (batteries, flywheels, inertia) and gas micro turbines (rectifiers and inverters).

When discussing the use of technologies for smart grids in the scope of primary distribution networks, transmission networks and large-scale electricity generation, it is possible to preview these systems having their own sensors implemented in a few years. Additionally, the communication networks will have to be dedicated to each one of these purposes. However, considering microgrids, nanogrids, smart houses (7) and other small energy systems, the costs associated with the use of a vast number of sensors can restrict the use of these technologies or delay the date of adoption of them. Even in distribution networks that operates with smart grid concepts, the number of sensors can cause the aforementioned impacts. Reference (9) also discusses that the way to economically manage and operate energy networks in the future may be quite different from the current ones and that the use of parameters that quantify energy availability and quality will be used in energy cost negotiations.

Predictive maintenance, also known as condition-based maintenance (CBM), according to (10), can be defined as a maintenance policy that performs maintenance/adjustments actions before equipment failures occur, by evaluating their conditions and predicting the risks of failures in real time through the data collected from the equipment. The authors present a literature review on CBM, as well as a classification of techniques according to their approach (data-driven, model-based or hybrid) and a procedure for implementing a CBM. According to the authors, the implementation of a CBM involves several phases, ranging from data processing to maintenance operation, through diagnosis and prognosis. In addition, the authors discuss CBM implementation situations, addressing, for instance, a situation where little or no data is available. In this specific case, they suggest that if the option is to use machine learning techniques, an unsupervised learning approach may be better to build the reference model identifying normal and abnormal situations and only then apply supervised learning by reinforcement, in order to make CBM algorithms more accurate.

2. PROBLEM DEFINITION

The research problem consists on developing a system in which micro grid generation infrastructure management service providers will be able to implement virtual electric power plants (VPP) by aggregating microgrids implemented in their own or third-party physical spaces. In this way, the service provider will be able to manage the remote maintenance of its assets, aiming at the project specifications, the predictive maintenance of failures and the verification of the performance loss in components of the generation system.

The system's development also provides the real time modeling and management of contracts for the sale of surplus energy in the free market. This feature is relevant due to the new regulatory framework expected to be implemented shortly. A bill for the Modernization and Opening of the Electric Energy Free Market, based on the result of the Public Consultation 033/17-MME, is already under analysis by the Office of the Presidency of the Republic. From the monitoring of the electrical parameters of the microgrids and the consumption data of the units, the micro grid infrastructure manager will be able to act with competitive advantage in the free market through the available data of the aggregate generating units with surplus. The system also provides for a contract model that will allow the transmission of power flow from surplus units to deficit units between subscribers or members of this service. Figure 1 shows an initial model of the proposed system.

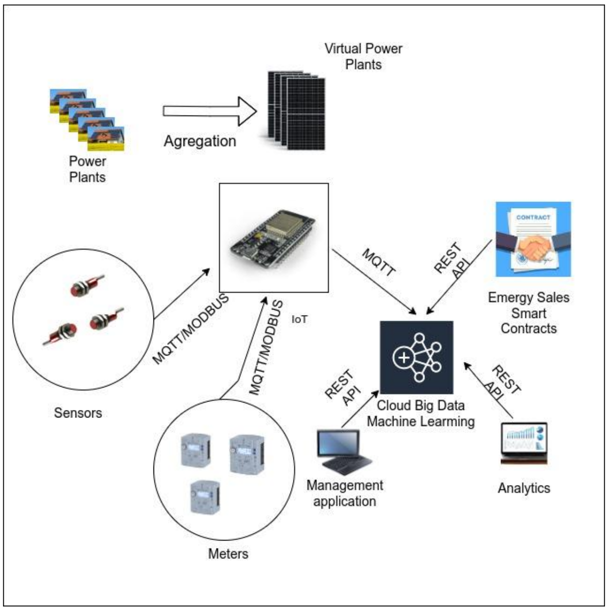

Figure 1 - Model of the integrated management system for distributed electricity generation services infrastructure

3. PROPOSED MODEL

To solve the research problem, it is proposed the development of an IoT hardware for data acquisition and transmission, using the MQTT communication protocol to send the data to an MQTT data server (MQTT broker) installed in a computing cloud provider. The data sent to the MQTT broker are consumed by a Web Service that provides their storage and availability in a Web application capable of performing maintenance management, from reading the electrical and climatological parameters of the micro grid

3.1 IoT Hardware

In the present proposal, the IoT device will be responsible for communicating with the frequency inverters installed in the photovoltaic plant to collect information for computerized maintenance management such as voltage, current and generated power. In addition, it must communicate with climatological stations that provide information on temperature and insulation of the panels.

The continuous monitoring of electrical and climatological information will enable to compose a signature of the generation behavior system in normal, through a machine learning algorithm for condition-based maintenance (CBM) which will allow managing non-compliance conditions and alarm to plant operators.

To acquire this information, the IoT device must have a WiFi interface to communicate through the MODBUS protocol (11), very commonly available in frequency inverters and climate stations. The implementation of the SUNSPEC specification is also planned, which contains a specific data model for energy generation systems from alternative sources.

An LPWAN (Low Power Wide Area Network) interface is provided for communication with panel sensing devices (such as insolation and temperature) that may be distant from structured data networks in large photovoltaic parks. An alternative to this is the implementation of a private LORAwan (Long Rage Wan) network (12) with low-energy and low-cost endpoints, coupled to the photovoltaic panels and a gateway coupled to the IoT device that will communicate with the inverters and climatological stations.

A low-cost IoT gateway device must be connected in series with the utility's energy meter in order to acquire the consumption data of each associated consumer that will participate in the generation sharing. These data will be available in a cloud computing system for processing the management of energy sales contracts in the free market.

3.2 Sunspec Alliance

According to (13) the SUNSPEC specification, maintained by the SunSpec Alliance, which is a trade alliance of developers, manufacturers, operators and service providers working together to seek open information standards for the distributed energy industry. SunSpec standards enable interoperability of components and operational aspects of photovoltaic, storage and other distributed energy power plants on the smart grid - including residential, commercial and scale systems by reducing costs, promoting innovation and accelerating industry growth. More than 70 organizations are members of the SunSpec Alliance, including global leaders from Asia, Europe and North America. Membership is open to corporations, non-profit organizations and individuals.

The SunSpec Alliance Interoperability Specifications describes informational models, data exchange formats and communication protocols used in distributed power systems resources. These specifications' purposeis to reduce the cost of implementing the system, they allow applications to be stored using a single, standardized view of a solar plant's components, regardless of their component manufacturer and model.

3.3 MQTT Protocol

The MQTT protocol, an acronym for the term Message Queue Telemetry Transport, is an extremely simple and lightweight messaging protocol designed for devices that do not require high bandwidth consumption. These devices interact like publish/subscribe, that is, the exchange of information is done by publications addressed to subscribers in publishing places called brokers. The broker addresses publications and makes them available to registered subscribers on certain topics.

Due to the simplicity of coding and the need for little information other than the data to be transmitted (no overhead) it has become ideal for the IoT scenario. With MQTT, devices do not need to be constantly synchronized with the server. The sensors, when sending their readings, allow the network itself to discover the path and the best synchronization to deliver the information. In addition, MQTT allows you to use devices with low processing power and low memory capacity.

Developed in the late 1990s by Andy Stanford-Clark from IBM and Arlen Nipperda from Arcom (now Eurotech) for the purpose of connecting pipeline sensors to satellites, it is a communication protocol that does not require synchronization between the sender and receiver on both space and time (14), this favors scalability in network environments that are unreliable from a continuity of service perspective.

MQTT became an open OASIS standard in 2014, with support for various programming languages and open source implementations (14) and unlike other protocols, such as HTTP (Hypertext Transfer Protocol) and Extensible Messaging and Present Protocol (XMPP), manages the MQTT to be much lighter and more flexible due to the publish and subscribe model.

The great advantage of MQTT is that both publishers and subscribers do not need to be synchronized to send and receive messages, however, it is possible to send messages to the broker synchronously and continue execution only after confirmation and reception. Since the publisher and subscriber are decoupled, there is no way to know if there is any subscriber on the topic that "listens" to the messages that will be sent, and depending on solution requirements and quality of service levels, it is sometimes necessary to make subscribers and publishers send a message indicating that they have received and processed the information (15).

In the context of this work, the MQTT publisher will be installed on the IoT device that will collect data from the micro network management devices and send them to the MQTT server, also called a broker, installed in a cloud computing service provider.

3.4 Web Services

Web Services are services available over the Internet, which use the XML (Extensible Markup Language) standard to exchange messages, regardless of the type of Operating System or programming language (17). Regulated by The World Wide Web Consortium (W3C), Web Services supports open standards for communication among applications on different platforms. By implementing this kind of service, any programming language has the ability to communicate over the Internet. One of the main advantages of Web Services stands on different programming languages, on different development platforms, can communicate through open and well-defined standards (18). All Web Services protocols were created from XML definitions. This type of integration is not new on the Web since CGI programs (Common Gateway Interface) and Java servlets have been used for many years to communicate applications. Starting from the concept of Web Services, we have the promise of some standardization, facilitating the integration of applications (17).

In light of this proposal, a Web Service will be developed to consume the information published by the IoT device in the MQTT broker and store it in a standard SQL database in view of it being made available to a computerized maintenance management and dispatch management application, finishing with sale of energy on the free market. A RESTful Web Service is going to be used, owing to the low transmission overhead and simplicity of implementation. For implementation, the microframework coded in Python language, called FLASK (https://www.fullstackpython.com/flask.html) is going to be used as well, which has an embedded RESTful API.

3.5 Condition based Maintenance

According to the authors in (23), condition-based maintenance (CBM) is a decision-making strategy that can allow real-time diagnosis of impending failures and also the prognosis of future equipment integrity. To be implemented, the periodic or continuous collection of data from several sensors is necessary and requires the development of a predictive model that can trigger alerts for the corresponding maintenance. The authors also differentiate two important aspects of a CBM process: diagnosis and prognosis. Diagnosis is related to the detection, isolation and identification of faults in abnormal situations. Prognostics deals with predicting failures and degradation before they occur.

In (24) the authors report that the CBM process involves topics such as data mining and artificial intelligence and has been used in applications such as automotive, manufacturing, aviation, defense and other industries. The authors also report that supervised regression and classification machine learning algorithms are used quite frequently in the CBM process. For situations where historical data are not available, the authors suggest that an approach using unsupervised machine learning algorithms may be a good option, and this learning approach requires the construction of a reference model that identifies normal and abnormal operating situations. In (25), the authors identify two approaches to unsupervised methods, namely: (i) Data subspace structure and its (ii) clustering characteristics. The first works with a smaller number of features than those available in the original data and the second works with a grouping of the data, reducing the number of objects when compared to the original set.

An example of application in solar energy generation can be found in (26). In this work, the authors applied convolutional neural networks to monitor the operation of photovoltaic panels based on the prediction of the daily electrical power curve of neighboring panels. In this way, it is possible to have an indication of failure if a significant deviation is observed between the predicted and observed curves. The authors demonstrated through numerical experiments that the proposed method is able to accurately predict the power curve of a panel in good working order.

3.6 Management of energy sales contracts

In the same way that the large-scale insertion of Digital Gateways (DG) into the network brings challenges and opportunities for efficiency gains in the operation of the system, the same can be said about its effect on the design and operation of the market. The competitive Brazilian electricity market, as it is organized, with centralized settlement at the transmission level, is a well-defined and accepted paradigm in the industry. This market established by Law 10,848/2004 - the New Model of the Electricity Sector promoted significant changes in the regulation of the electric sector with a view to (i) providing incentives to private and public companies for the construction and maintenance of generation capacity; and (ii) ensure the supply of electric energy through bidding processes, aiming at reasonable tariffs. Among the main changes introduced by the New Electricity Sector Model Law, is the creation of two environments for the commercialization of energy.

With the insertion of DG and digitalization of measurement, it becomes desirable to extend the competitive market at the distribution level with the formation of a retail market with direct access to consumers. The design of this market is anchored, according to (27) on the participation of DG and microgrids in electricity markets, which, in turn, depends directly on the level of liberalization of the market in which they are inserted. The participation of micro networks is more effective in de-verticalized markets where there is competition at the retail level, prices with sufficient temporal and spatial granularity and where there is recognition of local value. Thus, arising from the design of a microgrid, which is capable of establishing an open platform for DGs and loads, controllable or conventional, to transact energy and services with each other and, when in connected mode, with the market and network operators. In this condition, the micro-network would settle the balance simultaneously in two "markets": internal (local balance – trading within the micro-network itself) and external (export balance – interaction with the free market).

4. BLOCKCHAIN IMPLEMENTATION

A power quality monitoring prototype provided by a micro grid was implemented using Blockchain technology.

In this prototype, the periodic readings of the inverter output voltages are concentrated in a gateway that communicates with the inverters through the MODBUS protocol, as shown in Figure 1. The gateway transmits the data through the MQTT protocol to a monitoring center . This data is recorded in a Blockchain database. For this first prototype, the XooA Blockchain platform was used (26). The data then is stored on a centralized XooA Blockchain database called XLDB.

A smart contract is triggered whenever the values of the voltages generated by the inverters are in disagreement with the power plant design and insulation conditions. In this contract a penalty for the commissioning team is tokenized, with that, the maintenance performance of the plant is automatically measured. When the accumulated exceeds a certain threshold determined in a service level agreement, an amount of crypto coin can be transferred by another smart contract to the power plant commissioning service contractor.

The data acquisition system via MQTT and data registration in the XLDB database was implemented in the NODE-RED platform (27). The smart contract was implemented on the XooA platform and tokenized on the Etherium (28) virtual wallet.

Figure 2 shows the NODE-RED flow for recording data in XooA's XLDB and triggering the smart contract

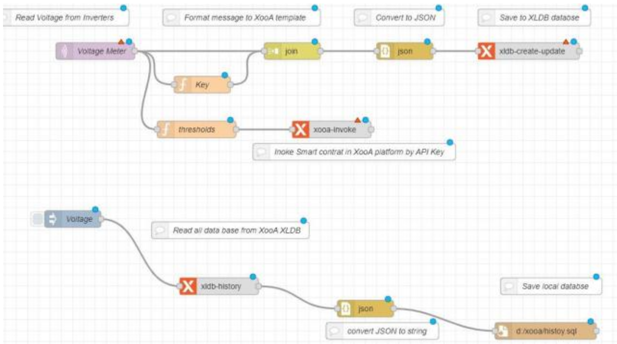

Figure 2 - Blockchain Implementation in NODE-RED with XooA Platform.

5. CONCLUSION

The present work consists of the modeling and specification of requirements and components for the management of maintenance and energy sale contracts within the scope of a distributed generation plant of energy by alternative sources. Its main contribution is to point out the technological arrangements and demonstrate the feasibility of implementation in the context of the new regulatory framework foreseen for the Brazilian electricity sector.

The implementation of the solution approach is at an early stage, but among the main results is the validation of the MQTT protocol for asset management and the study of machine learning techniques for predictive maintenance management. The Blockchain implementation, based on the

XooA platform area, is validated with a hardware emulator. In addition, an IoT hardware prototype and LoraWan endpoint has already been developed for acquiring electrical and climatological signals.

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