Distributed Energy Resources Parameter Monitoring in Microgrids Using Blockchain and Edge Computing

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Distributed Energy Resources Parameter Monitoring in Microgrids Using Blockchain and Edge Computing

J. Campillo, J.A. Dominguez-Jimenez, H. Ariza, E.D. Payares, J.C. Martinez-Santos

***Abstract*—An increased share of distributed renewable energy sources requires flexible tools for providing reliable and cheap electricity. Smart meters provide information at the consumer level, which could be used as the main source for real-time energy micro-transactions, however, one of the main concerns about direct transactions is information security. Conventional electricity markets rely on centralized information exchange, nevertheless, when intra-day, distributed, electricity consumption and production exchanges are required between customers, this approach might not be enough. This paper presents a proof-of-concept for using Blockchain as a tool for managing the operational transactions in a DC microgrid. The distributed nature of this technology provides an inherently safer approach, by providing an immutable database for transaction history. One of the challenges of using this technology, however, is the required computing power at the nodes and the limited capacity available in the smart meter. To overcome these issues, the authors used a distributed computing technology, -edge computing-, where computation and storage are located closer to the customer, to improve response times by handling the required computational tasks of the Blockchain tool. This approach proved not only to be practically viable but also, offers important insights about the scalability and capabilities of the technology.**

***Index Terms*—Microgrids, Blockchain, Edge Computing, Smart Grids, DER**

I. INTRODUCTION

Electricity accounted for 19% of the total final energy consumption in 2018, compared to just over 15% in 2000. Since that year, it has experienced a steady sustained growth of 3% annually, about two-thirds faster than the total final consumption. A significant portion of the supply share has been sourced from the increasing amount of new renewable energy installations, mainly solar and wind, which now provide over 6% of the global electricity supply, compared to 0.2% in 2000 [1].

As the share of wind and solar power plants in the power system increase, so do the requirements for flexible operational and economical systems, that guarantee the reliability of the network, while providing customers with pricing schemes according to the energy supply matrix at any given time.

The early stages of the power grid relied on large generation stations to nearby cities to fulfill the basic needs of light and heating. Nowadays, it can supply most of our needs, including indoor comfort (HVAC systems), communication (internet, mobile phone, computer), security, transportation (plug-in electric cars, public transport), public lights, and even critical loads such hospitals. Emerging technologies of the current century have put multiple short-term challenges and stress on the conventional power grid making it become a complex system that requires bi-directional power flow and communication standards that allow the customers to produce and consume energy, thus the term prosumers. For instance, solar photovoltaic (PV) systems' owners can sell their excess production to nearby customers or store it on local batteries for later use. This and other novel features stand for a more robust power system, known as smart grids.

Smart grids may include distributed energy resources (DRE), electric cars, energy storage systems as well as also conventional loads [2]. They offer multiple benefits to customers, including real-time monitoring, efficient energy management, variable pricing mechanisms, remote monitoring (track of energy usage), among others [3]. All these features combined with the increasing adoption of mature renewable sources such as solar PV and wind power and the ever-increasing oil prices have pushed the interest of end-users and network operators to include the microgrid (MG) concept into their schemes [4]. MGs are, in short, a series of electrical loads, DRE and energy storage systems that operate locally as single controllable entity [5]. They provide four main characteristics to remark, such as integration platform (for local generation, storage), two operational states (grid-connected and islanded modes), enabling active operation (bidirectional power flow), and scalability (from appliances to industrial levels) [6].

There are two main groups of MGs: AC and DC. However, DC MGs show multiples benefit compared to the AC counterparts. For instance, DC MGs offer lower losses, higher efficiency, and more reliability. They exhibit reduced control states and conversion stages [7]. Several studies have addressed approaches to simulate the behavior of DC MGs. However, most of these studies used commercial software and

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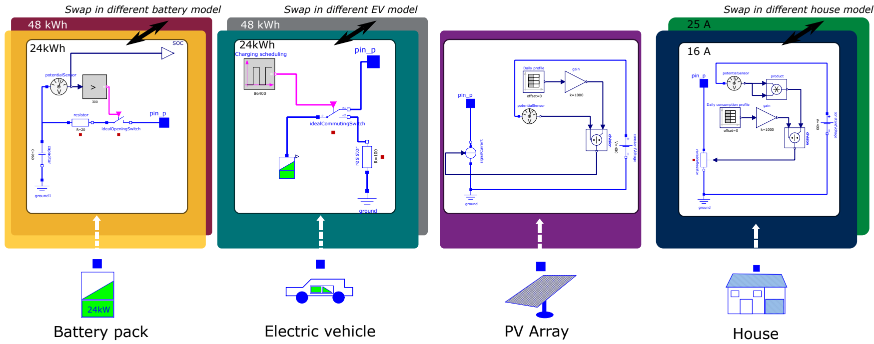

Fig. 1. Object-oriented representation of the most important models of the library

models while others use real-world data.

The main problem of these approaches is that they are not often aware of the challenges for the communication infrastructure (latency, loss of packets, collisions, processing times) and the ones related to physical installations (terrain conditions). Most of these studies usually assume ideal conditions that are often not available in real-life scenarios. The most challenging issues for communications in smart grids, in general, are tied to delay requirements and bandwidth [8] as well as the limited processing capabilities of the end-devices.

This gap offers an opportunity for developing reliable solutions that can emulate more realistic scenarios of MGs. This work presents a library for modeling DC MGs using the object-oriented modeling language Modelica (*version 3.2*) coded in OpenModelica (Release 1.13.0). This library, allows the user to simulate different topologies and scenarios, using real-world data from householders and distributed generation as well as simulated charging patters of plug-in electric cars. An edge computing-based architecture was developed to face processing capabilities limitations on the end-user devices. To provide reliable, private, and safe data management, blockchain was selected as the underpinning technology to monitoring the electrical parameters of the microgrid.

The paper is structured as follows: Section II introduces the context and challenges. Next, Section III presents the methods used to carry out this work as well as the library description. Section IV presents the framework architecture and the hardware and software requirements. Later, Section V exposes the results obtained from running a test case. Finally, Section VI summarizes the main results from this work.

II. Context

Concerns about using DC or AC electricity started during the late 1800s with Tesla and Edison. Although most of the electrical loads are typically AC, the most promissory trend points to the transition to DC-based electrical schemes. Two main factors drive the current outbreak of DC technology: first, the sustained growth of PV and wind generation, as well as the continuously increasing market share of electric vehicles [9], [10]. Second, energy storage systems such as fuel cells, supercapacitors, batteries, and superconducting magnetic-based energy storage all opearate on DC [11]. Therefore, converting this power to AC becomes an unnecessary intermediate step that results in increased power losses and costs. Lately, the low cost of materials required to manufacture power electronic converters combined with fast switching, advanced control systems for DC converters, reduced prices in silicon and lithium are providing DC technology with great momentum [12]–[14].

These and several other factors provide DC MGs as a potential solution to enhance the conventional electrical network [15], [16]. However, DC MGs are still at an early stage and there are still many challenges to be tacked. On the one hand, the significant reductions on their performance and reliability when varying the control strategy, layout/topology to be implemented, power electronics components and the optimal sizing of the network, among others [17], [18]. Adequate design and planning may aid in mitigating these problems. On the other hand, the issues related to the low sensitivity regarding fault currents while working in islanded-mode [19]. The use of diesel and flywheel current sources combined with adaptive protections and optimal estimation of the system average interruption duration index (SAIDI) represents a potential solution to overcome this problem [20], [21].

Nevertheless, there are multiple pivotal concerns about the performance of MGs on the communication, protection, and operation requirements [8], [22]. Despite the large importance of protections, delays and limited bandwidth conditions can significantly affect the operational performance of the MG [23]. A real example of this is the Ontario case, where they are experiencing serious issues on communication delays in scheduled regulation signals between the installed energy storage systems and the Independent Electricity System Operator (IESO). Unappropriated management of these delays may affect drastically frequency regulations.

Nowadays, most of the existing tools for simulating MGs are built using licensed software. These tools allow testing a vast variety of scenarios, so they become very useful when performing off-line diagnostics and analysis, however to run these proprietary code on embedded devices is often not allowed. Open-source modelling and simulation frameworks would increase the flexibility and compatibility among different hardware solutions, however there are not enough open-

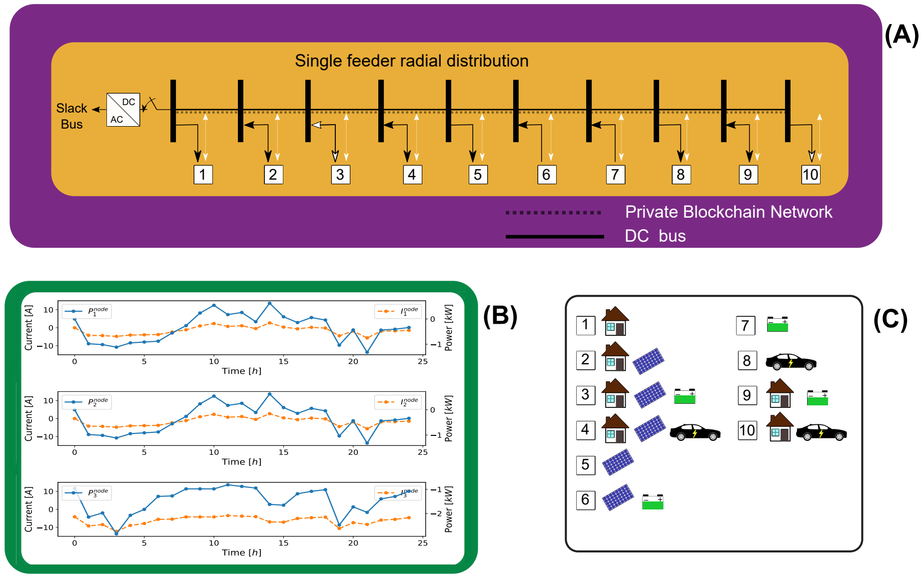

Fig. 2. Representation of the test system distribution (A). Illustration of the power flow in the three first nodes (B). Information about loads and resources in each node.

source tools that enable these possibilities on the hardware-side. This area depicts a niche to be exploited since most of the challenges existing today are related to communication latency, packet losses, and collisions that can be emulated using distributed low-cost hardware devices. Besides, the integration of the edge computing concept represents a promissory solution to reduce the overhead of end-devices.

III. Methods

This work presents an approach that enables distributed simulation of a DC microgrid using a self-made open-source library, edge computing, and blockchain. To reduce computing requirements on the end nodes, the simulation of the operational variables is currently limited to steady-state conditions, however, transient behavior modeling is under development. The efficiency of the power converters is set to be 100%. The energy demand for each house model used real-life electricity consumption information from the large household energy demand dataset described in [24].

A. Library Description

For modeling the DC microgrid, an object-oriented library was developed using the Modelica modeling language. This library aims to manage load flows and power distribution. This library includes models for houses, electric vehicles, solar PV panels, power converters, sensors, buses, and batteries. Figure 1 illustrates the models and the objects inside each of them. Figure 2 illustrate the test case. Below, there is a detailed description of the models the library comprises.

1) Electric Vehicles and Battery Models: Two battery packs were modeled. Both operate at 300 Volts DC, and their capacities are 24 and 48 kWh. These packs were integrated with a charging schedule controlled switch to simulate a daily driving behavior. The battery packs have a 50% initial state of the charge (SoC).

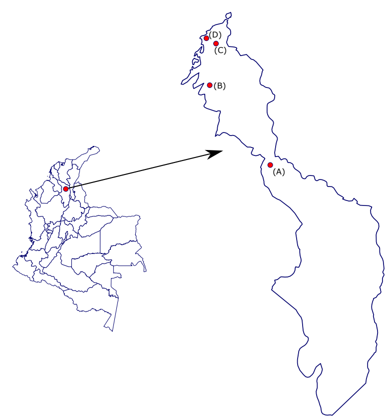

Fig. 3. Locations of the end-devices

2) House Loads: Two house models were considered from real-world typical residential consumption profiles presented in [24]. The first model represents a small house. This model includes a 16 amps fuse and does not consider electrical-heating demand. Contrarily, the other model accounts for a larger family house equipped with a 25 amps fuse, and it includes electric heating consumption.

3) Photovoltaics: Solar PV distributed generation was modeled from real-world daily generation profiles.

4) Transmission Lines:

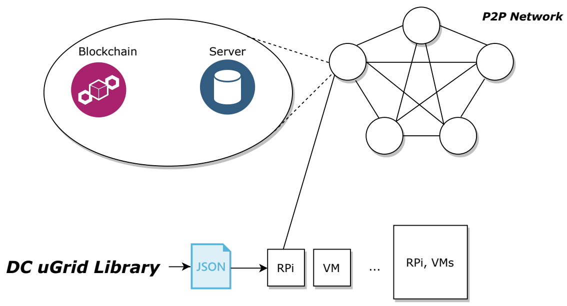

Fig. 4. Illustration of the layers and their elements

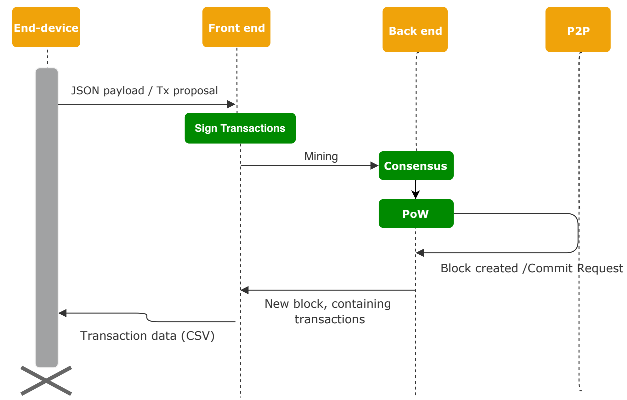

Fig. 5. High-level architectural description of the implemented blockchain scheme

IV. System Implementation

A. Physical Layer

This layer contains all the end-devices as well as the information provided by the proposed library. Simulation results are imported onto the library using comma-separated values (CSV) format and then converted to javascript-object (JSON) format. There is a JSON file per node containing a *timestamp* and operational variables i.e power, voltage, and current. The procedure initiates the data acquisition from the mentioned library in Section III-A. This pre-processing stage converts these data into transactions.

B. Cloud Layer

The code was written in Python 3.6.8 using the Flask 1.1.2 framework. Table I shows the specifications details. The API was implemented as a RESTful web service, and the system is deployed on a virtual server in the cloud under the $microservices$ architecture. Each node has an $instance$ on the cloud. Figure 3 illustrates the allocations of the nodes. These nodes are running on a Linux operating system with AMD64 architecture. Table II shows the details. Note that in real-life implementations, although cloud services bring significant advantages, these services should be the most near possible to the end-users to avoid time delays. In this work, eight computers and two Raspberry Pi act as end-devices.

TABLE I
Software Specifications

Programming languange	Python 3.6.8
Framework	Flask 1.1.2
Architecture	Microservice

TABLE II
VMs Specifications

Operating system	Ubuntu 16.04 AMD64
Processor	Intel i5-4210U 1.70GHz
RAM	0.5 GB
Disk	10 GB HDD

1) Blockchain: A BC-based platform was designed to turn the monitoring task in MGs into a reliable and useful solution. To create the BC network, we considered a Hypeledger Fabric-based architecture. It accounts for an open-source solution supported by the Linux Foundation, IBM, and several other companies. The information on the electrical parameters of each node is stored separately in different BCs. The purpose of using multiple BCs, instead of a single one with all the data, is to enable high modularity. As a result, the permission management to monitor the data is facilitated while guaranteeing privacy.

Transactions are created and automatically brought into a stack of *Unconfirmed transactions*. Afterwards, the *consensus* algorithm selects one transaction and validates it to further be added to a new block. However, at this point, the procedure has not been yet validated. This task is carried out by the *Proof of Work* (PoW) algorithm. If the transaction was completely validated, then the block is added to the blockchain of the respective node.

V. Results & Discussion

This section presents the results. Simulations were conducted considering a single bus electrical distribution feeder for 24 hours. To measure the quality of the traffic in the network, the results were evaluated through the number of collisions and the consumed time per transaction. These collisions account for the most challenging issue in real life, as they occur when multiple users requested at the same time. As all the transactions are equal in size, we considered average values.

Figure 6 summarizes the results. On the one hand. similar performance is observed on both variables on the VMs. The most optimal scenario regarding the time elapsed accounts for milliseconds. Additionally, the worst scenario stands for about 140 seconds, which is still acceptable considering the time resolution. On the other hand, considering the collisions, the worst case is about 10 collisions, and the average varied between one and two per transaction. In addition, no larger differences were found between the VMs and the RPis. It was

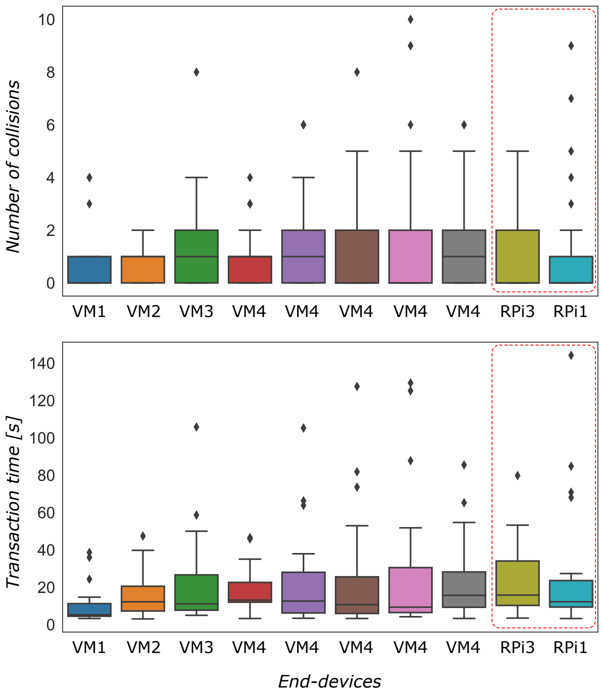

Fig. 6. Summary of time elapsed and the collisions per transaction in each end-user during 24 hours

as expected since the services were not deployed on the end-devices but over the edge.

To establish a better comparison, we conducted the same test but running the services on the end-devices locally. Results showed an overall reduction by almost ten times on the overhead of the end-devices by deploying the services on the edge. Therefore, these results may encourage distribution system operators to implement similar strategies that enable more efficient communication schemes and the introduction of decentralized technologies as the blockchain case.

VI. Conclusions

This work presented the design of a object-oriented and open-source library for modeling DC microgrids to simulate a distributed network using edge computing. This library enables rapid prototyping with the drag and drop concept, considering real world data. Significant reductions on the overhead of the end-devices were found. Deploying systems on the edge can decrease by ten times the overhead comparing with local deployments. The use of the blockchain as the supporting technology of P2P networks allows reliable recording of transactions while preserving the privacy of users.

Despite the insights this work showed, additional issues should be addressed on the development of the library and the communication infrastructure as well. For instance, the development of components and models on the phasor domain, and the capabilities of the library to carry out simulations under transient conditions. On the other hand, the designed P2P network could be tested over more challenging scenarios, including dynamic pricing and transactive energy schemes.

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