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► **To cite this version:**

Abdellatif Elmouatamid, Youssef Alidrissi, Radouane Ouladsine, Mohamed Bakhouya, Najib Elkamoun, et al.. Towards an IoT/Big-Data Platform for Data Measurements, Collection and Processing in Micro-grid Systems. Conference, Jun 2021, Fez (Maroc), Morocco. pp.279-289, 10.1007/978-3-030-73882-2_26 . hal-04607725

HAL Id: hal-04607725

<https://hal.science/hal-04607725>

Submitted on 11 Jun 2024

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Towards an IoT/Big-Data Platform for Data Measurements, Collection and Processing in Micro-grid Systems

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Abstract. The recent infrastructure of the buildings is becoming socio-technical systems that integrate different heterogeneous entities (e.g., sensors, actuators, lighting, HVAC, occupants, renewable energy, storage systems), which could interact dynamically and in a collective manner to balance between energy efficiency, occupants' comfort, sustainability, and adaptability. This new infrastructure is known as the "Micro-grid" (MG) system concept. However, the main challenge for this infrastructure is real-time monitoring and data processing, which requires the use of new information and communication technologies. More precisely, making these buildings more energy-efficient while ensuring occupants' comfort require incorporating mechanisms and techniques, which allow entities interacting in order to perform suitable actions (e.g., turning On/Off HVAC and lighting, balancing the fluctuation between power production and consumption). In this work, a new holistic architecture of smart buildings is presented by improving the main layers of MG systems. This architecture is proposed in order to integrate all buildings' aspects with the main trade-off is to efficiently manage the building while maintaining a suitable occupants' comfort. In fact, an MG system is structured into three layers following the proposed holistic architecture. More precisely, we shed more light on the MG system's layer that integrates recent IoT/Big-Data technologies for data gathering, processing, and control.

Keywords: Micro-grid, Smart Buildings, IoT/Big-Data platform, Information and communication technologies, renewable energy sources, Energy management.

1 Introduction

The integration of RESs (renewable energy sources) for large-scale of electrical energy production has recently accelerated because of evident climate change, insufficiency of fossil resources, and greenhouse gas emissions problem. RES are clean and eco-friendly sources and their abundance and renewable nature are among the most important factors for their integration into SG (smart grid) networks. Mainly, the simple consumer of electricity is becoming a producer of electricity due to the use of these RESs with the possibility to store and consume locally the electricity. However, these green energy sources come with new challenges, mainly their seamless integration with existing electrical networks. In addition, another important challenge for this new electricity infrastructure is real-time monitoring and data processing, which requires new ICT (information and communication technologies) based infrastructures (Fig. 1). The main aim is to ensure sustainable and reliable renewable energy generation systems [1]. Therefore, this integration of ICTs, energy distribution systems, as well as distributed energy generation systems (e.g., RESs), creates what is commonly named “Smart Grid”. In fact, SG represents the new smart electrical network, since it brings the flexibility to integrate new electrical services, such as electrical vehicles, and enables consumers to be energy producers by integrating RESs using a bidirectional communication network [2]. In fact, due to the development of IoT (internet of things) infrastructures and its related intelligent services, the electricity grid has new capabilities to monitor, manage, and control its components and then takes advantage of sophisticated bidirectional interactions.

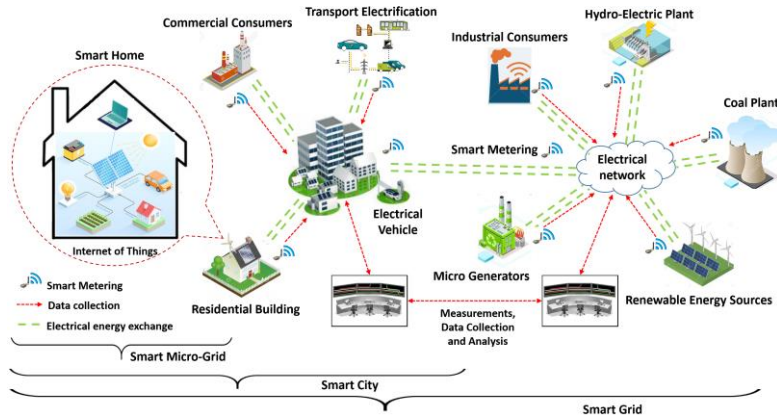


Fig. 1. Global architecture: From SG to smart MG.

Moreover, the ICTs integration enables various smart and automatic services, such as smart metering infrastructure, smart control and management for D/R (demand/response) balance, advanced electricity marketing, and intelligent energy storage for electrical vehicles integration. However, despite this progress, some research work stated that the SG is experiencing new challenges. Mainly, the SG is based on the actual infrastructures of power distribution grids, which are limited by the unidi-

rectional exchange of electricity [3]. Therefore, face these challenges; other concepts have been developed together with the revolution of SG, such as the IoE (internet of energy), the IoT, and the IoS (internet of services) [4]. Especially, the development and the emergence of smart MG systems could resolve some of the abovementioned SG challenges. MG could simplify the management of electrical energy, from centralized to distribute EM. In addition, in MG systems, different types of energy can be managed locally with the possibility to interconnect different MGs in a distributed manner.

In this work, a new holistic architecture of smart buildings is presented by improving the main layers of MG systems. The proposed MG system is a smart and active building that combines ICTs/Big-data infrastructure, RESs/storage systems, EM/control strategies, and electrical power grids. Mainly, the main component of the energetic system is presented, which is installed in our deployed MG system. We focused on the modeling of each component of MG layers, especially for sensing and measurement using our ICTs/Big-data infrastructure.

2 MG layers structure for energy efficient buildings

The MG system is structured into three horizontal layers: passive building layer (e.g., building envelope and insulation, architecture design), active building systems layer (e.g., HVAC system, Lighting), and RESs system layer (e.g., PV, wind, storage). These layers are monitored by one vertical layer for communication and ICTs integration. This vertical layer integrates mainly an IoT/Big-Data platform in order to measure, analyze, predict, and forecast actions depending on the actual and predicted context. In particular, our MG system is a smart and active building that combines ICTs/Big-data infrastructure, RESs/storage systems, EM/control strategies, and electrical power grids. This new concept of a building is more interactive for both consumers and energy producers. In fact, consumers will reduce the cost of their energy consumption based on the used control approaches, which take into account the real-time cost of the power and the predictive power generation, for efficient D/R management [4, 5]. Moreover, this MG structure offers the possibility to integrate new buildings' services, such as electrical vehicles, which can be used as a storage device to compensate the energy in the building by integrating the "Grid-to-Vehicle & Vehicle-to-Grid" techniques.

2.1 Communication technology used for MG system

The ICTs have a fundamental role in the performance of MG systems operation and its practical deployment. In an MG system, a large number of distributed components, such as the end-users, generators, and energy storage systems, require a reliable, sophisticated, and fast communication infrastructure to reach the mandatory of such systems. Therefore, effective communication systems should be normalized to enable real-time exchange of data in MG systems in order to collect the necessary information used for the EM (energy management) of the system. Mainly, the communica-

tion technologies that are used actually in MG systems can be classified into two categories, wired and wireless technologies. Table 1 presents the different communication technologies, which can be used in the MG system with the specified international standards [6, 7].

Table 1. Communication technologies for MG building systems.

	Type	Technology	Standard
WIRED	Power line	PLC	ISO/ IEC 14908-3
	Serial	RS-232, RS-422, RS-485	
	Ethernet	Ethernet IEEE 802.3	IEC-61968
	Bus-based	CANBus	IEC-61970
		Modbus	
		Profibus	IEC61850
	SCADA	PLC RS Ethernet IEEE 802.3	IEEE STD. 1815- 2012, IEEE 60870
WIRELESS	WLAN	Wifi	IEC61850
		Lifi	IEC61850
		Bluetooth	IEEE 802.15.1
		ZigBee	IEC-61968 IEC-61970
		WiMax	IEEE 802.16j/m
	Cellular networks	3G	
		4G	IEC61850
5G			

2.2 Data sensing and communication

The building's transition to a smart MG system requires the distribution of the communication as well as a distribution management system. For instance, the IEEE Standards Association approved the OpenFog Reference Architecture, developed by the OpenFog Consortium, including Intel, Cisco Systems, Microsoft, Dell, ARM Holdings, and Princeton University, as an official standard, under the name of IEEE 1934 [8], for IoT communication in MG systems. The standard classifies the interaction of interconnected units for streaming and real applications into three classes: i) Machine-to-Machine, in which any component can send/receive data or command to/from any other one using the capabilities of IoT, ii) People-to-Machine, the users can control each machine, which can be adapted depending on the occupants' comfort, and iii) People-to-People, in which users can exchange data through a cooperation mechanism. In our studies, sensors are used to collect contextual data, which are submitted to our remote platform for storage or further analytics. Mainly, current and voltage sensors are installed to gather data from RESs, storage devices, and load consumption. Mainly, three types of sensors outputs can be specified, current loop output, voltage output, and digital output. The sensors based on current loop output are calibrated over a specified range against various engineering units to convert the real value, such as the temperature, pressure, and current, to an equivalent current value

measured by the deployed microcontroller. The output of the individual calibration certificate is compared to a mathematical manipulation made to obtain the absolute value. The loop's operation is straightforward in which the sensor's output signal is first converted to a proportional current, with the less current (generally on mA) presents the sensor's zero-level output and the high current represents the sensor's full-scale output. Therefore, the voltage output sensors can have various voltage outputs (5V, 10V, from -5V to +5V and more) that are calibrated over this range against various units. The output is compared to the individual calibration certificate for the specified measurement range for which the sensor is selected. Generally, there are two types of voltage output signals, differential and single-ended measurements. The differential voltage signal is "floating", meaning that has no reference to the ground. The measurement is taken as the voltage difference between the two wires. The benefit of this method is noise elimination because the noise is added to both wires and can then be filtered out by the common-mode rejection of the data acquisition system. For single-ended measurement, it considers as the voltage difference between a wire and the ground. The noise is only on the positive wire and as a result, it is still measured along the output voltage of the sensor. Mainly, the transmission of the signal for long distances produces corresponding lower voltages at the end receiver due to the wiring and the interconnecting resistance. Also, the voltage devices are sensitive to the noise pickup for which the shielded wires are used to minimize this noise.

However, many sensors use a digital signal rather than analog signals of voltage and current. Face to the noises and the measurement perturbs, it is more robust. The two most common digital communications are RS-232 and RS-485. The RS-485 is more used because it only specifies the electrical characteristics of the generator and the receiver. It does not specify or recommend any communications protocol, only the physical layer. Modbus, Profibus, Canbus, and SDI-12 are all examples of communication protocols employing the RS-485 style signal. Therefore, the major advantage of the RS-485 system is that sensors can be transported; meaning that each sensor has its own individual address and many can be all attached to one cable. This means that multiple sensors only use up one port on the data logger saving considerably on cable and data logging costs.

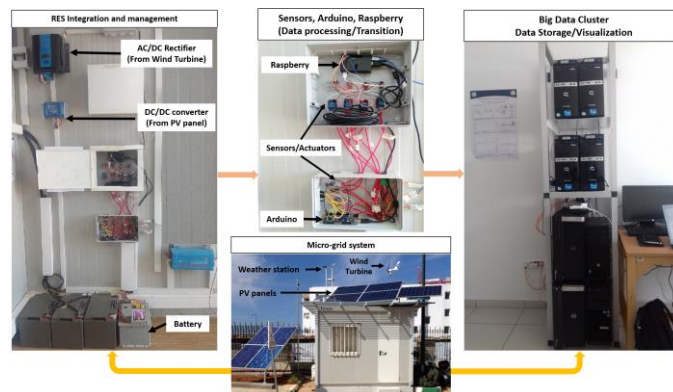


Fig. 2. Monitoring platform architecture.

Therefore, our deployed MG is equipped with a component for measuring power consumption and production. In fact, a set of current and voltage sensors have been installed for power measurement as shown in Fig. 2. The system contains an Arduino, which allows collecting the data from different sensors and send it to a micro-computer (Raspberry pi) connected directly to the IoT/Big-Data platform. In fact, sensors transmit analog signals to the microcontroller, which converts them into numerical data. For example, a voltage sensor is used to measure the output PV voltage with an accurate range that considers the maximum voltage of the PV installation. For that, a tension divider bridge is used to convert the values from zero to 5V, which is the Arduino accurate range. In fact, the Arduino program converts obtained values to tension data. Moreover, the Arduino transmits these data to the Raspberry for activating the right action according to the deployed control algorithm.

The next section introduces our MG system's architecture. In particular, we highlighted the necessity of integrating recent IoT/Big-Data technologies for gathering external and internal data, which have been used to generate predictive actions (e.g., regulating the room temperature by forecasting the building's occupancy, ventilation speed variation according to the forecasted CO₂, intelligent and predictive control of energy flows management using forecasted power production, consumption, and battery SoC).

2.3 IoT/Big-data platform for data collection

The aim was to develop a research testsite integrating the different components of an MG system. As shown in Fig. 2, the system integrates PV panels, WT, batteries, and the utility grid connected together in order to supply electricity to the building's services according to actual contexts. The system is monitored by an IoT/Big-Data platform, which is used to collect, analyze, and store the data for EM and control strategies development. Moreover, several scenarios are deployed in order to develop a research platform that considers the concept of MG systems with the different components of the different layers.

Real-time and context awareness information could be exploited for developing predictive and adaptive context-driven control approaches using recent IoT and Big-data technologies together with real-time and ML (Machine-learning) algorithms [9, 10]. The communication platform is composed of four main layers, sensors/actuators layer, data acquisition, data processing, and data visualization/storage together with further services and applications for context-driven control (Fig. 3). The MG is mainly equipped with a component for measuring the different necessary parameters (e.g., current, voltage, temperature, wind speed), for interacting with the passive and the active equipment, for regulating the comfort for the occupancy, and for managing the power production and consumption. In fact, a set of sensors is installed depending on the desired scenarios. Regarding the data acquisition layer, a Kaa application is developed (i.e., IoT technique) [11] which is used to receive data from deployed sensors. We have also used MQTT, which is a publish-subscribe-based protocol for IoT applications. For data processing and storage, Storm services are used [12].

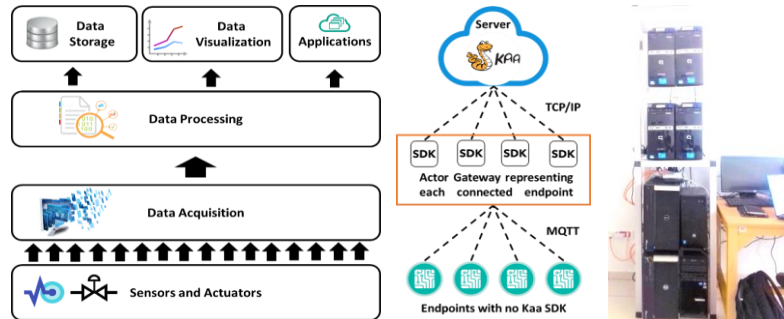


Fig. 3. IoT/Big-Data platform architecture.

Mainly a topology composed of Spouts and Bolts was designed and developed to allow receiving and processing streaming data from sensors. The spouts receive the data from the Kaa application, and then transmit it to the Bolts for processing and storage into the database (e.g., MongoDB) for further in-depth analysis. The services layer includes real-time visualization and storage together with the control of active equipment and RESs power production and consumption monitoring and management. The platform was used for data gathering and processing of internal and external building's context. For instance, it was used to build occupant information (e.g., number, presence, behavior, activities), since is a major input for control approaches in energy-efficient buildings (e.g., active systems control) [9]. In fact, comprehensive fine-grained occupancy information could be integrated to improve the performance of occupancy-driven control of HVAC, lighting, and ventilation systems.

3 Experimental platform of MG systems

Approaches developed in the frame of this work are deployed and tested in real-sitting scenarios in two MG systems. The first, named EEELab (Energy Efficient Building Laboratory) is used as a testbed for testing scenarios and validation. The second MG system is a real house, which is deployed during Solar Decathlon Africa competition, and it is deployed in Green Energy Park in Benguerir, Morocco. Both MG systems are used actually as a research platform for MG system development. The main aim is to measure, collect, analyze, and store the different data in the deployed MG systems. Mainly, the collected data are, especially, the indoor/outdoor temperature, the indoor CO₂ variation, the weather conditions, and the power production/consumption. Therefore, the measured data are used to develop different scenarios as the occupant's detection, the comfort amelioration, and the EM/control for the deployed RESs/storage systems. In this part, we focus on the different measurements realized for the energetic system.

Regarding the external context, we have deployed a weather station. In fact, for several scenarios, we need to gather internal and external context data. We have built a weather station near the WT and PVs in order to have as precisely as possible the data concerning wind speed, direction, irradiation, temperature, and humidity. The weather

station was deployed and used to collect the data for real-time visualization and processing for further usage by other building's services and applications. Moreover, D/R control approaches are therefore required for balancing the intermittent RES generation and the delay might occur between power production and the actual building's consumption. The main aim is to develop a control card to test the different studied control strategies for EM. Unlike existing systems, which are used as a black-box to collect and manage the energy in MG, the deployed control card allows us to measure, monitor, manage, and deploy our algorithms [13]. Therefore, different objective functions can be taken into account when optimizing and designing a control strategy, like the smoothing of the production, the continuity of the power generated to the consumer, the energy cost, and the C/D cycle of the batteries [13]. For that, a control strategy should be deployed to satisfy the constraints designed by the optimization functions. The main communication infrastructure is employed for total energy measurement and management purposes. This infrastructure provides the autonomous operation with the required measurements, decisions, and control by collecting data through the sensors and producing the commands for the Hw/Sw card presented in Fig 4, which is connected to the control switches used in the hybrid system [10].

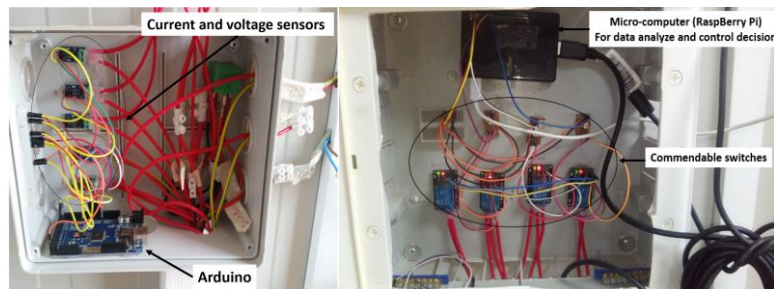


Fig. 4. The deployed Hw/Sw control card.

For the different scenarios, the proposed IoT/Big-Data platform could be used to measure different parameters in the MG system. Depending on the studied scenario, suitable sensors are selected and can be connected to this platform for data collection, monitoring, and processing. Mainly, the measured parameter is used to control efficiently the deployed MG system. Moreover, a case study is presented for a large-scale installation in which the developed control card and the IoT/Big-Data platform are used to measure and store the data collected by the deployed current and voltage sensors for the total installed RESs, battery storage system, and load consumption. As shown in Fig. 5, the green curve presents the power generated from the eight PV panels for 24 hours. This power is calculated by measuring the PV current and voltage variability during the day, which depends on the weather conditions (e.g., temperature, irradiance) changeability. At the same time, the battery SoC is calculated using our battery characterization system installed in the MG system. Moreover, the power consumption is measured and stored for the same period. These parameters are the main input for the EM strategy.

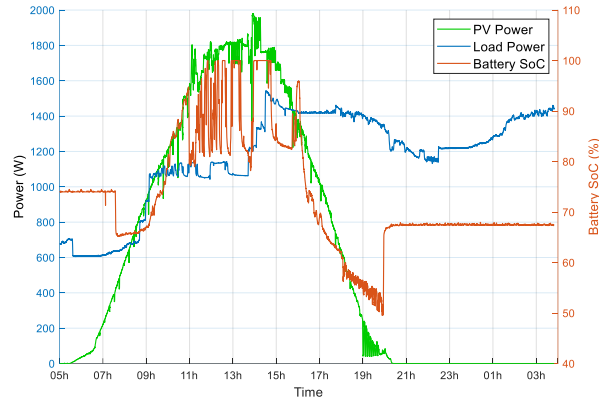


Fig. 5. Power measurement scenario in our deployed MG system platform.

However, due to the limited number of pages of this work, the obtained results are summarized in Table 2 for the different measurements realized in the deployed MG system focusing on that are used for EM in the deployed hybrid RESs system. Table 2 presented the obtained results for 10 days of the test. Actually, the house is used as a research platform and it is planned to deploy the test control scenarios, tested in a medium-scale, for large and real rural MG systems.

Table 2. Energy balance in the deployed MG system.

Day	Energy injection	Energy extraction	Energy demand	Central inverter	Local inverter	Correlation	Peak production	Battery capacity
14-09-19	1.39	0.86	3.08	3.6	2.28	0.73	7.7	4.8
15-09-19	2.93	4.08	13.32	12.17	9.35	0.7	7.7	4.8
16-09-19	3.91	1.04	5.99	8.85	5.01	0.83	7.7	4.8
17-09-19	2.5	2.91	11.08	10.67	8.24	0.74	7.7	4.8
18-09-19	3.19	1.71	8.01	9.49	6.3	0.79	7.7	4.8
19-09-19	0.47	3.96	13.34	9.85	9.38	0.7	7.7	4.8
20-09-19	1.75	1.57	9.49	9.67	7.97	0.87	7.7	4.8
21-09-19	1.5	1.91	11.76	11.36	9.9	0.84	7.7	4.8
22-09-19	2.9	1.14	6.36	8.12	5.24	0.82	7.7	4.8
23-09-19	3.85	0.98	5.15	8.02	4.18	0.81	7.7	4.8

4 Conclusions

The main aim of this work is to introduce an MG platform by focusing on communication and data monitoring concepts. The MG platform connects the building's components using sensing/actuating, IoT/Big-Data technologies in order to leverage real-time gathering and data processing for RESs production and loads' consumption. The platform was deployed and several scenarios have been tested and evaluated. The proposed data gathering techniques can be an interesting reference for the researches to have their proper platform for data collection that can be used in the research works. The deployed mechanisms are open sources and the hardware is not expensive. In the future works, several scenarios will be developed using the deployed

IoT/Big-Data platform, especially, that concerns EM and control, the active/passive equipment control, and the occupant's comfort management. In addition, machine-learning algorithms will be developed and tested in real scenarios using real data to train the proposed algorithms.

Acknowledgments: This work is supported by MIGRID project (grant 5-398, 2017-2019), which is funded by USAID under the PEER program. It is also partially supported by HOLSYS project, which is funded by IRESEN (2020-2022).

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