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Research paper

A Novel IoT-as-a-Service Strategy to Achieve Energy and Cost Saving In Microgrids

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Abstract

Smart Grids play a crucial role for always more efficient, flexible and reliable integration of technologies in the electricity marketplace. At the "edge" of Smart Grids, appliances and consumer devices consume electricity by Microgrids. End-users need easily and dynamically accessible electricity marketplace and heterogeneous renewable energy sources (e.g., solar, wind, etc.), in order to satisfy energy needs. This implies two main challenges: 1) managing the variable availability of renewables, mainly due both to variable electricity marketplace conditions and to a not-continuous energy sourcing; 2) managing the energy supply/demand ratio especially in presence of scarcity or surplus conditions in the electrical energy providing service. In this paper the authors propose a novel two-levels Internet of Things-as-a-Service (IoTaaS) strategy to "win" the above-mentioned challenges.

Keywords: *Cloud computing; energy management; internet of things; IoTaaS; smart grids.*

1. Introduction

The worldwide liberalization process of the electricity market is evolving towards new strategic approaches and opportunities for both energy consumers and suppliers. The new *European Union* target [1] is at least a 27% share of renewable energy consumption, and it is both technically and economically feasible for renewable energy to satisfy over 60% of China's primary energy consumption and 85% of electricity consumption by 2050 [2]. In such a scenario, **Smart Grids**, i.e., "new" power grids equipped with intelligent sensors, collect information in real time optimizing the distribution of energy and integrating renewable energy (e.g., wind, solar, hydro, tidal, geothermal, and biomass). At the "edge" of Smart Grids, consumers can adapt (both in time and volume) their energy usage to different energy prices throughout the day to save money on their energy bills. As part of this "macro" environment, a **Microgrid** is a *localized set of electricity sources and loads, normally connected to the electrical Grid (i.e., On-Grid), that can be controlled and operated in a coordinated way either while On-Grid or while islanded (i.e., Off-Grid or island-mode).* Basic components in *energy-aware* and *low-carbon* Microgrids are: *i)* local renewable generation sources; *ii)* controllable electricity loads or demand of the network; *iii)* energy storage; *iv)* the point of common coupling (PCC). In the On-Grid typology, multiple electrical loads are located in a tight geographical area and owners easily manage them. The Off-Grid or Isolated are generally present in remote sites (e.g., remote communities or remote industrial sites) where the deployment of the On-Grid is not feasible mainly due to geographical position, technical and/or economic constraints. A further distinction can be made on different application context (e.g., Community, Campus, Institutional, Military Base, Commercial, Industrial, etc.), types of generation source that feed electricity to consumers (e.g., the above-mentioned renewables), and between Alternating Current (AC) and Direct Current (DC) Microgrids. In such a scenario advanced optimization methods can be applied by implementing a **Microgrid Energy Management System (EMS)**, for example in order to improve the efficiency and the resiliency of the Microgrid. Moreover, Cyber-Physical Systems can enable a Microgrid to open up the possibility for consumers to access the electricity marketplace, and therefore to manage the electricity consumption from variable and heterogeneous renewable energy sources in a dynamic and prompt manner. This results in two main challenges: *1)* managing the variable availability of heterogeneous renewable energy sources, that can be due both to variable electricity marketplace conditions (i.e., price) and to a not-continuous energy sourcing; *2)* managing the energy supply/demand ratio especially in presence of scarcity (i.e., electricity peak) or surplus conditions in the electrical energy providing service.

In this paper we propose a *Software Defined Energy Management* strategy, based on the use of the **Internet of Things (IoT)** paradigm and its "cloudization" (i.e., its on-Cloud management) in **IoT-a-a-Service (IoTaaS)** [3] environments, to achieve energy and cost saving objectives in Microgrids. **Energy Routers (ERs)** [4] are required to incorporate a large number of renewable energy resources and to manage efficiently the energy supply and demand. ERs adjust dynamically the energy distribution in the Microgrid and represent the *communication nodes* to the **Cloud** through the *Internet*. The *data infrastructure* of the Microgrid, at the ERs, can be optimized for low power consumption and can be designed to support large networks with millions and millions of devices through the use of *low power* technologies, standards (i.e., ITU-T G.9903 (G3-PLC), ITU-T G.9904 (PRIME), IEEE P1901.2 , IEC 61334 (S-FSK)) and protocols (e.g., the *LoRa* long-range wireless protocol).

2. Related Work

In this Paragraph we introduce recent contributions in scientific literature about the energy management systems at the Microgrid architectural and functional level.

In [5] the authors present a coordination architecture for islanded Alternating Current (AC) Microgrids, which considers the appropriate charge profiles for battery-based energy storage systems. The proposed strategy considers proper dynamic behavior and reliable operation modes for the islanded power system, and relies only on local measurements and actions without the use of additional communication channels.

The energy management strategy proposed in [6] uses a Hybrid Renewable Energy System (HRES) capable to satisfy load energy demand, to ensure the energy flux management and to optimize batteries utilization. However, how the authors assert, it should be improved based on three important factors: *load forecast, energy generation forecast and energy selling price*. We take into account these necessities in our strategy.

A simulation based multi-objective optimization approach [7] is applied to the design of cost-effective energy efficient buildings for residential buildings in the Bahamas. Homeowners can reduce yearly electricity usage and consequently energy bills, while maintaining the comfort level of the home. Unlike this study, we propose a framework whose design starts from the reasonable use of *open hardware*, *open software* and *open data* technologies. We plan to reduce the customer's dependence on the hardware supplier, by removing the obsolescence of the implemented solutions and favoring the secure access to services both for customer and communities.

The architecture design proposed in [8] focuses on a comprehensive solution for Smart Grid controlling by integrating all the controls of storage, security and IoT networks. The philosophy of our approach, instead, addresses: *i)* the optimization in using appliances and consumer devices through the IoTaaS; *ii)* the educational purpose to guide the customer towards a "virtuous" use of electrical devices through dedicated apps (e.g., Android app); *iii)* the energy management at the Microgrid level towards principles of sharing and energy solidarity (for example between condominiums).

In [9] the authors propose an energy management platform based on the use of the IoT. The system efficiently collects energy resource information in the home in order to reduce energy wastage and also to provide information for analyzing energy consumption patterns. The work confirms the necessity in collecting big data from the smart grid and the trend in using the IoT for this purpose.

In [10] the authors present and discuss the #SmartMe Energy system implemented at the University of Messina as part of the #SmartMe crowd-funding project. The goal was to optimize the use of all the electrical equipment in order to reduce energy consumptions and costs also improving sustainability and comfort inside offices (i.e., at the edge of the Microgrid).

3. The IoT-as-a-Service (IoTaaS) Strategy

3.1. Preliminary Analysis: the On-Grid / Solar PV plus Battery Scenario

In order to better understand our vision, before to introduce the architecture design and the IoTaaS functionalities, we make a preliminary analysis by considering an applicative example. We consider a consumer has an On-Grid (i.e., grid-connected) solar photovoltaic (PV) system for his home and must be absent for a period of time (e.g., for a day, in the summer season, etc.). All the energy produced by the plant will therefore not be used at home. However, the absence of automatisms associated with the negligence of the consumer would contribute a consumption of electricity, considered not negligible (i.e., due to the standby condition or to a left ON device), which can be eliminated. Once activated, the system will allow the energy to be fed into the distribution network and accounted for at the output of the on-site exchange meter without losses due to unwanted consumption. Upon return, the consumer will turn ON the utilities and he will make free use of all the energy previously injected. In this case, the exchange counter will count the energy drawn from the network, without the aforementioned losses. The presence of a home energy storage unit allows the energy produced to be accumulated in batteries that are in turn capable, for example, of returning the energy accumulated during the day in the evening and at night. Generally, a suitable charge controller adapts the electrical parameters of the photovoltaic modules to the recharge of the battery bank, also checking the charge levels and supplying electricity to the consumer.

3.2. IoTaaS Strategy at the lower Microgrid level

Figure 1 shows the architecture designed for the proposed strategy.

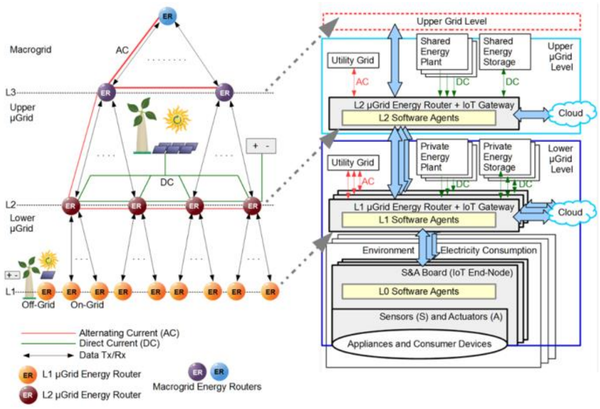

Fig. 1: Simplified architecture of the proposed IoTaaS Energy Management.

From the bottom to the top, for each environment we identify a first set (i.e., electricity consumption) of appliances and consumer devices to manage for both the energy consumption and monetary cost reduction. Each environment is graphically represented by a rectangle and includes the IoT End-Nodes, i.e., electronics boards equipped by Sensors (S) and Actuators (A). Sensors monitor the electrical and environmental parameters. Actuators execute the energy-aware automatisms on the power lines. Both monitoring and control are carried out through the deployment of *software agents*, resulting in various benefits by automating complex or repetitive tasks. Labels *L0,1,2* identify the typology of software tasks/operations which characterize the corresponding level in the architecture. L0 differs from the upper L1 at the IoT Gateway devices, thus in turn regulating the communication and the exchange of data between the IoT End-Nodes and the Cloud. The IoT Gateway supports the *Energy Router* to exchange data packets from/to one or more environments (mainly depending from the environment and technology constraints) and the Cloud. The "core" of the Energy Router remains to manage efficiently (i.e., responding fully to its functions or its purposes) the energy supply and demand in the grid. At the lower L1 Microgrid level, the Energy Router allows consumer to benefit from the sale or purchase electricity by renewables in the Off-Grid or in the On-Grid configuration, and then from its own plants or from other private plants of people which is available to sell/buy energy. In the On-Grid configuration, consumers can also access the *Utility Grid*. Usually, it is a commercial electric power distribution network which takes electricity from a generator (e.g., from fossil fuel boiler and generator, diesel generator, wind turbines, hydroelectric systems) and transmits it at a distance to the consumers through a distribution system. Moreover, energy can be exchanged from/to private energy storage batteries, for example based on thresholds for maintaining optimal operating levels (charge/discharge cycles). Data gathered from the IoT End-Nodes, together with data related to the energy routing are useful to calculate (in the Cloud) costs and benefits in the bill.

3.2. IoTaaS Strategy at the upper Microgrid level

At the upper architectural level of the Microgrid, the new label L2 identifies a different set of software tasks/operations. Unlike the L1 typology, these latter are executed through the L2 software agents in order to: *i)* enable the L2 Energy Router to manage the energy supply and demand from/to the lower level, shared energy plants and storage, Utility Grid, and eventually with upper Grid levels; *ii)* manage the data communication with the Cloud through the L2 software agents deployed at the L2 IoT Gateway. If the lower level is optimized to address the best use of appliances and consumer devices, and of private plants and storage systems, the upper level manages the access to bigger energy infrastructures. These latter are usually designed to serve large entities (e.g., apartment buildings, communities, organizations) in order to improve the energy efficiency of the entire "big" pool of electricity consumptions.

3.3. Managing IoTaaS through the Cloud

The main role of the Cloud in the Microgrid context is to control the energy routing between the different Microgrid levels. This role is executed by deploying "ad-hoc" the related IoT services: functioning profiles (e.g., network tables, configuration, storage commands, security) are defined via software by automatically deploying the above-mentioned software agents at the IoT devices. The control of the Microgrid is enabled at the Cloud through different *software defined engines* or *controllers*. The Cloud platform we propose in the presented strategy is based on the **OpenStack** open source software. OpenStack controls large pools of compute, storage, and networking resources, which are managed through a dashboard or via the OpenStack API. At Cloud side it is possible: *i)* to guarantee a protected access to the Cloud for the Suppliers which are enabled by customers (e.g., by a prior informed consent) to use consent data for new technical-economic improvements or new ad-hoc services; *ii)* to provide mobile applications (e.g., Android) to inform the consumer about its consumptions, its good or bad practice in using appliances and devices, or to suggest virtuous behaviour, but not only; *iii)* to make data accessible by providing tools to streamline publishing, sharing, finding and using data.

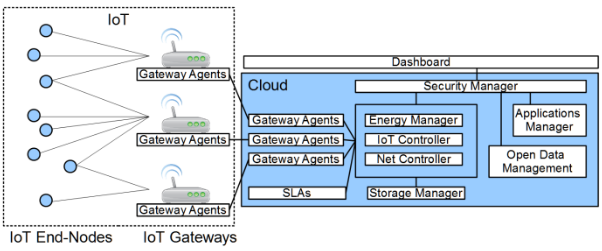

Fig. 2: IoTaaS Block Diagram

Figure 2 summarizes the main blocks which characterize the proposed IoTaaS Platform. Focusing on the Cloud, a set of control units are located and coordinated with each other in order to achieve energy and cost saving goals in Microgrids. These control units are deployed in form of software engines (i.e., tools or sets of functionalities) and are summarized as follows.

- **Energy Manager**. It is responsible for the energy-aware control and management of the Microgrid, by generating the related transactions. It also implements *brokering service* aimed at consumers or companies to achieve more benefits about energy and cost-saving purposes. Its key-roles are: *i)* to gather data from the Energy Routers through the *Gateway Agents* to be stored and computed at Cloud; *ii)* conveying the packets of energy through the Microgrid and managing its scalability based on the monitored *supply and demand* parameters and on the information from the other software engines; *iii)* to handle the failures by generating alternative paths for each route.
- **IoT Controller**. Both IoT End-Nodes and Energy Routers generate a large volume of data from the monitored environments and about their functioning. Moreover, the energy management is dynamically executed at different levels of the Microgrid and for different typologies of IoT devices. Therefore, to control and manage them and their data is mandatory. To this end, the IoT Controller is the engine which enables the configuration procedures to be executed at each node.
- **Net Controller**. It is responsible for the setup, the management and control of the IoT Network, e.g., a LoRa Wide Area Network (LoRa WAN) [11].
- **Security Manager**. It is responsible of monitoring and managing the security aspects. *Keystone* is an OpenStack service that provides API client authentication, service discovery, and distributed multi-tenant authorization by implementing OpenStack's Identity API.
- **Storage Manager**. OpenStack has several storage instruments to manage: Block Storage (Cinder), Object Storage (Swift), Image Storage (Glance), Ephemeral Storage (Nova). However, we need to configure, control and manage all the storage resources. This operations are executed inside the Storage Manager.
- **Application Manager**. It allows consumers to create their own accounts in the Cloud to manage their appliances and devices.
- **Open Data Management**. Our choice is to integrate the use of the *Comprehensive Knowledge Archive Network (CKAN)*. Data, in fact, can be accessible confidentially or in the form of Open Data. In this case, through the web-based CKAN data-stores, the system allows the storage and distribution of datasets, thus offering REST API interfaces.
- **SLAs Engine**. This engine allows the system to manage the Service Level Agreements (SLAs), and in particular the Green SLA (GSLA) [12] for our sustainability purposes.
- **Gateway Agents**. are deployed both at the IoT Gateways and Cloud side. They provide connectivity between the Energy Routers and the Cloud through the Internet in order to execute the planned operations by the above-mentioned engines.

3.4. The Energy Management System Algorithm

The Algorithm includes brokering and energy routing processes. The pseudo-code on the right in **Figure 3** reports the logical flow about the dispatching of electricity on a forecast time period *T* (e.g., on the 24 hours) in a Microgrid. The strategy takes into account the electricity demand forecast (edf), the electricity supply forecast (esf) from the consumer's AC/DC electrical supply systems, the battery charge level (b) at the end-user (u) which can be considered as consumer or supplier depending by the presence of a need or surplus of electricity at its own "node" in the Microgrid.

Algorithm 1 Energy Management System Algorithm

while true **do**
  for $t = 0$ to $T - 1$ **do**
    $\epsilon(t, u) = edf(t, u) - esf(t, u); \quad with\ t = 1, 2, ..., 24; \quad u\ is\ the\ user.$
    if $(\epsilon(t, u) < 0)$ **then**
      if $(thm \leq b(t, u) \geq thM)$ **then**
        brokering:
        $maeo(|\epsilon(t, u)|, t) = max(S);$
        routing:
        $|\epsilon(t, u)| \rightarrow (s_{maeo} \in S);$
      else
        $w_b(t, u) = thM - b(t, u);$
        $r(t, u) = |\epsilon(t, u)| - w_b(t, u);$
        brokering:
        $maeo(r(t, u), t) = max(S);$
        routing:
        $w_b(t, u) \rightarrow (b(u) \in E);$
        $r(t, u) \rightarrow (s_{maeo} \in S);$
      end if
    else
      if $(\epsilon(t) > 0)$ **then**
        brokering:
        $maeo(\epsilon(t, u), t) = min(S);$
        routing:
        $b(t, u) \rightarrow (u \in E);$
        $w_b(t, u) = thM - b(t, u);$
        $w_b(t, s_{maeo}) \rightarrow (b(u) \in E);$
        $r(t, u) = \epsilon(t, u) - b(t, u);$
        $r(t, s_{maeo}) \rightarrow (u \in E);$
      end if
    end if
  end for
  wait(T1)
end while

Fig. 3: The Energy Management System Algorithm

The algorithm focuses on to guarantee an adequate level for battery charge between two minimum and maximum thresholds, i.e., respectively thm and thM in the algorithm (e.g., between the 20% and the 80%). Brokering is executed in order to determine the most advantageous economic offer (maeo) both in case the user needs of electricity (the minimum monetary cost) and the user wants to sell it (the maximum price offered by suppliers). The label S in the algorithm is the “set” of possible suppliers or buyers, also including private/public providers by the Utility Grid. The operative part is executed by the Energy Router which follows the directives from the Energy Manager. The Energy Manager at the Cloud side analyses the data flows from the IoT Nodes, deals with managing both the brokering and the routing and drives the Energy Routers according to the implemented rules.

4. Conclusion

The strategy proposed in this paper is based on the use of IoT and Cloud to implement energy management systems through the IoT-as-a-Service (IoTaaS) paradigm. Related algorithm is designed to achieve energy and cost saving goals in electrical Microgrids. Our strategy involves the use of the most advanced and widespread open source technologies both at the “edge” of the Microgrids and at the Cloud side. Unlike other well-known solutions proposed in literature or present in the electricity market, our strategy provides the use of open hardware IoT boards which facilitates the software customization and the deployment of software agents. One of the leading advantages of using an open source hardware/software technology is that “smaller” electronic companies or start-ups can build IoT devices much cheaper and faster. Moreover, the proposed strategy makes it easier to set-up, maintain, and update projects, contemporary allowing the growth of communities of potential developers interested in sharing improvements to the software code or hardware. To enforce this topics, we designed a framework which provides for the use of OpenStack services. In future work we plan to experiment our IoTaaS strategy outside the Academia/University context by collaborating with interested businesses/suppliers, and involving citizens as part of a broader educational project for a virtuous and sustainable use of appliances and electrical devices.

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