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Simple electric utility platform: A hardware/software solution for operating emergent microgrids

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HIGHLIGHTS

- A platform with computing, communication, and control features is introduced.
- Functional roles for enabling a full-fledged microgrid are discussed.
- Cloud-based computing approaches for optimization in microgrids are presented.
- Appropriate cybersecurity measures for a management platform are discussed.
- Application of the platform in a secondary layer optimization problem is shown.

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ABSTRACT

Along with the technical feasibility of microgrids, the importance of supervisory communications, computing, and control (CCC) systems that are necessary to operate a microgrid in a stable and economically feasible manner have been firmly established in the literature. While several investigators have proposed and demonstrated algorithms and applications of CCC, the functional entities and responsibility centers for realizing CCC within microgrids in the context of multiple independent customers and distribution system entities have not been situated and/or studied. In this context, the term emergent microgrid may be used to define an electrical network that consists of local generation, loads, and storage. Such a grid has the potential to be clustered as a microgrid, but does not have all the CCC features to become a full-fledged microgrid. In this paper, a simple electric utility platform (SEUP) that is an end-to-end solution with all the hardware/software interfaces and components necessary for augmenting emergent microgrids with CCC into full-fledged microgrids is presented. SEUP abstracts the details of sensing and CCC for the microgrid developers, installers, operators and end-users to provide a seamless system. SEUP is distinctive from other CCC platforms in that it is entirely based on publicly available infrastructure resources (wireless cellular networks, internet and cloud computing) without any intellectual property restrictions. The paper introduces the functional roles, main architecture, components and security features of SEUP along with the results from a sample application case of a laboratory-scale power system.

1. Introduction

A *microgrid* can be defined as a power system with a relatively high penetration of non-dispatchable energy sources (solar, wind, etc.). There is more emphasis on localized generation and distribution where the nominal generation capacity and load demand are in parity with each other. One of the important features that makes microgrids different from macrogrids (legacy power system) or other distributed energy systems is the delicate balance of energy supply and demand.

Advancements in power electronics, battery technology, computing and communication along with challenges of macrogrids such as aging infrastructure and complex expansion have led to the emergence of microgrids for a number of applications [1]. Microgrids have shown to be a good option for resilient power systems in the event of natural disasters such as hurricanes, storms and earthquakes [2–4]. Studies have shown the positive impact of electrification on poverty in areas which lack electricity access [5].

Small and medium scale dc systems are also gaining popularity. Reasons include advancement in power electronics, growth of consumer electronic devices, data centers for computing, and wide adoption of PV-based technologies [6]. Many studies focus on the primary layer of control [7–10] and are mainly analytical or simulation based.

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Nomenclature

CCC	communication, computing and control
EC	electricity client
DERA	distributed energy resource aggregator
DSO	distribution system operator
GO	generation operator
HEM	homegrid energy manager
MGO	microgrid operator
MEM	microgrid energy manager
SEUP	simple electric utility platform
TSO	transmission system operator

Experimental and pilot projects have been implemented for applications such as data centers [11–15], telecommunication [16,17], and commercial buildings [18]. These systems have minimal secondary and tertiary management capabilities, which limits implementation of services like demand side management, energy pricing, and forecasting.

On the other hand, ac microgrids are necessary for wide-scale adoption of microgrids in residential and industrial segments. Due to higher penetration of renewable energy and power electronics, microgrids are low inertia systems. In macrogrids, the presence of synchronous machines provides an inherent layer of control (primary layer), whereas microgrids often resort to emulation of characteristics of synchronous machines through droop control to provide this primary layer control [19–23]. The main advantage of droop control is the elimination of extra layers of control and communication. This works well when the energy supply is several magnitudes higher than the demand. However, in a microgrid where the energy supply and demand is comparable, additional layers of control are necessary to overcome the inability of droop control to handle such scenarios [24,25]. In such cases, the secondary layer of control is responsible for minimizing voltage and frequency deviations and for restoring the grid to the desired set-points to ensure a reliable and economical operation of the microgrid. A number of optimization techniques have been proposed based on linear programming (LP) and non-linear programming (NLP). These techniques have mainly been applied to simulation/emulation based systems. They include artificial bee colony optimizations [26,27], ant colony optimizations [28,29], coalition based aggregation [30–35], and particle swarm optimization [36–39]. While NLP approaches are powerful, they require large computation power, time and cannot always guarantee achieving the global minimum. On the other hand, LP approaches [40,41] are simple and require less computational power, making them ideal to implement on single board computers (SBC) with nominal processing power. The LP based methods have been studied and implemented in a number of studies [42–46]. These studies mainly apply LP methods for demand response and dispatch using resource constraints, prediction and forecasting techniques with the goal of reduction of overall costs, emission levels and energy usage. In contrast, this study uses a LP-based optimization technique for coalition based architecture among different buildings in a microgrid with critical peak pricing (CPP). Such an optimization is beneficial for reducing peak demand charges encountered by a large facility with several un-coordinated buildings. This is done by forming a coalition and coordinating to reduce the peak demand of the entire facility. The results of the optimization are demonstrated on a experimental laboratory scale dc microgrid test-bed that emulates an office building and a lab building that form an emergent microgrid.

Several studies have studied and implemented critical peak pricing [47–51]. Most of these studies reduce CPP charges for a single home or a building using intelligent or optimized scheduling. In contrast, this study focuses on reducing CPP charges for community or institution level power systems such as campus or industrial microgrids which are grid connected. These microgrids house several buildings which might lack coordination between them. Installing the SEUP platform in these buildings along with a central cloud based energy manager allows for coordinated demand management. This leads to reduction in CPP charges for the entire facility.

To achieve secondary and tertiary level control, energy management systems are necessary for smart management of the microgrid. Several studies in literature have proposed architectures, simulation based systems or experimental prototypes [52–56]. Most of these studies focus on the implementation of optimization and control schemes and provide very little detail on the hardware and software architecture of the energy management platforms which is the key for reliable and economical functioning of a microgrid. For plug-and-play capability, scalability and flexibility, technologies such as internet of things (IoT) and cloud computing play a key role. Although applications of cloud computing have been explored in the context of power system technologies [57–65], they have not been developed and studied definitively in the context of microgrids and fall short of proving complete end-to-end solutions for microgrid operations.

The goal of this paper is introduce a platform that is open, transparent and readily adaptable to particular applications as necessary. A platform based approach for realizing the secondary and tertiary control of microgrids is attractive, because it defines both the physical and abstract entities with particular functional responsibilities. Such definitions are useful in developing appropriate operating protocols to integrate with electricity consumers and distribution utilities if and when it is necessary [66]. Furthermore, a solution that reaches beyond the secondary and tertiary layers to include economic and commercial aspects of the electricity enterprise would enable convenient and cost-effective deployment of microgrids. Towards this end, a *simple electric utility platform* (SEUP) that utilizes open-source hardware, software components and globally accessible communications and computing infrastructure is introduced as an integrated solution for operating microgrids. The platform enables microgrid application developers to deploy their services without having to develop the entire infrastructure in house.

The main contributions of this paper may be summarized as follows:

- Comprehensive functional roles of the SEUP to provide CCC solutions for converting an emergent microgrid to a full-fledged microgrid are enlisted and discussed.
- The architectural features of the microgrid management platform to provide users (developers, installers, researchers) with end-to-end capabilities abstracting the computing, communication and control infrastructure are introduced. This allows them to develop and deploy microgrid applications easily.
- The implementation of cloud based computing approaches for performing typical secondary and tertiary layer optimization problems in microgrids, along with appropriate cybersecurity features are discussed.
- The application of the platform for implementing a typical secondary and tertiary layer optimization problem is illustrated using an example case study.

Various functional roles of SEUP are outlined and defined in Section 2. The nomenclature of its hardware and software components are included in this section. Section 3 gives an overview of the SEUP environment within a microgrid and its various constituent elements, including the homegrid energy manager which is the core laborer of SEUP, and the microgrid energy manager which lays the supervisory infrastructure necessary to coordinate all constituents of the microgrid. Section 4 defines the specific architecture and details of the homegrid energy manager, and Section 5 does the same for the microgrid energy manager. Section 6 describes the security features of SEUP meant to

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