# The Cloud-based Control Platform for Multi-source Renewable Energy System

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**Abstract.** Intermittent renewable energy supply combined with electric and thermal energy storage technologies can cover the highest possible share of electricity, heating and cooling needs. However, their integration within the HVAC (Heating, Ventilation and Air-Conditioning) systems could result in far too complex installations, requiring intelligent energy management platforms for achieving their energy-efficient work. This paper introduces a cloud-based control platform, deployed to one such multi-source/sink renewable energy system, that performs all control and monitoring tasks through its hierarchically organized algorithm structure. This cascade control paradigm entails conventional control enrichment by more intelligent superior optimization, which evaluates not only the current energy demand and state of resources but also the inherent flexibility on the demand side and predictive aspects of the local energy production from renewables. On the other hand, the control system layered architecture relies on SCADA system solution, with proven modularity, flexibility and connectivity, making the system easily upgradeable and accessible by the end-users.

**Keywords:** HVAC System, Cascade Control, SCADA System, PLC, Cloud Platform, Third-Party Application.

## 1 Introduction

The increase in the world's population has led to an enormous increase in the number of residential and commercial buildings, and thus more frequent installation of air conditioning, heating and cooling systems, so-called HVAC systems. As they are an indispensable part of today's living comfort, but also important energy consumers, their energy efficient work is crucial. Also, it is not uncommon for such systems to be integrated with non-conventional, renewable, energy sources such as geothermal and solar energy. It is known that increasing their share leads to a reduction in carbon dioxide emissions into the atmosphere, helps to improve the security of energy supply and thus reduces dependence on imports of energy raw materials and electricity. However, the task of monitoring and controlling energy flow, especially in cases of systems that integrate multiple different energy sources, storage media and consumer devices, becomes too complex for human operation, and the question of the importance of using adequate software for these purposes arises. Therefore, this paper will elaborate on an instance of the advanced, cloud-based, control platform deployed for one such system, which is, actually, one of the demonstration sites within the European Horizon 2020 IDEAS project.

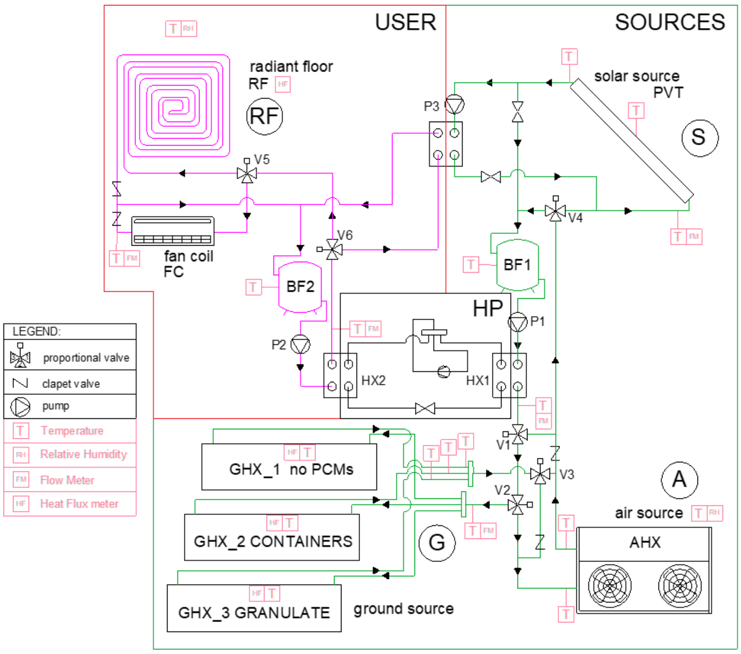


**Fig. 1.** P&ID diagram of the considered HVAC system installation [1]

### 1.1 Technologies within the pilot site

The considered multi-source/sink renewable energy system features an HVAC system with non-standard water-to-water heat pump (HP) integrated hybrid technology that combines several different renewable energy sources: solar electric and thermal, in the form of a solar panel (photovoltaic panel) with an additional heat exchanger, in other words known as a solar collector (photovoltaic thermal collector, PVT), geothermal horizontal heat exchangers (GHXs) and an air-to-water exchanger (AHX), **Fig. 1**. As regards the whole pilot site integrated components, there are, as well, thermal buffers (BFs) with so-called phase change materials (PCMs) and, finally, radiant floor and fan coils, as the main air conditioning units. The availability and cost-effectiveness of sources exploitation varies depending on the annual season, time of day, generally speaking, climatic conditions. For instance, GHX thanks to its large thermal capacity, is the most stable source, usable both in winter and summer conditions, for heating or cooling purposes, respectively. Still, its finite capacity prevents its long-term exploitation, which further leads not only to the disruption of the flora and fauna of the surrounding land, but also to the reduction of its thermal capacities. In order to avoid scenario like this, there are various approaches including its recuperation using remaining sources when the thermal heating demand is not a priority (UHS mode, **Table 1**) or, making the alternative energy source sub-optimal choice for supplying the heat pump system (A, S, AS modes, **Table 1**). For the purpose of giving a broader context, the plant could be found in twelve different operating modes [2], each one with meaningful purpose, accomplished through the appropriate set-up combination of system actuators (three-way, two-way valves, heat pump, circulation pumps, air-heat exchanger device).

**Table 1.** Foreseen operating modes

| Cases | Acronym | Exchangers | Aim |
|---|---|---|---|
| Solar source | S | PVT | Use of PVT for heating |
| Ground source | G | GHX | Use of GHX for heating/cooling |
| Air source | A | AHX | Use of AHX for heating/cooling |
| Ground + Air source | GA | GHX + AHX | Use of GHX & AHX for heating/cooling |
| Solar + Air source | SA | AHX + PVT | Use of AHX & PVT for heating |
| Solar + Ground source | SG | GHX + PVT | Use of GHX & PVT for heating |
| Solar + Ground + Air source | SGA | GHX + AHX + PVT | Use of GHX, AHX & PVT for heating |
| Free Heating | FREE_H | PVT | Use of PVT for direct heating |
| Free Cooling | FREE_C | GHX + AHX | Use of GHX & AHX for direct cooling |
| Underground heating storage | UHS | GHX + AHX + PVT | Use of AHX & PVT for ground heating storage |
| Underground cooling storage | UCS | GHX + AHX + PVT | Use of AHX & PVT for ground cooling storage |
| PVT cooling | PVT | AHX + PVT | Use of AHX for PVT cooling |
| Solar source | S | PVT | Use of PVT for heating |

## 2 Methodology

### 2.1 Cascade control paradigm

The control system methodology, algorithmically, consists of two conceptually separate but collaborative parts of the entire hierarchically organized cascade control structure: low-level and high-level control [2]. The task of collecting and analyzing incoming signals from sensors, generally, from the plant, their joint analysis, in order to provide set-points to be tracked and to take adequate control actions upon actuators, belongs to low-level control. It works under the constraints set by "far-sighted" high-level holistic optimization strategy, which enables looking at long-term performances. Operating in a mode selected by the higher management structure, low-level control as conventional short-term control strategy where actions are planned on, for example, a daily level, can be extended through the use of longer simulation horizons and, in turn, achieving higher operational efficiencies should be possible. In doing so, the high-level control strategy is able to consider production and consumption of different sources of energy, state of charge of different energy storages, the planned demand profile and any available flexibilities regarding that demand, proposing optimal reference for the operating mode selection and relevant set-points adjustments recommendation in significantly longer time span, than low-level control as classic control does (see **Fig. 2**).

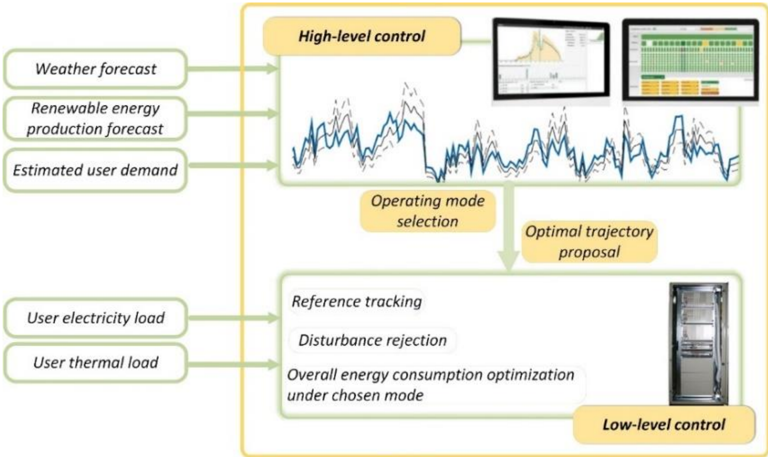


**Fig. 2.** Cascade control paradigm illustration

## 2.2 Control system architecture

The control system design has been driven by the requirement to allow the described cascade control paradigm while ensuring the independence and undisturbed plant operation in the event of limited connection with the cloud platform or lack of suitable software upgrades. Therefore, major consideration was made towards the low-level control, which performs actual control actions against plant actuators, features a conventional control logic that is running on the control devices within the plant itself.

Namely, deployed supervisory control unit represents an instance of the IMP's (Institute Mihajlo Pupin) proprietary VIEW4 SCADA (Supervisory Control and Data Acquisition) system h/w and s/w technology [3][4], custom designed to be coupled with existing technologies within the equipment of  pilot site plant [5], to fulfil the IDEAS project goals and, finally, to afford the raised degree of freedom to the project research community. Whole equipment in charge of process data acquisition, remote or local monitoring, represents RTU (Remote Terminal Unit, often called process stations as well) and completely meets the standards and requirements of the ISO / OSI reference model (International Standard Organization / Open System Interconnection Reference Model). Real-time control is mainly accomplished through the coupling of Atlas Hydra PLC (Programmable Logic Controller) [5] and accompanying I/O modules with the plant devices, while the superior central role belongs to superior VIEW4 SCADA core server. The former one posses three main databases, **Fig. 3**, and its main function could be described as collection of process data through communication with process stations, processing, archiving that data, and, finally, providing basic support for their latter analysis and adequate operation of human-machine interface (HMI) subsystem. Due to the scale of the regarded system, its control unit represents centralized system with allocated engineer's station. IDEAS control system is created in the way that there is no static local working station for an engineer at the plant space, but it could be easily connected to the whole RTU equipment or just to the SCADA server – touch panel, via Ethernet cable, with proper engineer's machine configuration. Nevertheless, the PLC and/or SCADA server also have the ability to connect to an external TCP / IP network through which the device or system communicates with other participants on the network for the purpose of requiring two-way data exchange, which allows system operators to have remote access from the office with all monitoring and control capabilities and engineers with properly configured machines to remotely deploy brand new versions of PLC software, PLC control application or HMI amendments.

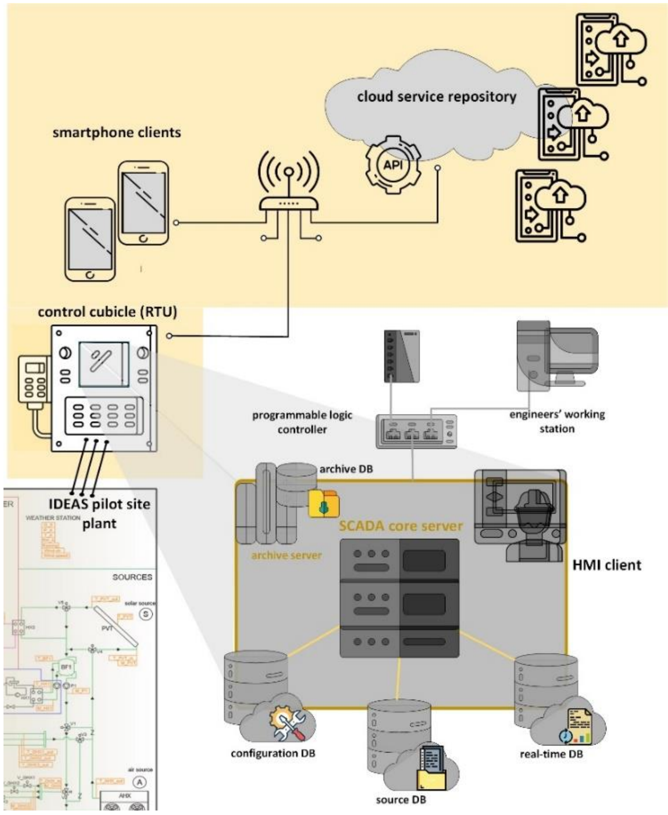


**Fig. 3.** Control system architecture

### 2.3 Integration with the cloud platform

The question is how the IDEAS optimization services, among which, high-level optimization algorithm, the forecasting algorithms, the electric domain optimization, the integral (thermal and electrical) optimization, the feasibility assessment, etc. can be deployed? There are multiple possibilities for the realization of envisioned control paradigm and control unit coupling with the end-user. Namely, the SCADA server modularity and flexibility on the application level primarily, leaves room for hosting these algorithms, but as the probably more robust infrastructure, stands out another solution. It implies SCADA server proven connectivity towards other advanced hardware and cloud platforms, provided by the implemented standard network services (such as telnet, SSH, FTP, SFTP, HTTP). The foreseen remote cloud service repository, **Fig. 3**, could host those persistent script-based services containerized using Docker and accessible via an API (Application Programing Interface). In that way, specific service activation could be demanded via HTTP request, providing the service with necessary input data in suitable data format, the service would then process the inputs, potentially log its operation, and return the results whether used for operational or analytical purposes. Hence, this Web server will provide a key interface between control unit and external applications, both Web client and the mobile application.

# 3 Discussion

## 3.1 External interfaces for third-party applications

Aside of the expert control system user (precisely called operator), who can directly or remotely access the existing HMI subsystem, there are obvious needs for providing the external end-user interfaces. To provide the interface to the control system, mobile App development requires properly designed API, directly defining the subset of functionalities offered to the external clients and consequently, to the end-users. Briefly, the end-user will be provided with the numerous monitoring capabilities in terms of tracking: active energy flows in the system, production capacity of every single energy source, their share in the heat-pump system supply, state of thermal buffers charge, power consumption of the existing appliances, etc. Previously exposed mostly is focused on the source part of the system, while when it comes to the user side, available will be: relevant weather data, information about indoor space temperature, relative humidity, air-conditioning units (fan coils, radiant floor) impact in achieving thermal comfort and caused temperature/energy distribution in that regard.

Aside of monitoring functionalities, the external interface will be enriched by control actions allowed to be taken by the end-user, such as facility temperature set-point adjustment and decision whether priority goes to the thermal comfort accomplishment and/or DHW (Domestic Hot Water) production or to the cost-effective operating. Taking into account all aforementioned and some preprocessing related to the meaningfulness of the certain mode activation, suitable subset of operating modes can be offered to the end-user for selection. This feature corresponds to the regime known as "Semi-automatic", realized within the control application running on PLC, with the main difference that for those needs will be implemented with higher level of abstraction, intuitive and self-explanatory for average mobile application user. Optionally, more advanced features like those true operators have could be offered to the privileged users (experienced researchers, from the project consortium, for example) and such a functionality could be supported through the "log-in service" that would return valid tokens, in other words, proper authentication and authorization mechanisms. This and many other possibilities will be thoroughly considered in the extended version of the paper.


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