Digital transformation of the energy ecosystem through all-in-one IoT edge-cloud solutions

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Abstract. Research and innovation actions for all renewable energy technologies, being recently a new trend in the attention of innovative startups ecosystem implementations and commercialization, with the main objective to improve the environmental sustainability. One of the most popular renewable energy technologies is Concentrated Solar Power (CSP). It generates solar power by using mirrors or lenses to concentrate a large area of sunlight into a receiver, having a solar power tower, which consists of an array of dual-axis tracking reflectors (heliostats) that concentrate sunlight on a central receiver a top a tower. The challenge regarding CSP systems is to design of heliostat components to support goals of low-cost solar-thermal energy for both high-temperature industrial process heating, as well as high-efficiency electricity production, coupled with thermal energy storage. Integration of any 3rd party hardware and sensors into an all-in-one platform, proposed to be fully cloud-based, utilizing the latest developments in cloud infrastructure, Relational Database Management System (RDBMS), and Time Series Database Management System (TSDB) capable of absorbing millions of records, as well custom algorithms can optimize heliostat positioning and performance in a real-time.

1 Introduction

Renewable energy technologies are the baseline on which to build a global climate neutral future. All renewable energy technologies are addressed as they have all a strong international market potential, which recently has been a new trend in the attention of innovative startups ecosystem implementations and commercialization, and it will be coherent with the global policy of industrial leadership worldwide. They encompass renewable electricity, renewable heating and cooling, water desalination and renewable fuel technologies. It is imperative to enhance affordability, security, sustainability, and efficiency for more established renewable energy technologies, and to further diversify the technology portfolio. Research and innovation actions for all renewable energy technologies aim to also improve the environmental sustainability of the technologies,

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delivering products with reduced greenhouse gas emissions and improved environmental

performance regarding water use, circularity, pollution, and ecosystems. Cloud computing is the next phase in the advancement of internet-based computing, and it allows information technology capabilities to be used as a service. As smart devices move outside of the cloud infrastructure environment, the IoT can increase efficiency, performance, and throughput. Edge-cloud computing is the next phase in the growth of internet-based computing, allowing for the delivery of information and communication technology (ICT) resources through a network. In cloud infrastructure, the IoT can benefit from increased efficiency, performance, and payload. The presentation of cloud computing has supported the manner of development and dissemination, and industrial electronic business packaging. As a result, IoT and cloud are now very close to future internet technologies that are compatible with IoT systems. The development of a solution edge cloud based on digital enablers such as IoT aim at increasing the integration of renewable energy sources, as well as the local generation and consumption of energy and processing of data by piloting at scale open source, environmentally friendly, easily upgradeable and energy-efficient, based on commonly agreed open standards.

Concentrated Solar Power systems (CSP - one of the most popular renewable energy technologies), generate solar power by using mirrors or lenses to concentrate a large area of sunlight into a receiver, AA) as stated in [1]. CSP has a solar power tower, which consists of an array of dual-axis tracking reflectors (heliostats) that concentrate sunlight on a central receiver atop a tower. Electricity is generated when the concentrated light is converted to heat (solar thermal energy), which drives a heat engine (usually a steam turbine) connected to an electrical power generator. The challenge regarding CSP systems is to design of heliostat components to support goals of low-cost solar-thermal energy for both high temperature industrial process heating, as well as high-efficiency electricity production, coupled with thermal energy storage.

Achieving a decarbonized energy sector by 2050 will require the development of cost effective technologies beyond today's commercial technologies. Increased deployment of solar technology, in particular, will require the deployment of flexible and dispatchable generation and energy storage technologies, like concentrating solar-thermal power (CSP) with thermal energy storage, to ensure reliability of the grid.

The term "smart grid" refers to an electricity distribution system (grid) in which modern information and communication technology applies to achieve maximum efficient production, transmission, distribution and use of electricity. This usage includes data and information collected from users and producers in order to ensure a reliable and constant supply of electricity. Smart grids have many potential benefits. Firstly, smart grids enable the decentralization of energy production. This may include net electricity consumption measurement, where individual consumers are allowed a two-way flow of electricity, so that the excess energy they produce is returned to the network. Secondly, the smart grid can ensure that the state the network uses its energy resources most efficiently.

In a joint approach as analyzed above, the IoT is primarily concerned with challenges that arise in a dynamic and shared environment. IoT is a broad category that comprises of various adaptable and unusual devices with limited storage, power supplies, and performance capabilities. These constraints establish a barrier and impedance to the development of IoT systems, and include complex issues such as compatibility, efficiency, full functionality, and availability. So, one of the most promising methods that may be combined with IoT to overcome such limitations is edge-cloud computing. The cloud provides shared resources (network, storage, computers, and software) distinguished by ubiquity, low cost, and aesthetic characteristics. In addition to its overview character, this paper demonstrates a proposal and vision how this platform may use cloud resources and services to gather, transfer, analyze, process, and store data. It may also use cloud resources
and services to collect, transmit, search, analyze, and store data generated by complex scenarios.

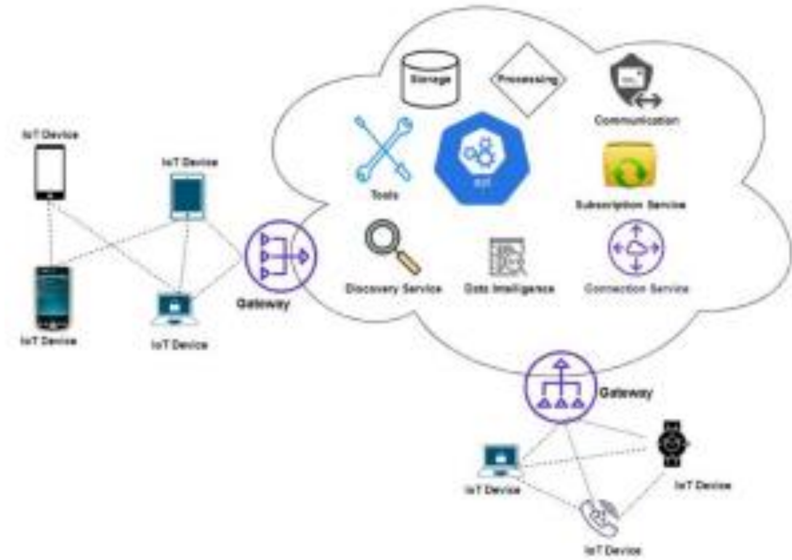

Figure 1. Edge-Cloud based IoT System example; *Source: https://www.mdpi.com/2624-6511/4/3/64*

2 Problem background

CSP is often compared to PV (photovoltaic solar) since they both use solar energy. While solar PV experienced huge growth in recent years due to falling prices, solar CSP growth has been slow due to technical difficulties and high prices. In 2017, CSP represented less than 2% of worldwide installed capacity of solar electricity plants.

Given that they both rely on solar energy, CSP and PV are frequently contrasted. While solar PV has grown rapidly in recent years as a result of lowering prices, solar CSP has grown more slowly because of challenging technological issues and expensive costs. The challenge regarding CSP systems is to design of heliostat components to support goals of low-cost solar-thermal energy for both high-temperature industrial process heating, as well as high-efficiency electricity production, coupled with thermal energy storage. A typical commercial heliostat is compared against an advanced design with alternative approaches to cut cost and move toward the cost reference of $50/m2. Though, a large cost can be attributed to key components such as drives, mirrors/facets, and supporting structures/foundations.

1) *Heliostat drives* represent one of the most expensive components in a heliostat, comprising 22% of the design's total cost. The specific drive and rotational assembly costs associated with this design would account for 57% of $50/m2 cost target for heliostats, demonstrating the need for further cost reduction. Though it's needed to provide a literature review on a variety of existing and proposed drive system design options for heliostats cost reductions.

Figure 2. BrightSource's current twofacet pedestal heliostat design; *Source: Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power, link to reference?*

2) *Heliostat mirrors/facet* cost reduction represents a significant gap, with current prices being nearly double of the heliostat cost target of 50/m2. There are multiple pathways to cost reductions, including material selection, facet design, mirror gap, aspect ratio, and reduced design requirements that's needed to identify.

3) Nearly all commercial heliostats use a pedestal that supports a rotating torque tube. These structures tend to be fabricated from structural steel and are therefore material-intensive. A large mass of raw material inputs into assemblies (e.g., steel into the heliostat's structure) is not only a significant cost, but one that is inherently susceptible to large fluctuations in commodity prices. Some variegated geometries that potentially reduce material usage are in commercial use. Torque tubes have been eliminated entirely in several recent applications. Cost reduction of heliostat structures is primarily a question of steel usage and respective frame coatings (paint, hot dip process, etc.). Though, it's needed to identify the pathways for reducing the cost of *heliostat structures*.

Figure 3. Heliostats installed at Noor III in Morocco; *Source: Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power, link to reference ?*

4) *Heliostat control systems* ensure that each individual heliostat in a field tracks the angle bisector between the sun and the solar receiver. Control systems also manage the flux on the receiver by varying the number of heliostats in use. For every CSP system, the number of heliostats pointed at the receiver needs to be adjusted depending on the sun's position in the sky. For example, at noon in the middle of summer fewer heliostats need to be pointed at the receiver than late in the afternoon on a winter's day.

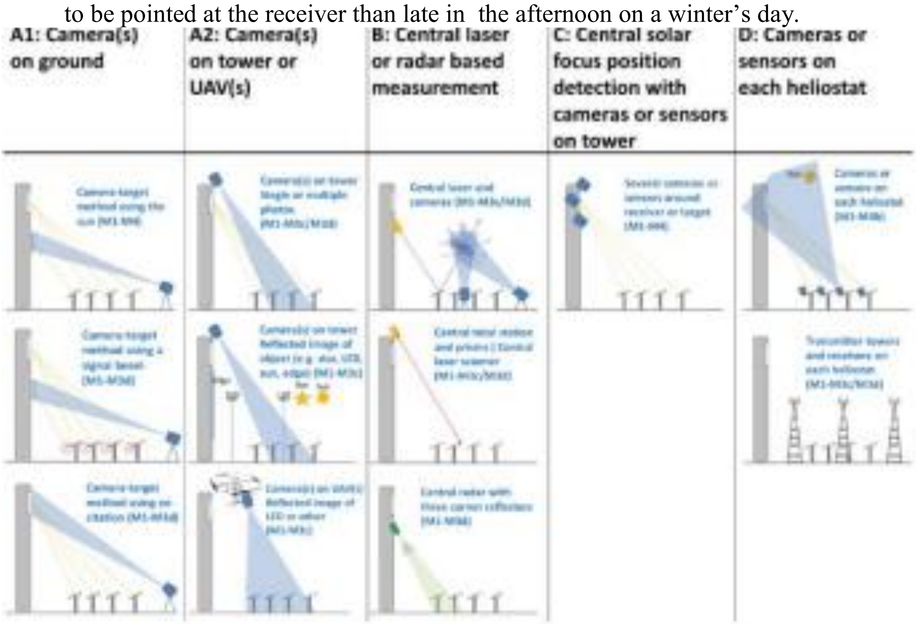

Figure 4. The five different classes (A1, A2, B, C, D) of techniques that have been explored for closed-loop calibration systems; *Source: Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power, link to reference ?*

5) A truly *wireless Heliostat* is not only controlled, but powered, wirelessly. Traditionally,

heliostats have been controlled by buried copper or fiber optic wired networks, but in recent years there has been movement toward wireless communications. Wireless communications offer simplified plant design and cost reduction due to both material reduction and reduced labor hours at construction. Although wireless systems offer cost reductions, various approaches could introduce significant technical, cybersecurity, and other safety issues. There are currently no standardized requirements and testing capabilities to validate both functionality and safety as the CSP industry transitions to fully wireless control.

Figure 5. Wireless BrightSource heliostat at Ashalim with top-mounted PV panel; *Source: Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power, Sourse : https://www.nrel.gov/docs/fy22osti/83041.pdf*

3 Existing solutions

Heliostats comprise static and dynamic components required to operate within a highly controlled manner to provide accurate solar flux pointing during CSP operation. The general composition includes a reflective area, control system, and a mounting and tracking mechanism.

Electronic control of the heliostat drive train is required for adjustment of the heliostat structure so it can track sun position to reflect concentrated sunlight toward a receiver. These mirrors are not properly aligned to hit the proper focal point (Solar Power Tower). So, we don't know where these mirrors are, which means they are not synchronized with the real time data.

Today, vast software solutions are available for managing traditional PV solar but there is nothing on the market that addresses more complicated and specific needs of heliostat or High-Concentration Solar Collectors. All known heliostat or CSP plants run and operate on custom designed software solutions specific to their needs with specific hardware used. Most of the heliostats currently in the field are designed and build roughly 10-20 years ago. Their electronics are outdated and they do not transmit real-time data (their position) or accept commands in a real-time. This existing solution is often inaccurate or misaligned, and it is very difficult to integrate new or updated sensors, controllers or other 3rd party equipment.

4 Methodology

To solve this challenging problem in a cost-effective manner, I suggest integrating existing azimuth slewing drives and linear actuators (Gear-Drive) into real-time data environment. This can be achieved by installing inexpensive microcontrollers (Raspberry Pi, Arduino, or others) that can send Gear-Drive data to Edge-Cloud infrastructure via low latency IoT specific pub/sub (MQTT) architecture and receive commands to control them.

This can allow seamless integration of any 3rd party hardware and sensors into an all in-one platform, proposed to be fully cloud-based, utilizing the latest developments in Edge-Cloud infrastructure, Relational Database Management System (RDBMS), and Time Series Database Management System (TSDB) capable of absorbing millions of records. Custom algorithms can optimize heliostat positioning and performance in a real-time. It can be capable of reacting to various disastrous events, perform remediation operations, and automate disaster recovery functionality.

The all-in-one IoT edge-cloud platform can run, manage, and optimize trackers and heliostat or CSP farms, which incorporates various Software Algorithms, Website, Portal and an App.

A specific algorithm can optimize tracker positioning and performance in real-time. It can be capable of reacting to various disastrous events, performs remediation operations, and automates disaster recovery functionality. A developed API can allow seamless integration of any 3rd party IoT hardware and sensors into the all-in-one IoT Edge-Cloud platform.

A physical (hardware) CSP plant is proposed to be a demo environment where to implement a piloting of all-in-one IoT Edge-Cloud platform solution, *as for example as follows below*:

- *Tracker Management*
    - *Sensor Readings*
    - *Hardware Controls*
    - *Hardware Automation*
    - *Real-Time Communication*
    - *REST API*
    - *Security*
    - *Disaster Recovery*

A demo (prototype) all-in-one IoT edge-cloud platform solution can run, manage, and optimize trackers and heliostat or CSP farms, *as for example as follows below*: • *All-in-One Platform Management*

- *Tracker Management and Automation*
- *Data Analysis and Machine Learning*
- *Analytics and Real-Time Reporting*
- *Security and User Management*
- *Business Continuity and Disaster Recovery functionalities.*

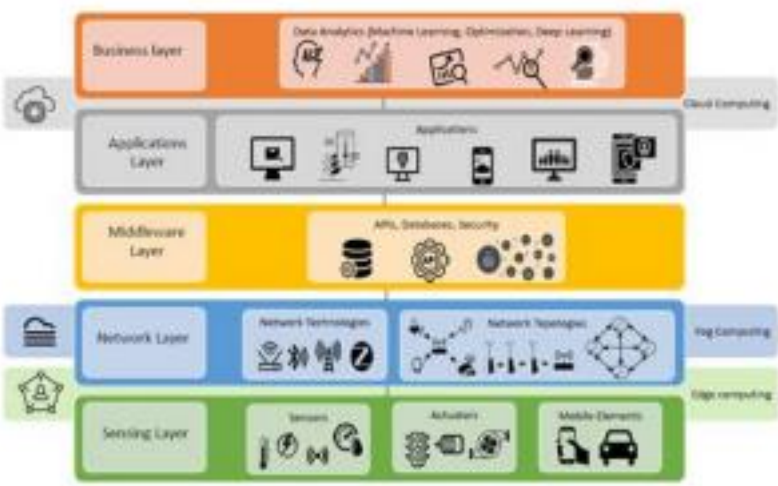

Figure 6. IoT Edge-Cloud based Architecture Example; *Source: https://www.mdpi.com/2624-6511/4/2/24*

5 Further work and results

The all-in-one IoT edge-cloud platform proposed, is in an ongoing research process. It will be the heart and brains of the Heliostat Farms and CSP Plants, and of innovative startup ecosystem initiatives as a new trend in their attention supporting sustainable development. It will bring together all the hardware into one ecosystem and give users full control over them with User Defined and Customized Automation Rules or Manual Control when needed. Predefined Automation Rules, Start-Up and Shut-Down Sequences, Disaster Recovery, and Business Continuity functionalities will be further enhanced with ability for user-defined Custom Automation Rules. Users will be able to define any scenario using "if this then-that" logic based on any sensor readings or outside parameters (weather, time, etc.,). All hardware will be interconnected via IoT standards and protocols.

This all-in-one IoT edge-cloud platform will simplify integration and management of new or existing Heliostat Farms and CSP Plants. By design, it is proposed to be modular, extendable, and easy to integrate new or updated sensors, controllers, or other 3rd party equipment.

It will also establish a network of constructed hydro technical facilities, to provide information on the use of energy from renewable energy sources and create conditions for the sustainable use of natural resources.

A detailed roadmap conduct will demonstrate the ability to save costs, modernize and integrate existing infrastructure and new developments. The concept will be presented to different solar manufacturers in CSP field and will include the possible development and pilot this proposed solutions.

The solar industry is rapidly evolving. This solution allows to stay head-to-head with current technological advancements, new components and continuing improvements, giving the industry ability to reduce costs of energy generation, enhance performance and increase sustainability.

5 Conclusions

This paper presents an overview of the using the Internet of Things technologies and methodology in energy ecosystem.

By providing a detailed discussion of CSP Plants and its challenging problem for solution, we present IoT as a vital enabler of energy ecosystem services, and further the research and discussion will continue for the all-in-one IoT edge-cloud platform model proposed.

Accurate information could be accessed, analyzed, and controlled by cloud-based enabling technologies to assist experts, businesses, and people in making smarter policies to enhance the standard of peoples' life.

When devices and information are connected to an energy ecosystem's physical systems and facilities like CPS, expenses may be reduced and efficiency improved. Through the assistance of the Internet of Things in this paper the author explored and discussed the edge-cloud-based IoT applications and their roles in energy ecosystem (specifically solving the CSP challenge).

More applications can be discovered, and their importance in renewable energy can be discussed, in future research.

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The references should be called in the text as example see AA)

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Helga Sallaku holds a Bachelor degree in Computer Science from the University of Shkodra "Luigj Gurakuqi", the Master of Science degree in "Information Systems – Computer Science" from University of Tirana, and actually she is a PhD Candidate in International Doctoral Studies on “Sustainable Development” at the University of Montenegro, Podgorica, Montenegro, supported by Erasmus+ EU Program.
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Helga has over 18 years of working experience in the field of Information Communication and Technology (ICT) contributing in its development in the city of Shkodra, and beyond, around Albania.
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In 2022 she started a new journey related to innovation in USA, working as an Innovation Researcher at the University of Arizona Center for Innovation based in Tucson, Arizona, the place so called “The Big Fish into The Small Fish” - a startup incubator network located in the Southern Arizona region, integrated at the university level, that turns ideas and inventions into strong, scalable and sustainable businesses, from which she got the opportunity to be emerged in the US IT field, leading nowadays the IT Department in American Dental Companies – a patients oriented company, improving dental services and business operations in dentistry with the support of cloud
edge software systems integrated with AI and IoT devices, providing more sustainable processes and services. Helga has also just been promoted as a Mentor affiliated to Computer Science bachelor and master students at the University of Arizona during 2023-2024 academic year, within the “2023-2024 Women in STEM Mentorship Program”.