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Aspects Regarding the Development of an Urban Smart Grid

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Abstract: *Energy resources are essential for the functioning of modern society and their connection with smart grids. Developing an urban smart grid involves a multi-faceted process of upgrading and optimizing electrical infrastructure and represents a holistic approach to transforming urban energy ecosystems, aligning with global sustainability goals, while providing cities with resilient electrical infrastructure and efficient to face the challenges of the 21st century. This paper proposes to identify the theoretical and applied concepts related to the engineering of the control system that is the basis of a smart urban network, to present the relevant elements regarding concepts, structures, algorithms, and mathematical models. The paper contains an analysis of what exists in practical approaches, simulation platforms, connections to the Energy Internet, and examples of each. In the last part, it presents contributions and future research directions.*

1. INTRODUCTION

Energy resources are important for the functioning of modern society. They provide the energy needed to power various aspects of our daily lives, including transport, lighting, heating, and industrial production.

Fossil fuels and other energy sources are essential for propelling vehicles, ensuring mobility and connectivity for road, air, rail and sea transport, they are also used to heat homes in the cold season and to cool them in the warm season, providing comfort to residents.

Electricity is used to light homes, commercial buildings and streets, which is also used to power household appliances, electronic devices and other essential equipment for our daily activities.

Buildings have a significant impact on the environment: they consume about 40% of natural resources, generate almost 40% of carbon dioxide (CO2) emissions and contribute about 40% to the total waste produced, Najjar et al., (2019a).

Traditional energy sources such as fossil fuels have a negative impact on the environment through greenhouse gas emissions and other pollution. The development and adoption of sustainable and renewable energy sources are becoming increasingly important to ensure a sustainable future and reduce the negative impact on the environment.

Energy innovations such as solar, wind, hydropower and energy storage technologies are key to meeting the energy needs of modern society sustainably. Global electricity demand is expected to grow significantly, highlighting the imperative to improve energy efficiency in modern buildings Najjar (2019).

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2. RESEARCH METHODOLOGY

The process of developing a smart urban network is a complex undertaking involving multiple stages to modernize and optimize the city's electrical infrastructure.

The efficiency of renewable energy systems, such as solar photovoltaic panels and solar heating systems, requires meticulous planning and rigorous analysis to maximize performance Buonomano et al. (2018).

City officials and utility companies work together to set project goals and directions, by considering the need for energy efficiency, smart grid management and carbon reduction. Existing electrical infrastructure is analyzed to identify weaknesses, areas of congestion and possible areas for improvement. The analysis helps determine the specific needs of the smart grid.

The next step is deploying advanced sensors in the urban landscape, tasked with collecting real-time data on energy consumption, network performance, power quality and environmental conditions.

The sensors are connected to a communications network, allowing data to be transmitted to control centers. The data provides essential information for real-time decision-making and network optimization. The collected data is processed by advanced analysis platforms to obtain useful information.

Data analysis helps to identify consumption patterns, potential breakdowns and efficiency opportunities. Management systems are implemented to allow effective monitoring and control of the network.

These systems can automatically detect failures, redistribute tasks to avoid overload and efficiently manage resources according to requirements. It integrates advanced technologies such as automation and remote control to optimize operations. Thanks to these technologies, quick reactions to changes in energy demand and unexpected events are possible.

The use of solar energy in buildings can be passive or active, adapting to climatic conditions, built environment specifications, and building energy requirements, including heating, cooling and electricity supply Hojjatian et al. (2021).

3. RESEARCH RESULTS

Numerous specialized software programs allow the simulation and optimization of photovoltaic systems (PV), including Sunny Design Web (SMA) (SMA Solar Technology AG, 2023), PVsol (Valentin Software, 2023), HelioScope (Folsom Labs, 2023), TRNSYS (2023), PVsyst (2023), Canal Solar (2023).

Researchers have adopted these advanced software programs to achieve specific goals. They served in the detailed design of the PV systems, assisting in the installation stages and providing a detailed assessment of the energy production over a calendar year.

These tools also enabled a rigorous analysis of the viability of the systems on various types of pitched roofs, thus providing essential information for informed decisions. In addition, they facilitated an in-depth analysis of economics, including costs and benefits, to determine the financial feasibility of implementing these systems.

A study by Najjar et al. (2019b) presented a structured experimental design to optimize the power generation of photovoltaic systems. He used the PVsol software platform, thus approaching the simulation and facilitation of the design and implementation phase of these systems in building structures.

Similarly, Ozcan et al. (2019) used PVsol and TRNSYS applications to evaluate the annual production capacity of a photovoltaic system. Through their empirical research, these specialists have validated the effectiveness of the PVSOL software, achieving an impressive 94.33% performance in terms of accuracy and reliability.

In a significant study, Badawy et al. (2022) investigated the opportunities for implementing photovoltaic systems on pitched roofs in Egypt. To ensure an optimal design, they used PVsol Premium software to analyze all areas of the roof. Their research focused on evaluating the efficiency of monocrystalline and thin-film technologies in grid-connected photovoltaic systems, with a focus on historic buildings. PVsol was instrumental in the detailed performance analysis of the various technologies, evaluating the annual yield and performance indicators. Their major conclusion highlighted the limitations of polycrystalline technology in terms of durability and suitability in historic buildings with specific climatic conditions. Thus, the study underlines the imperative of adopting photovoltaic technologies adapted to such distinct contexts.

In an in-depth review, Cristea et al. (2020) investigated the economic implications of residential grid-connected solar PV systems. To make simulations and projections relevant to different regions in Romania, they adopted the PVsol Premium 2019 application. This research was not limited to simple evaluation; it involved a meticulous assessment of economic viability, considering many key variables and carrying out sensitivity analyses to outline realistic scenarios with fluctuating energy prices. In their process, they used robust financial indicators such as net present value, internal rate of return, profitability index and investment payback period to ensure a comprehensive assessment of the effectiveness of different approaches. Their conclusion highlighted not only the effectiveness of PVsol but also the adaptability and precision of this platform, confirming it as an unparalleled tool for reflecting and analyzing the results of their rigorous research.

4. FUTURE RESEARCH DIRECTIONS

Smart grids are designed to be adaptable to evolving technological changes. Future innovations in energy and communications can be seamlessly integrated, thus keeping the network up to current and future technology standards.

Efficiency in the use of energy and reduction of losses contribute to the sustainable growth and economic efficiency of the electrical infrastructure.

Finally, the development of smart grids contributes to the transformation of cities into smart hubs, where technology, sustainability and quality of life are harmoniously integrated. It is redefining how cities function and respond to the needs of communities, adapting to the demands of our century.

By taking a holistic and integrated approach, researchers and practitioners continue to address urban smart grids that not only bring immediate benefits in terms of energy efficiency but also contribute to building a more sustainable and resilient future.

This is an essential part of transforming urban infrastructure to meet the increasing challenges of the 21st century and contribute to the achievement of global sustainability goals.

5. CONCLUSION

Smart grid technologies are constantly evolving, measuring their efficiency and reliability. These properties of the technologies are essential in the field of energy efficiency and smart grid management. The central objective of this analysis was to present a detailed assessment of the performance of the most effective technologies in the field.

Our conclusions are particularly relevant for specialists and experts who want to identify and adopt the optimal solution in various scenarios, integrating new technologies to monitor and control the network in real-time.

The study highlights that systems based on advanced artificial intelligence algorithms are superior in the efficient management of smart grid networks.

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