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Review

IoT-Enabled Campus Prosumer Microgrid Energy Management, Architecture, Storage Technologies, and Simulation Tools: A Comprehensive Study

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Abstract: Energy is very important in daily life. The smart power system provides an energy management system using various techniques. Among other load types, campus microgrids are very important, and they consume large amounts of energy. Energy management systems in campus prosumer microgrids have been addressed in different works. A comprehensive study of previous works has not reviewed the architecture, tools, and energy storage systems of campus microgrids. In this paper, a survey of campus prosumer microgrids is presented considering their energy management schemes, optimization techniques, architectures, storage types, and design tools. The survey is comprised of one decade of past works for a true analysis. In the optimization techniques, deterministic and metaheuristic methods are reviewed considering their pros and cons. Smart grids are being installed in different campuses all over the world, and these are considered the best alternatives to conventional power systems. However, efficient energy management techniques and tools are required to make these grids more economical and stable.

Keywords: campus microgrid; prosumer market; batteries; energy management system; distributed generation; smart grid; renewable energy resources; energy storage system

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1. Introduction

Energy crises have become major challenges in the economic development of a country. In this modern era, machinery is considered a more effective replacement for humans in many sectors. Smart devices are constantly being developed, which makes our routines in life much easier. In today's world, it is impossible to imagine a life without these smart devices and machinery. However, everything comes with a price, and the price of this ever-increasing dependence on machinery is the substantial consumption of energy resources [1]. These smart machines operate on electricity which is produced by the utilization of non-conventional energy resources such as coal, oil, and gas. The rising utilization of these fossil fuels has result in two major environmental disorders. The first is the fast depletion of fossil fuels and the second is the production of hazardous gases and waste materials, which results in a direct increment of environmental pollution. The organization for economic cooperation and development (OECD) indicated in 2018 that the United States had the strongest gross domestic product rate [2], but British petroleum ranked the air quality index of the United States as the poorest in comparison to other countries of the world [3]. Polluted air in any country is a major cause of the demise of its people [4]. Fossil fuels are non-renewable, and so their continuous depletion results in gradually increasing energy generation prices, which increases inflation, especially in underdeveloped countries. Further, few countries have a major share of these non-renewable energy resources, which makes the ones that do powerful enough to control the economies of those countries whose electricity production largely depends upon fossil fuels. The excess utilization of nonrenewable energy resources for generation is discouraged by modern researchers [5].

Electricity produced from fossil fuels is transmitted to far-flung areas and then distributed. In addition to the energy losses during generation, these transmission and distribution phases have also several types of losses, and in some cases, these losses may rise by more than 50% [6]. An alternative approach is to eliminate the transmission phase and use distributed generation instead. In this type of generation, plants are directly located near the consumer loads. Losses can be minimized using distributed generation. These distributed power plants may use renewable energy resources such as solar [7], wind [8], and biogas [9] or nonrenewable energy resources such as geothermal energy [10], diesel generators [11], and furnace oil [12] for power generation. To minimize the environmental impacts, the usage of green energy resources is suggested in these distributed power generating stations [13]. Another benefit of these green energy resources is their renewable nature, for which they have also been termed renewable energy resources (Res). Res are environmentally friendly and renewable, but the only hurdle in the utilization of these types of resources is their intermittency, which is due to their extreme dependence upon weather conditions [14]. To reduce this problem, several techniques have been proposed in the literature, such as the incorporation of properly sized storage, architectural modifications, optimization, energy coordination schemes, etc. The generating stations operating on REs with a proper power coordination scheme and communication structure between the producers and consumers are called smart grids. Smart grids typically operate as isolated or grid-connected modes. In an isolated mode, a smart grid provides power to a connected consumer without having any connection with the main power grid, and storage then becomes necessary for these smart grids to overcome the intermittency problem of REs. In a grid-connected mode, the smart grid supports the main grid and provides ancillary services, in addition to fulfilling the consumer load requirements [15].

Small-scale smart grids which simultaneously produce and consume electrical power are termed prosumer microgrids [16]. The basic structure of a microgrid is represented in Figure 1. These microgrids can be of various types, from hospital to residential and industrial to institutional. A research institution should not depend upon the main grid for its energy requirements, especially if the main grid produces energy from conventional energy resources. A load of institutions is commercial, and these institutional microgrids are considered more important due to the research and development facilities available in an institution. These types of microgrids are also called campus microgrids [17]. The Internet of Things (IoT) is a modern technology that enables an operator to remotely monitor and control the activities of a smart grid using smart sensors [18]. The devices present in a smart grid's interface communicate bidirectionally, and they are prone to external cyber-attacks. Cyber security is also very important to secure a smart grid from external hacking attacks and to protect consumer data [19].

The organization of the paper is given here. The methodology is given in Section 2. An overview of campus energy management is presented in Section 3, different energy management schemes are discussed in Section 4, simulation tools are discussed in Section 5, IoT-enabled secured microgrids are disused in Section 6, and the conclusion is given in Section 7.

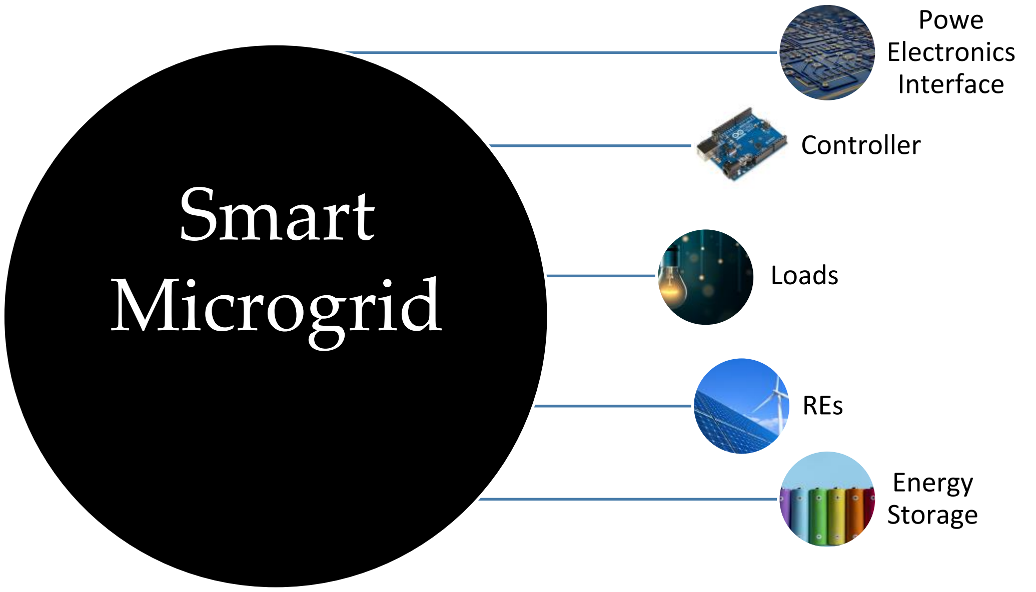

Figure 1. The basic structure of a smart microgrid.

2. Methodology

In this paper, a comprehensive review of the latest research work related to smart campus microgrid energy management is presented. The main focus of the work was to target the papers discussing real-time or simulated campus microgrids, with the restriction that each selected paper must contain at least one aspect of campus microgrids.

The methodology of the review was the same for all the selected papers as all used different energy management schemes for campus microgrid designs and optimization. The previous studies are categorized based on their architectures, storage methods, optimization techniques, simulation tools, and IOT technologies. The review study was carried out by reading the papers critically and identifying the significant points in the papers. Table 1 highlights the most important papers selected for each category.

Table 1. Criteria table of selected papers.

Sr. No	Selection Criteria	Cited Papers
1	Simulated or installed campus microgrid	[20–33]
2	Campus microgrid architecture	[34–46]
3	Storage technologies	[47–61]
4	Optimization techniques	[62–79]
5	Simulation/cost analysis tools	[80–100]
6	Internet of Things (IoT)	[101–105]

3. Overview of Campus Energy Management

Energy management is defined as a process to optimize energy production from REs and transmit this energy to consumers while cost-effectively minimizing the risk of system failure and gas emissions [106]. The concept of energy management began in the 1970s with the name of energy control centers, also known as ECCs. This concept was further expanded with the inclusion of different control schemes such as demand side management (DSM), load control (LC), demand response monitoring (DRM), etc. [107]. A simple energy management process consists of energy planning, execution, monitoring, verification, and understanding its usage. This process is represented in Figure 2.

Figure 2. Simple energy management process.

The management of energy in a microgrid is critical because it is directly related to the economics of the grid. In campus prosumer microgrid energy management, the production of renewable energy resources present at a university campus is monitored, controlled, and optimized for the campus load. Worldwide, campuses of different universities are being converted to microgrids with REs as generation sources and environmentally friendly energy storage [20]. Most of the research published has contained simulated campus microgrid solutions, but practically working microgrids are also being developed at universities [21–28]. A simulation model of a campus microgrid was developed in Serbia for the University of Novi Sad in 2018, and it used photovoltaics (PV) and wind in conjunction with biomass and energy storage facilities. The concept of electric vehicles (EV) was also included in this research work, both as a consumer and a producer of energy in V2G mode [29]. In Italy, an energy-efficient microgrid solution was presented by Stefano et al. for the University of Genova. Multiple aspects of a campus microgrid were analyzed, taking into consideration the grid-connected, as well as standalone, operations [30]. However, this research lacked a feasibility analysis and the regulation problems of the proposed microgrid. Kritiawan et al. performed an in-detail feasibility analysis for a campus microgrid at Sebelas Maret University, located in Indonesia [31]. Voltage regulation is an important factor that should be taken into account when designing a campus microgrid [32]. Valentina et al. designed a microgrid for an island located in Singapore to improve the voltage regulation and power factor of the system. This design consisted of PV and diesel generators as generating sources, and it resulted in the lowest operational costs [33]. A pictorial representation of several campus microgrids installed all over the world is provided in Figure 3.

3.1. *Objectives of Campus Microgrid Energy Management*

The prime objective of energy management in a university campus microgrid is to optimally allocate generation and storage resources in a way that achieves the minimum per-unit cost of energy with maximum efficiency, while reducing gas emissions. Campus microgrid energy management may have single or numerous objectives such as resiliency, power quality, voltage and frequency regulation, reduced cost of energy, profit maximization, and life expectancy of transformers [108–111]. Universities can also obtain a green certificate by replacing the existing power infrastructure with a renewable energy-based microgrid [112]. Important objectives of a campus microgrid are represented in Figure 4. Campus microgrids should be efficient and reliable [113]. An energy-efficient campus microgrid solution was presented by Young et al. for the Gwanak Campus in South Korea, and it aimed to reduce the cost of energy by 21% and gas emissions by 110 TOE [114]. The economy is the most important element of a campus microgrid. Universities should be able to generate energy for the lowest possible cost. Currently, electric vehicles are becoming famous due to their environmentally friendly nature. The integration of these EVs with the lowest charging cost is another objective of campus microgrids. EV integration with a campus microgrid may cause stress on transformers [115]. Similarly, REs which are not properly sized may cause reactive power imbalances in a system, which may lead to frequent disconnections [116]. Low power outages and the continuity of supply are other objectives of campus microgrid energy management [117]. The achievement of all objectives in a single study is impossible. Most of the existing research includes a balance between economic and technical objectives.

Figure 3. Campus microgrids at different universities.

3.2. Architecture of Campus Microgrids

Campus microgrids are designed to control the power production and utilization from REs and coordinate with smart metering, protective, storage, and load management devices, with the help of a control system, to achieve minimum costs and maximum efficiency. Architecture and infrastructure are two common terms used to describe the design of a campus microgrid. Microgrid infrastructure refers to all the components that a microgrid contains, such as transformers, smart metering devices, protection systems, switches, communication technologies, and cables [118]. The infrastructure of a microgrid should be resilient, which means that it should be capable enough to withstand extremely faulty conditions and recover quickly in the case of any disturbance [34]. Architecture defines how microgrid components connect to allow energy to flow and to enable storage. Both civil and electrical architecture are important factors in the design of a campus microgrid. In this paper, we will focus on the electrical architecture of different campus microgrids. A microgrid can operate in three different modes: off-grid, on-grid, and on/off-grid. Architecture generally changes slightly depending on the mode of operation. Campus microgrids typically work in the on-grid mode so that they can support the existing grid in the case of excessive supply. The common architecture of a microgrid may consist of three different bus configurations: centralized DC bus configuration, centralized AC bus configuration, and hybrid AC/DC bus configuration. The architecture of typical off-grid campus microgrids follows the DC centralized bus configuration, which is shown in Figure 5. In this architecture, the DC resources are directly connected to a centralized DC bus bar, while the AC components of the microgrid are connected via converters [35–37].

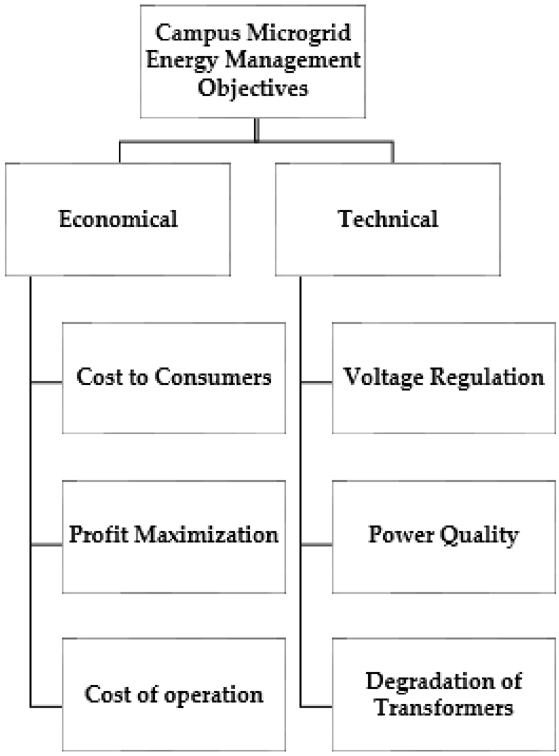

Figure 4. Important objectives of energy management in campus microgrids.

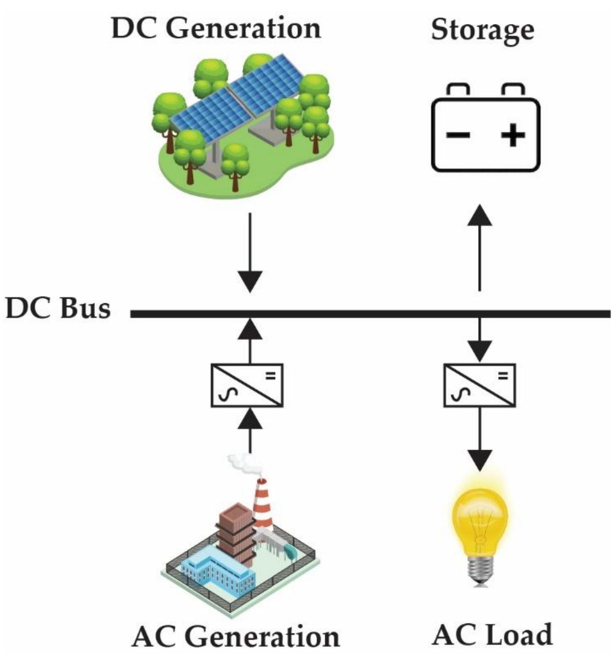

Figure 5. DC bus architecture of campus microgrids.

A typical AC bus configuration is shown in Figure 6, and it is the opposite of a DC bus configuration. This type of architecture requires higher voltage, which results in lower losses. REs largely supply direct DC, and it becomes less economical to first convert the power of REs into AC before supplying it to the central busbar; therefore, this type of configuration is found in few reach papers [38–41].

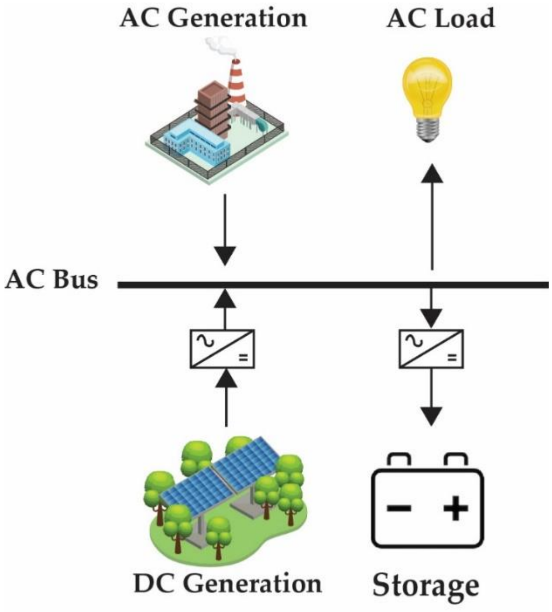

Figure 6. AC bus architecture of campus microgrids.

An advanced architecture for a campus microgrid is shown in Figure 7. It consists of both AC and DC busses, where the AC bus connects the AC components and the DC bus connects DC loads, storage, and generation. Finally, a bidirectional inverter connects these two buses [42–45]. In the literature, several studies have compared the types of architecture discussed above, and they concluded that a hybrid architecture for microgrids is more beneficial [46].

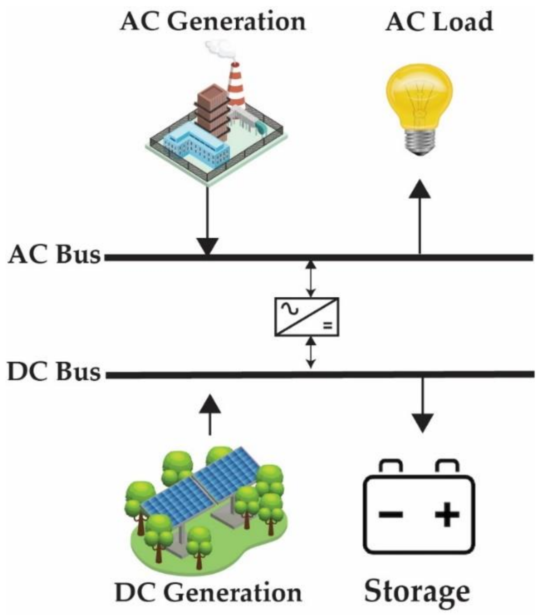

Figure 7. The hybrid bus architecture of campus microgrids.

3.3. Storage Technologies

Storage is a core component of a microgrid which serves many purposes during its operation. Besides providing power to load during the absence of generation, storage is used to provide ancillary services to smart grids, such as peak shaving [119], balancing the load profile [120], and improving system reliability [121]. In particular, a standalone campus microgrid cannot be sustained without the necessary storage facilities. A large portion of the total installation cost is attributable to the cost of storage. Storage degradation cost is another important factor that affects the overall system cost. Muqeet et.al [47] proposed a campus microgrid for the University of Engineering and Technology in Taxila, Pakistan. The authors considered the battery degradation cost in their design and compared different models, concluding that a properly scheduled storage technology results in a reduced cost of energy. There are several types of energy storage devices (ESDs) available, such as thermal [48], electrical [49], mechanical [50], electrochemical [51], and chemical [52]. With the advancements in plugin electric vehicles (PEV), these can also be used as storage devices in the vehicle-to-grid (V2G) mode of operation [53]. Storage configurations can be divided into three main categories: single storage configuration, multi-storage configuration, and swappable storage configuration [54]. In most of the existing literature, a single type of storage device is used in campus microgrids, while some advanced research designs have focused on the use of multiple types of storage technologies to improve their efficiency and useful life and reduce overall operational costs [49]. Riad Chedid et al. redesigned a campus microgrid for the American University of Beirut to reduce its dependence on a diesel generator. In the proposed design, REs replaced the fossil fuel generation with a combination of battery energy storage devices, which resulted in tremendous average annual savings of USD 1,336,000 [55]. Reyasudin Basir et al. proposed a microgrid design for the University Kuala Lumpur in Malaysia, and they proved that a grid-connected campus microgrid with battery storage was the most economical solution for this university [56]. When comparing different battery energy storage technologies, lithium-ion technology is considered the most suitable option. Yuly V. Garcia et al. designed a campus microgrid for the University of Puerto Rico in the United States. In the proposed design, solar and combined heat and power (CHP) technologies were used to reduce the fuel price. It was concluded that a combination of lithium-ion storage with solar generation and CHP provided the lowest fuel cost for a 10-year scenario [57]. A single storage device can be economical, but it always has some drawbacks which can be overcome by using multiple energy storage devices. Leskarac et al. proposed the use of PEV storage with a fuel cell to minimize the costs of operation for large commercial building microgrids [58]. A similar system was designed by Kumar et al. for the Nanyang Technological University of Singapore. It was concluded that a microgrid containing solar and natural gas as generation with PEV and fuel cells as storage could perfectly achieve the demand response targets [59]. Pedro Moura et al. practically demonstrated the use of multiple energy storage technologies for a campus microgrid at the University of Coimbra in Portugal to achieve the lowest cost of energy. The installed system contained PEV and li-ion batteries as storage systems, while grid-connected PV generation made the campus a net-zero-energy building. In [60], Hanane Dagdougui proposed the use of Li-ion batteries with a combination of a supercapacitor and hydrogen storage to improve the storage life and reduce the operating costs of the system. Rong-Jong Wai proposed the use of an ultra-capacitor and batteries as the storage medium for the economic design of the National Taiwan University of Science and Technology in Taiwan [61]. Current research is more focused on developing new storage technologies and making the existing storage technologies more compact.

4. Energy Management Schemes

The management of flowing energy between a campus microgrid, energy storage, a conventional grid, and the load is the most important element for reducing the cost of energy. Figure 8 represents the details of different optimization algorithms for the energy management of campus microgrids.

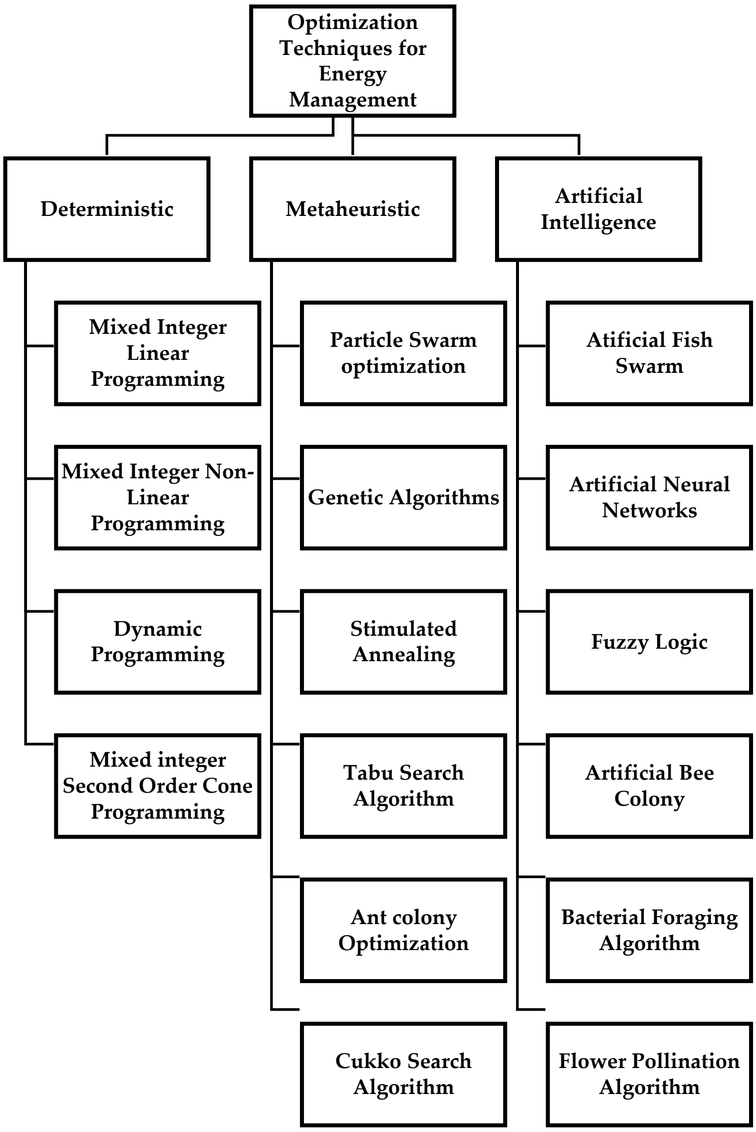

Figure 8. Classification of some important optimization algorithms for energy management.

The main objective of energy management in a microgrid is to increase efficiency by optimizing energy generation and storage systems [122]. Techniques used for optimizing campus microgrids are classified into three main categories: deterministic [62], metaheuristic [63], and artificial intelligence [64]. Each technique has unique benefits and drawbacks.

4.1. Deterministic Techniques

Deterministic techniques are primarily used to solve continuous objective functions. This technique involves the use of dynamic programming (DP), mixed integer nonlinear programming (MINLP), and linear programming (MILP) methods to solve an objective function. These methods are famous for providing precise results, but they are time-consuming and very difficult to use with distinct objective functions. Li-Bin et al. used mixed integer linear programming in MATLAB to optimize their proposed microgrid for the University of Engineering and Technology in Taxila [65]. Yeliz Yoldas et al. proposed a campus microgrid design for the Malta College of Arts, Science, and Technology. The proposed system was formulated using MILP, and compared with the stochastic approach, it was concluded that the use of MILP provided better optimal results [66]. In [67], the authors used mixed integer linear programming for the successful energy management of a campus microgrid located in Pakistan. Kayode Timothy Akindeji et al. used quadratic programming to optimize the microgrids of two campuses. The results depicted the effect of different weather conditions on campus load profiles, and it resulted in a substantial savings on fuel for the existing diesel generators by connecting them with a properly optimized microgrid [68]. For objective functions having second-order integers, the mixed integer second-order cone programming technique (MISOCP) is used [69]. In the dynamic programming technique, an objective function is divided into parts and then optimized.

4.2. Metaheuristic Techniques

Unlike deterministic techniques, metaheuristic algorithms provide an approximate solution. These are self-learning algorithms that take comparatively less time to reach a global solution. A famous example of a metaheuristic algorithm is the particle swarm algorithm. There are many metaheuristic algorithms present in the literature [70], such as Harmony Search (HS), Genetic Algorithms (GA), Particle Swarm Optimization (PSO), Ant colony Optimization (ACO), Stimulated Annealing (SA), Tabu Search (TS), Cuckoo Search (CS), Teaching Learning Based Optimization (TLBO), Jaya-Harmony search (JHS), Krill Heard (KH), Variable Neighborhood search (VNS), etc. For the campus microgrid at Yalova University in Turkey, Aykut Fatih Güven et al. proposed the use of the Jaya-Harmony search algorithm to optimize the energy management process, and they compared the results with PSO and HOMER. It was concluded that the JHS algorithm provided the most optimal component sizing [71]. To further increase the efficiency and convergence of metaheuristic algorithms, a combination of these algorithms is recommended [72]. For example, PSO provides fast convergence compared to GA [73], but it lacks flexibility, and so a combination of GA and PSO provides the best results both in terms of convergence and flexibility [74]. Mohamad Almas Prakasa and Subiyanto Subiyanto used a fusion of a genetic algorithm and a modified particle swarm optimization algorithm for the cost-optimal design of a campus microgrid located at the Universitas Negeri Semarang in Indonesia [75]. The proposed design managed to reduce operation costs by 11.9%.

4.3. Artificial Intelligence Techniques

Artificial intelligence techniques are modern optimization algorithms based on artificial intelligence. These algorithms have the benefits of quick convergence, high speed, and good precision. Machine learning involves the use of artificial intelligence algorithms. Saheed Lekan Gbadamosi and Nnamdi I. Nwulu used the machine learning Waikato Environment for Knowledge Analysis algorithm for solar and wind forecasting for a campus microgrid at the University of Johannesburg in South Africa [76]. Letícia A.L. Zaneti et al. used the rolling horizon method to reduce the charging costs of campus bus charging stations by up to 52% [77]. Jangkyum Kim et al. used IoT (Internet of Things) sensors to collect live data from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon campus, and then they used this data to propose a microgrid energy management scheme. The system was optimized using an AI-based self-organizing map algorithm. Optimization by taking uncertainties into account resulted in a 3% reduction in peak power and a 2.16% reduction in the daily electricity price for the campus [101]. Deep learning techniques can be used for the prediction of energy prices and smart grid stability [78], but they are associated with some limitations. Türkücan Erdem and Süleyman Eken proposed the use of layer-wise relevance propagation to discover the relevance of each input. It was suggested that the primary input in the system was the time required for the participant response, accompanied by the pricing coefficient, and that the electricity consumption or production had a negligible effect on the stability [79]. Table 2 shows optimization techniques being utilized in the latest research.

Table 2. Some optimization techniques from the latest campus microgrid studies.

Ref	Campus Name	Country	Optimization Method	Outcome
[65]	University of Engineering and Technology, Taxila	Pakistan	MILP	• 36.6% savings for campus microgrid
[66]	Malta College of Arts, Science, and Technology	Malta	MILP	• GBP 17,226 net saving in storage • 100% optimal design
[68]	University of KwaZulu–Natal	South Africa	Quadratic Programming	Substantial savings on fuel
[71]	Yalova University	Turkey	Jaya-Harmony Search	• Better convergence. • Most optimal sizing
[75]	Universitas Negeri Semarang	Indonesia	Modified PSO and GA	• 11.99% reduction in system costs
[76]	University of Johannesburg	South Africa	Waikato Environment for Knowledge Analysis (WEKA)	• Reduced effect of RE unpredictability • Lowest system maintenance costs
[77]	University of Campinas	Brazil	Rolling Horizon	• 52% reduction in operation costs
[101]	Korea Advanced Institute of Science and Technology	Korea	Self-Organizing Map Algorithm	• 2.16% reduction in daily electricity costs • 3% reduction in peak power
[80]	Polytechnic of Porto	Portugal	Fuzzy logic	• Reliable consumption forecasting with less historical input

5. Tools Used for Energy Management of Campus Microgrids

5.1. MATLAB

MATLAB is a programming and development tool to develop several kinds of mathematical algorithms. It is widely used for campus microgrid system optimization purposes. L. Hadjidemetriou et al. used MATLAB as a tool for the optimization of their proposed microgrid for the Malta College of Arts, Science, and Technology [17]. Ali Arzani et al. proposed a campus microgrid for Clemson University, Clemson, based on the solar generation and battery energy storage that could provide power for a two-day islanding event. The authors used MATLAB for the component sizing of their proposed microgrid [101]. In Greece, Elencova designed a campus microgrid for the Democritus University of Thrace. The energy management scheme of the campus microgrid was designed using MATLAB [102].

5.2. Simulink

Simulink is a graphical programming tool for modeling work, simulating, and evaluating multidomain dynamic systems based on MATLAB. Its framework comprises a simple visual block diagramming tool and its libraries that can be modified. It is a very useful tool for constructing a simulation model of a campus microgrid. Yuly V. Garcia et al. simulated their proposed campus microgrid design containing solar, battery storage, and a CHP system for the University of Puerto Rico in the United States [57]. Moslem Uddin et al. used a Simulink (MATLAB) tool to model a campus microgrid for the Universiti Teknologi PETRONAS (UTP) in Malaysia. The proposed model was then used to perform economic and stability analyses [82].

5.3. LabVIEW

LabVIEW is also a graphical programming tool that can be considered an alternative to Simulink. This tool is widely used by designers and engineers for campus microgrid applications. Rachid Lghoul in [83] used LabVIEW and CompactRIO for data acquisition and the management of a campus microgrid at Al Akhawayn University in Morocco. Pedro Moura et al. used the LabVIEW tool for the development of monitoring software for a campus microgrid installed at the University of Coimbra in Portugal [84].

5.4. HOMER

HOMER is the abbreviation of Hybrid Optimization of Multiple Energy Resources. This tool is a favorite among researchers due to its simple interface and rich features. A complete financial analysis of a proposed microgrid can be completed using HOMER. It also provides an opportunity to compare different combinations of proposed active and passive components of a proposed microgrid to select the most economical one [85]. MD Sarwar et al. used HOMER for the design and economic analysis of a campus microgrid at Jamia Millia Islamia University in India. The results proved that the proposed system design was the most economic and environmentally friendly [86]. Ayooluwa A. Ajiboye et al. also used HOMER to identify the most economically feasible solution for Covenant University in Nigeria. The results showed that wind turbines were not suitable for this location, while a combination of solar, grid, diesel, and battery energy storage was a potential system for long-term economic benefits [87]. For green transportation at the Thiagarajar College of Engineering in India, 100 kW solar generation was recommended. The system was optimized using HOMER, and it was observed that the proposed microgrid reduced gas emissions by 49,303 kg per year [88]. Sheeraz Iqbal et al. used HOMER for the economic feasibility testing of a proposed microgrid for the King Abdullah Campus of the University of Azad Jammu and Kashmir. It was concluded that a hybrid system containing solar, battery, and grid was the best solution for this university campus [89]. T. M. I. Riayatsyah et al. performed a techno-economic analysis for Syiah Kuala University in Indonesia using HOMER, and they concluded that an RE-based system containing 62% energy from solar and 20% energy from wind could reduce the per-unit cost of campus energy utilization from $0.060 to $0.0446 per kWh [90]. Stephen Ogbikaya et al. used HOMER Pro for the optimization and economic analysis of a campus microgrid for a university located in Nigeria. The proposed optimized system resulted in 88% saving on electricity charges [91].

5.5. PVSyst

PVSyst is a powerful tool for campus microgrid design and optimization. It has many unique built-in features, such as 3D partial shading phenomena, solar system sizing [92], storage optimization, etc. However, the use of this tool is limited to the design of those microgrids which use only solar as a generation source. It is not possible to use this tool for microgrids having multiple energy generations [93]. David Morillón Gálvez et al. used PVSyst to model a grid-connected solar-based campus microgrid for the National Autonomous University of Mexico. The proposed microgrid resulted in reduced carbon footprints and had the shortest payback period (fewer than six years) [94].

5.6. CPLEX

CPLEX is a mathematical programming tool developed by IBM ILOG. This tool uses integer, mixed integer, and quadratic programming techniques to optimize microgrid design. It is compatible with several programming languages such as Java, C++, and Python [95]. Jingyun Li and Hong Zhao used a CPLEX solver to optimize a proposed campus energy management model based on an improved particle swarm optimization technique [96].

Apart from the above-mentioned softwares, there are many other useful tools for campus microgrid development and optimization, such as DER-CAM (Distributed Energy Resources Customer Adoption Model) [23], iHOGA (Hybrid Optimization by Genetic Algorithms) [97], SAM (System Advisor Model) [98], PSCAD (Power Systems Computer Aided Design) [99] and GAMS (Generic Algebraic Modelling System) [100]. Table 3 shows the energy management system and used tools in the literature.

Table 3. Tools used in the campus microgrid energy management literature.

Ref	Campus	Resources	Tool
[17]	Malta College of Arts, Science, and Technology	Solar, diesel generator, and BSS	MATLAB
[81]	Clemson University	Solar and BSS	MATLAB
[102]	Democritus University of Thrace	Solar and BSS	MATLAB
[57]	University of Puerto Rico	Solar, CHP, and BSS	Simulink
[82]	Universiti Teknologi PETRONAS	PV, gas turbine, and BSS	Simulink
[83]	Al Akhawayn University	Solar and BSS	LabVIEW
[84]	University of Coimbra	Solar, BSS, and EV	LabVIEW
[86]	Jamia Millia Islamia University	Solar, wind, and BSS	HOMER
[87]	Covenant University	Solar, diesel generator, grid, and BSS	HOMER
[88]	Thiagarajar College of Engineering	Solar	HOMER
[89]	University of Azad Jammu and Kashmir	Solar, grid, and BSS	HOMER
[90]	Syiah Kuala University	Solar and wind	HOMER
[94]	National Autonomous University of Mexico	Solar and grid	PVSyst
[123]	Seoul National University	Solar and ESS	MDStool

6. IoT Enabled Cyber-Secured Microgrid

There are several solutions available for smart campus microgrid energy management [103]. Technologies that are important for campus microgrid design, communication, and operation are RFID (radio frequency identification), cloud computing, wireless technologies, augmented reality (AR), mobile technologies, and IoT (Internet of Things) technologies [104]. Solar irradiance, humidity, and temperature sensors were used by Jangkyum Kim to acquire real-time data from a campus microgrid and then propose an effective energy management model for it [101]. M. Z. Elenkova et al. [102] produced a simulation model for the campus microgrid at the Democritus University of Thrace in Greece, and an efficient energy management scheme was introduced for operating this microgrid. This scheme used IEC 61,850 as a communication protocol. Hanaa Talei proposed the use of a cloud computing-based IoT platform to avoid unnecessary delays in campus microgrid communication systems [105].

7. Conclusions

In this paper, a comprehensive study of the various aspects of campus microgrids is presented. This paper describes the energy management of campus microgrids considering the objective, architecture, storage technologies, and different tools used. Different storage technologies are used for campus microgrids. A prosumer-based system is focused on having the characteristics of energy exchange. In modern techniques, AI is the optimal tool when compared to conventional tools. An Internet of Things (IoT) -enabled system is more advanced compared to a classical system. Therefore, IoT technologies are used for communication and signaling purposes. The softwares used for energy management systems are also studied to explore better options for simulations. Python is an advanced platform for analyses using AI tools. In the future, a technical paper will be presented focusing on advanced techniques and uncertainties of systems.

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