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Design of a Smart Nanogrid for Increasing Energy Efficiency of Buildings †

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† This paper is an extended version of our paper published in 12th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion (MEDPOWER).

Abstract: Distributed generation (DG) systems are growing in number, diversifying in driving technologies and providing substantial energy quantities in covering the energy needs of the interconnected system in an optimal way. This evolution of technologies is a response to the needs of the energy transition to a low carbon economy. A nanogrid is dependent on local resources through appropriate DG, confined within the boundaries of an energy domain not exceeding 100 kW of power. It can be a single building that is equipped with a local electricity generation to fulfil the building's load consumption requirements, it is electrically interconnected with the external power system and it can optionally be equipped with a storage system. It is, however, mandatory that a nanogrid is equipped with a controller for optimisation of the production/consumption curves. This study presents design consideretions for nanogrids and the design of a nanogrid system consisting of a 40 kWp photovoltaic (PV) system and a 50 kWh battery energy storage system (BESS) managed via a central converter able to perform demand-side management (DSM). The implementation of the nanogrid aims at reducing the CO_2 footprint of the confined domain and increase its self-sufficiency.

Keywords: renewable energy; nanogrid; photovoltaics; battery storage; demand-side management

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Citation: Yerasimou, Y.; Kynigos, M.; Efthymiou, V.; Georghiou, G.E.; Design of a Smart Nanogrid for Increasing Energy Efficiency of Buildings. *Energies* **2021**, *14*, 3683. https://doi.org/10.3390/en14123683

Academic Editors: Surender Reddy Salkuti and Luis Hernández-Callejo

Received: 9 May 2021
Accepted: 15 June 2021
Published: 21 June 2021

1. Introduction

Traditional power systems are based on large-scale fossil fuelled generators that use transmission lines through long distances for delivering the power to the consumers. Although this method is extensively used across the world, it has significant drawbacks in mitigating the challenges poised today for delivering the low carbon economy. In addition, more than one billion people across the world do not have access to the electricity network, mainly because they live in rural areas, where the supply of electricity and other utilities is not provided due to economic reasons [1].

Renewable energy sources (RES) distributed generation (DG) has been developed to mitigate the limitations of traditional power systems. Through DG, power is generated within a short distance from the supplied area, thus reducing the dependence on long transmission lines and consequently, increasing both the system's efficiency and reliability [2]. Compared to central power generators, the power capacity of such systems is usually much smaller, whereas their electricity generation mostly comes from RES, such as photovoltaics (PV) and wind turbines. Therefore, the implementation of DG also contributes to the reduction of CO_2 emissions. The main obstacles in the wider utilisation of RES DG are the financial resources required for the realisation of such infrastructures and the output power of RES that it is intermittent in nature and occurs at irregular intervals, thus generating the necessity for the use of energy storage systems and advanced local control for optimally managing the local grid. In order to address the issues related to DGs, a control system that optimises supply and demand, such as a microgrid, is utilised. Microgrids are power distribution systems that are able to manage various DG systems and meet the energy demands of small communities, such as multi-block residential buildings, hospitals, university campuses, etc. based on the electricity supply and demand. They can remain connected to the electricity grid or operate in islanded mode and can be either used in AC, DC or hybrid configurations. Microgrids can be scaled down even further to a nanogrid, i.e., a single building that is equipped with local generation, which is often RES, and when equipped with adequate storage, can operate in isolation from other power entities such as the national electricity network or adjacent DG systems. When a nanogrid is equipped with an energy storage system (ESS) advanced control features can be implemented, including demand-side management (DSM) based on the flexibility of the building's loads.

The use of a microgrid or a nanogrid does not imply that the system should be necessarily connected or disconnected to/from the utility grid, operate specifically to achieve 100% self-sufficiency or for financial gains, and has applications only in developed or developing countries. For example, Feldheim, a small village consisting of 37 houses in Germany, has managed through the development of a microgrid to achieve 100% self-sufficiency, independence from the electricity prices of the market, and to depend on the national grid only for exporting electricity and providing services [3]. On the other hand, an energy community developed in Urja Upatyaka, Nepal that consists of 1200 houses and managed through a private company, has managed to establish a stable grid operation, is able to secure for its residents lower electricity prices compared to the national grid and to avoid load shedding, which can be as long as 16 h per day in Nepal [4].

Through the adoption of DG systems, including nanogrid control architecture, the utilisation of on-site electricity generation and storage is promoted and the dependence of buildings on the external grid is reduced. Nowadays, a portion of around 40% of the global energy consumption is consumed in buildings and are therefore large contributors to the overall CO_2 emissions [5]. In an effort to minimise the dependence of buildings on conventional energy sources and thus, reduce their carbon footprint, the European Union (EU) has imposed the Energy Performance of Buildings Directive (EPBD). According to EPBD, all new public and private buildings should become nearly zero-energy buildings (NZEBs) by the end of 2018 and 2020, respectively, [6]. Among the minimum requirements of the Directive, which aims at the development of energy efficiency class A buildings, is the coverage of at least 25% of primary energy consumption of the building from RES. Thus, it is evident that the wider usage of a nanogrid power architecture can benefit the users through the management of the on-site generation, storage and consumption, as well as minimise their dependence on imported resources.

The scope of this paper is to provide design considerations for nanogrids with respect to their power structure, control topology, utilisation and control of available electrical loads, as well as motivation aspects for their adoption. In addition, the design of PVTL nanogrid in Cyprus is presented, which will form the testbed for future research activities of PVTL in an effort to address the high energy consumption in the building sector, provide a solution for rural areas and areas powered by weak grids, and promote higher grid penetration of RES while maintaining grid stability and power quality. Thus, through the utilisation of PVs, which coupled with energy storage technologies can increase the energy efficiency (EE) of buildings through the implementation of DSM under the concept of a nanogrid.

2. Design Aspects of a Nanogrid

The typical structure of a nanogrid distribution system is illustrated in Figure 1. It is defined as a single domain power system, such as a single building, consisting of on-site electricity generation for fulfilling its load requirements, can potentially have an ESS and a control unit, and is able to connect or disconnect to other power sources. On-site electricity generation can be a RES, typically based on solar or wind energy, or a conventional generator based on fossil fuels. Typical loads that exist in a house include white appliances, such as fridge, washing machine, oven and dishwasher, appliances used for heating and cooling, lighting, and other electronic devices, such as TVs, computers etc. Another component that is part of a nanogrid is a gateway that is used for the connection or disconnection to other power entities, such as adjacent nanogrids/microgrids and the national power grid, depending on its requirements. Through the gateway, a bidirectional trading can be established with the other power entities, thus exploiting financially the nanogrid. Finally, the controller is utilised to establish the efficient operation of the system. The supply and demand vary dynamically throughout the day; however, they rarely occur concurrently for prolonged periods of time. The nanogrid controller is responsible to perform DSM and reduce the mismatch between the building's consumption and production curves based on the flexibility of the loads and the available energy resources [7].

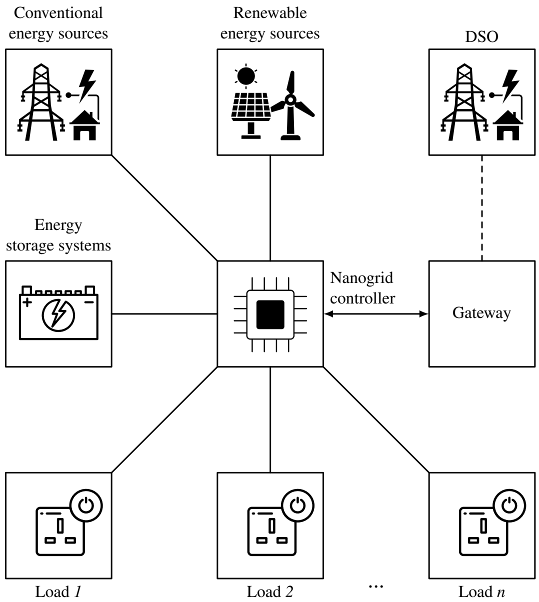

Figure 1. Typical structure of a nanogrid distribution system.

2.1. Types of Nanogrid Topologies

Nanogrids are mainly distinguished in two topologies, based on either AC or DC power systems. The general block diagrams for DC and AC nanogrids are presented in Figure 2. The type of source is common for both topologies in most instances, as a DC source is mostly utilised for the majority of applications. Despite that fuel cells and diesel generators have been reported in a nanogrid setting [8,9], the most favourable sources are battery energy storage systems (BESS) for storage, as well as PVs small-scale wind turbines for generation. Wind turbines usually output AC due to the use of induction motors, however, its output power is converted to DC, as its voltage and frequency are unregulated.

For DC systems, a DC-DC converter is normally used for reducing the voltage from the DC-link to a magnitude that is usable by the appliances that form the load of the nanogrid. The load converter is capable of outputting a wide range of DC voltages, depending on its application requirements [10]. In addition, a bidirectional AC/DC converter should be utilised as well in the case the nanogrid is not islanded, thus providing the connection to the utility grid or other power entities, such as aggregators, via a gateway. A bidirectional converter is required, as the locally generated power can be exported in addition to be consumed and stored, depending on the DSM scheme, whereas power should be imported in the case that the local resources are not adequate to cover the load requirements. On the other hand, an AC topology requires a DC/AC converter that outputs the DC sources to fixed AC voltage magnitude and frequency, which values depend on national grid regulations [11]. In the case of the loads, since most appliances are designed to be connected to the mains supply directly, the AC/DC converter is usually integrated into the device.

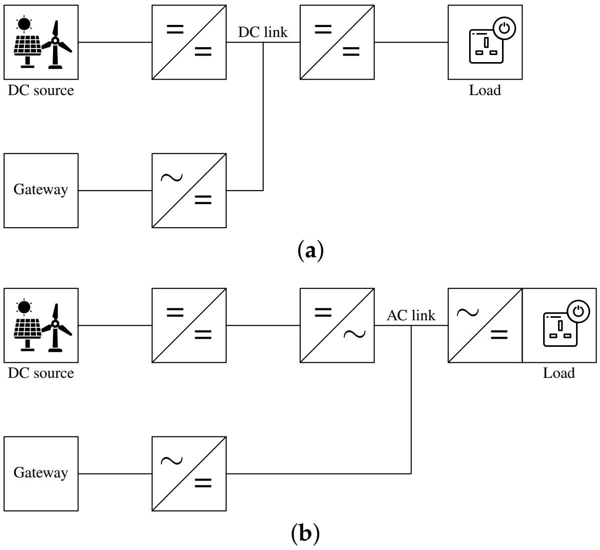

Figure 2. General block diagram for (**a**) DC and (**b**) AC nanogrid.

Both topologies have their benefits and drawbacks, and their selection depends on the nanogrid application and its ultimate purpose. For instance, in the case where the efficiency of the system is of utmost importance, a DC topology is more suitable, as one stage of power conversion is omitted [12]. Currently, AC topology is most commonly adopted; a decision that is mainly driven by financial motives. As the majority of electrical appliances in the market are supplied from AC power, retrofitting an existing building with DC loads would result in an increased cost of the nanogrid infrastructure. In addition, the DC topology requires additional protection measures to prevent faults such as short circuit, which further increase the cost [13]. As each case study has its own particularities, the selection of power structure must be based on the goals of the system [14,15]. Particularly, the selection of the nanogrid type should be based on the available resources, loads, and needs of the building. Regarding DC systems, currently there is no standard with regards to the operating voltage. However, 48 V supply is favourable, as it is able to power most of the common residential loads [16]. Although both DC and AC nanogrids have their merits, i.e., for DC systems the conversion losses are minimised, whereas for AC systems the initial capital cost is reduced, as the existing AC equipment can be used, a hybrid AC/DC system can benefit from both configurations, as the number of conversions is reduced for supplying all the existing AC and DC loads [17]. However, one of the main challenges for hybrid systems is to force the AC grid current at the point of common coupling to be a balanced 3-phase system with minor harmonics, while maintaining controllability of the power flow irrespectively of the instantaneous AC load [18]. In addition, communication and voltage stability for both AC and DC buses should be achieved, especially in islanding conditions [19].

2.2. Nanogrid Control Structures

Nanogrid control is required due to the mismatch between production and consumption, as they rarely coincide throughout the day. Thus, a nanogrid controller that has the ability to manipulate the consumption and production curves, in order to optimise the system through the coordination of generation, storage and consumption components, is essential for the financial gain of the system and its return of investment. In particular, through the controller the consumption can be altered in order to match the on-site energy resources of the nanogrid and reduce, or even eliminate, the dependence on the utility grid. There are various nanogrid control topologies that can be implemented, including central, decentralised, distributed, hybrid central, and hybrid distributed controls.

Central control, shown in Figure 3, is based on the connection of all the components that are part of the nanogrid to a central controller. Thus, information retrieved from the power generation system, storage system, and loads are processed in real time, in order to optimise the operation of the system. Additionally, information from environmental sensors, both indoor and outdoor, can be used in conjunction with the devices mentioned earlier. The main advantage of this topology is the fast control implementation and instant system knowledge, due to direct connection between all the components of the nanogrid to a single control unit. However, the use of a central controller requires high-bandwidth communication between the devices and the controller. Furthermore, the system is prone to failure, due to its reliance on a single controller.

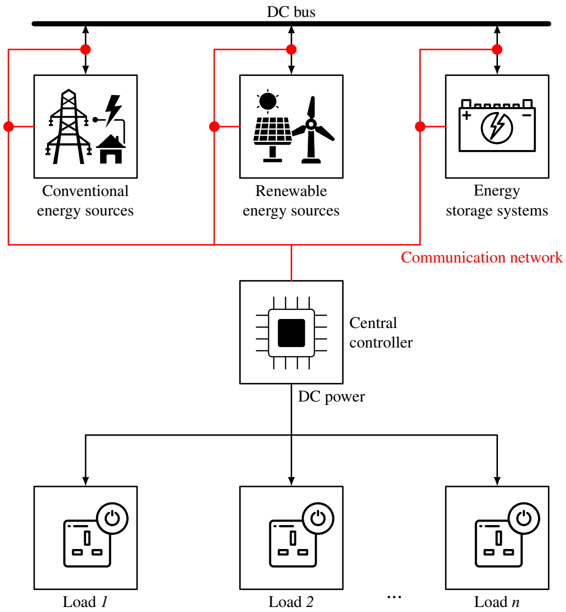

Figure 3. Central nanogrid controller.

Decentralised control on the other hand, operates on a device level and manipulates each device through a control node that is attached to it. Thus, any reliability and failure issues associated with central control are eliminated. Furthermore, it does not require high-bandwidth communication between the device and the control node. However, this control method has limited functionality, as the nodes can only control the devices they are attached to, without having the ability of a global system view. The schematic diagram of a decentralised nanogrid controller is shown in Figure 4.

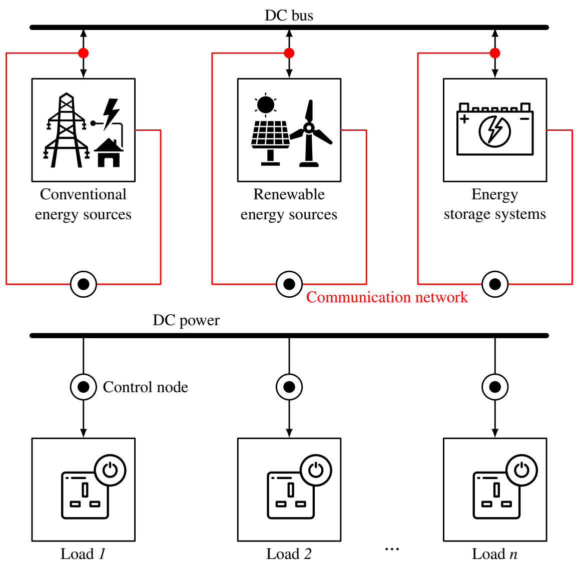

Figure 4. Decentralised nanogrid controller.

The disadvantages of decentralised control can be significantly reduced with the introduction of distributed control. The schematic diagram of a distributed control is shown in Figure 5. This control topology is based on a decentralised system with individual control nodes for each source and load, however, it adds the functionality of interconnection and communication between them. Thus, a cohesive control method can be achieved without the failure risks of a central controller. On the other hand, a high-bandwidth communication is required, as with the central control topology.

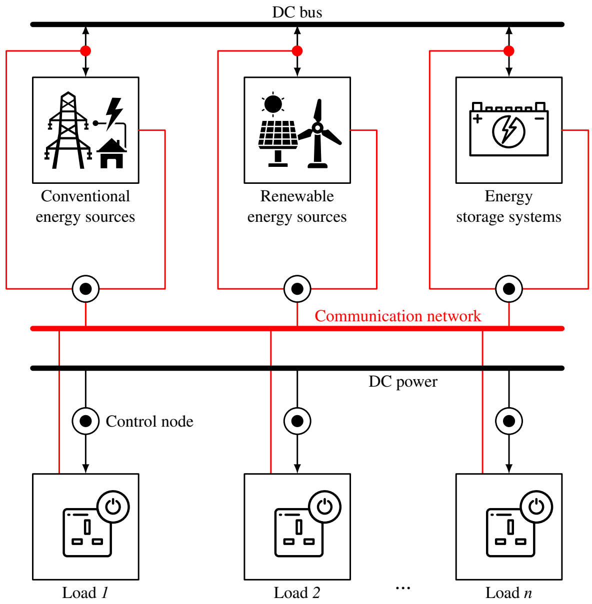

Figure 5. Distributed nanogrid controller.

Other nanogrid control topologies exist, such as the hybrid central and hybrid distributed controls shown in Figures 6 and 7. The former is a mixture of central and decentralised control by having a central controller that interfaces with individual control nodes. Hence, the reliability of the system is vastly improved, however, the nanogrid still relies on a communication network. On the other hand, hybrid distribution control extends the functionality of the decentralised control, by adding communications between the control nodes through the power lines. Thus, the system achieves control of individual nodes without relying on a communication network.

The structure of the controller should be selected based on the purpose of the nanogrid and the available resources. For example, a nanogrid has been proposed in [20], which is aimed at small-scale residential buildings, such as houses. The adoption of a central controller instead of a distributed one simplifies the installation for residential applications, as it offers compactness, quick and easy installation, and requires minor changes to the existing infrastructure. Moreover, the controller is able to cope with highly dynamic demand and generation, without compromising the system's stability. In contrast, the nanogrid control technique presented in [21] requires direct connection between each load and source, therefore, a distributed control technique has been implemented, instead.

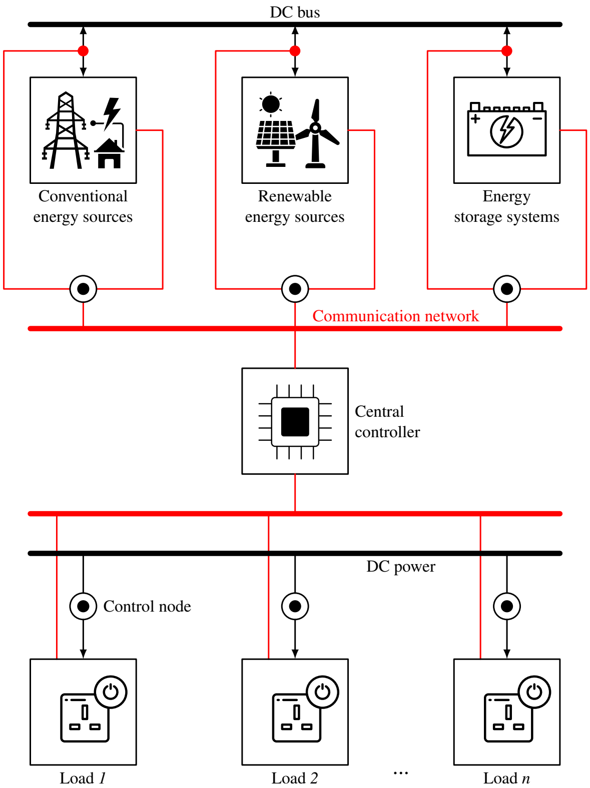

Figure 6. Hybrid central nanogrid controller.

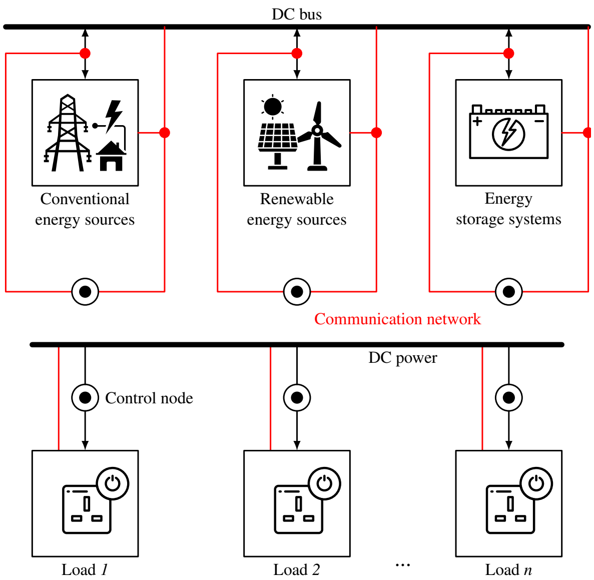

Figure 7. Hybrid distributed nanogrid controller.

2.3. Electrical Loads

There are numerous control schemes implemented for nanogrids, such as load shifting, droop control, valley filling and peak shaving. All of these control strategies aim at matching the consumption and supply curves. For the successful implementation of the aforementioned control strategies, the flexibility of the loads encapsulated within the nanogrid is crucial. Without adequate flexibility, the concept of a nanogrid becomes less effective and strongly depends on the production curve and energy storage capability of the system.

The most important type of load is the one that can be controlled thermostatically, as it can be utilised to store energy concurrently with a BESS. These loads require minimal to none human interaction, as they operate autonomously within predefined thermal boundaries. Thermostatically controlled loads, including water heating, room heating, and refrigerators, occupy a large share of the overall consumption in a residential building, which has been reported to be higher than 60% in some instances [22]. The main benefit of such loads is their ability to store energy in the form of heat by utilising the room space or a water tank as storage medium. Thus, by taking advantage of their slow thermal behaviour, their consumption can be shifted to match the RES production within a reasonable timeframe.

The control of these loads can be implemented via signals received by the nanogrid controller or by external entities, such as utility companies and aggregators, who aim at performing tasks such as voltage control, frequency control, or limitation of the amount of renewable energy penetrating the grid. The control by externals can be direct or indirect, depending on the level of access provided by the user. Direct control requires that the grid operator has access to the thermostatically controlled loads and can switch them on or off whenever deemed necessary. This method is beneficial for the grid operator, as it provides them with instant access to the loads and fast feedback to the system, however, it can add a layer of discomfort to the user. In particular, on-demand hot water and heating might not be achievable with direct control. On the other hand, indirect control allows only the user to access the loads directly, whereas incentives are provided to them by the grid operator. As such, the use of such loads can be applied at off-peak times, thus providing the user with financial benefit by using the off-peak pricing. An example of load control is presented in [23], where an electric water heater consisting of two elements has three levels of control, i.e., each element is controlled separately, and the two elements are operating concurrently. Thus, three cases of power consumption are created, thus allowing more control options depending on the system requirements. Thermostatically controlled loads can be a valuable asset, even at a larger scale. Through their exploitation in microgrid systems, high RES penetration can be mitigated and provide stabilisation of the grid, which can appear in the form of grid-tie line, power fluctuation smoothing, and improvement of power quality [24].

3. Adoption of Nanogrids and Their Impact

Nanogrids are widely utilised in rural, isolated areas where access to the electricity is not possible. In rural areas development of a central utility grid is a cumbersome process that requires time and a large initial capital cost. Nanogrids can be a more economical alternative to microgrids, in case the loads have large distances between them, such as islands or areas with low populating density [25]. The wider utilisation of PV power and the improvements in the lithium-ion technology allow for the implementation of nanogrids at a larger scale [26].

One of the strongest motivations for the adoption of nanogrids and in general, energy communities, is the financial benefit of the owner. As the initial capital cost for the implementation of such systems is often high, the prosumers should be compensated for their investment. Consequently, the effectiveness of a nanogrid control technique is often assessed over the financial gain of the system in comparison with an uncontrolled nanogrid infrastructure. The simplest form of a nanogrid control aiming at the financial gain of the user can be achieved through the scheduling of the BESS charging and discharging. In [27], the BESS is charged by both renewable and conventional energy sources, aiming at using the maximum solar power for its charging and achieve its optimal state of charge (SoC). The system also considers non-linearities in the discharging process of the battery and forecasting of the PV production. However, more advanced control techniques have been reported that also engage controllable loads in combination with the generation and storage devices. Specifically, in [28] an energy management system (EMS) has been designed by considering the financial gain of the prosumer through three steps; namely energy monitoring, DSM through the available smart appliances, and management of the ESS in order to match the forecasted generation. The implementation of the proposed EMS results in improvement of the energy balance within the nanogrid. Similarly, in [29] the use of smart devices and an EMS that controls the energy balance of the system has led to no usage of the grid for 92% of the year. Thus, by utilising a PV system, a BESS and lifestyle behavioural changes that result in load shifting, the grid usage has been reduced from 14.5 MWh/year to 1.17 MWh/year. On the other hand, instead of requesting the user's input for load flexibility, the thermal elements can be utilised to perform DSM without the occupant's interaction [30]. Thus, in order to enhance the living comfort of the building, the indoor temperature has been used as the input parameter for controlling the available heating and cooling elements. In this study, the indoor temperature is varied based on the predicted outdoor temperature, thus managing to maintain a high level of comfort and at the same time reduce the electricity cost. Thermal elements can also be utilised as a form of load shifting in countries where financial incentives are not available. Specifically, the maximum power point tracking (MPPT) can be used for shifting loads to time slots of the maximum PV generation. Thus, the thermostatically controlled loads can be triggered at those time intervals, resulting in a reported 44% reduction of the grid usage [31].

The success of the nanogrid adoption does not only rely on the financial gain of the prosumer, as it should also serve the interests of the aggregator and the distribution system operator (DSO), respectively, [32]. Thus, the aggregator should manage clusters of nanogrids as a virtual power plant, whereas the DSO power dispatching requests can be fulfilled by the aggregator and, therefore, prevent unnecessary renewable energy curtailment. Similarly, in [33] a prosumer-focused nanogrid is presented, where all the involved parties including the DSO, the aggregator and the nanogrid owners can alter their contribution, in order to maximise their profits and reach an equilibrium point. In this study, a modified objective function is suggested that requires feedback from the DSO as well and thus, aids all the participating parties to reach their ultimate equilibrium point. Moreover, a two-stage peer-to-peer (P2P) power exchange has been proposed in [34]. In this arrangement, the market participants form a dynamic supply-demand relationship, where the amount of exchanged power is firstly adjusted, in order to avoid unnecessary waste of renewable resources. In addition, individual trading preference is introduced for ensuring the fairness on market competition. Therefore, through this approach the market equilibrium is optimised and the market social welfare is increased.

A nanogrid power structure is ideal for a single building or house and its bidirectional connection to the utility grid provides all the features that are required for the usability of such a system. Despite that a nanogrid remains a niche application at the moment, its wider future adoption can unleash the full potential of the technology by establishing a hierarchical power system consisting of numerous nanogrids that are interconnected, thus forming a community and by extension, a microgrid. As shown in Figure 8, a nanogrid structure can serve as a component for a larger microgrid community. Hence, although there is a dinstiction between the two topologies in the literature, they can coexist. Through the formation of a microgrid consisting of interconnected nanogrids [35–37], features such as local power sharing and communication between the various power entities are available.

Specifically, bidirectional power sharing among interconnected nanogrids can provide advantages, such as maximum usage of locally generated power and minimum dependence on the utility grid. As the various buildings have different consumption curves and could potentially have varied production and storage capabilities, sharing of the excess power production aids in the utilisation of the surplus power within the interconnected nanogrid network, which ultimately results in financial benefits. Moreover, communication within the network is of utmost importance. On a nanogrid level, the devices are communicating with the control interface for the implementation of optimal power flow within the building. However, a network consisting of interconnected nanogrids should also have a level of communication in order to achieve optimal power flow between the networks as well as the utility grid, in order to exploit financially its resources via energy trading.

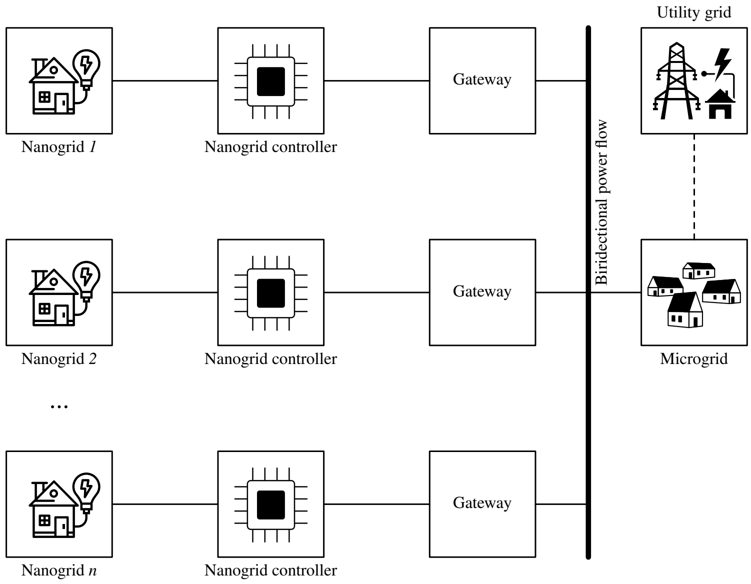

Figure 8. A microgrid consisting of a nanogrid cluster.

From the user point-of-view, financial strength can be established through the realisation of interconnected nanogrids. Within the network, each nanogrid can be treated as a source or a load, depending whether it needs to supply or request power. Thus, additional markets can be created between the nanogrids. In that way, power can be sold locally to a neighbouring nanogrid instead of the utility grid, which is beneficial for both the buyer and the seller, as the price per unit can be agreed between them without the grid operator acting as the middleman. For example, a P2P based on online energy sharing has been implemented in [35], resulting in improvement of the self-sufficiency and self-consumption of the nanogrid cluster, which is a combination of nanogrid-to-nanogrid and nanogrid-to-central controller power exchanges. A cluster of nanogrids installed on smart buildings has been also presented in [10]. The energy management of the cluster is performed by a cloud-based controller. Hence, an overall energy management is achieved by uniting all the load requirements, however, without the buildings being physically connected. The financial gain of a nanogrid cluster was also investigated in [38]. An energy management algorithm has been utilised for performing day-ahead scheduling of numerous residential nanogrids. Thus, each user inputs their preference with respect to a number of metrics, such as the energy consumption cost, battery degradation cost, and cost of user discomfort. The results of the algorithm show that the equilibrium point is reached as the nanogrid population increases, demonstrating the effectiveness of interconnected nanogrids. In addition, a decentralised droop control method has been used in [30], which uses the SoC of the battery of neighbouring DC nanogrids to facilitate power exchange between them. This method does not require communication between the nanogrids, as the power exchange is initiated based on a scheduled voltage threshold of the battery. Moreover, grid stability and islanding conditions are both concepts that can be adopted on a large scale through the creation of interconnected nanogrids. The former can be used for grid stabilisation, voltage control, frequency control, and real-time pricing, as the nanogrid is a versatile power system that can respond in a very short time to requests from the grid operator. The latter can allow the interconnected nanogrids to withstand power outages without compromising the operation of critical loads. In [39], a cluster of nanogrids in a microgrid configuration is considered, where the reactive power, current unbalance and harmonics are managed locally at each nanogrid. Therefore, transients between the microgrid and the utility grid are eliminated, as the microgrid can be deemed as a constant load in the main grid, resulting in smooth transitions between grid-connected and islanding operations.

The most common nanogrid configuration is the combination of renewable energy sources, an energy storage system and a mix of flexible and non-flexible loads that are part of a single building. However, nanogrid applications can extend beyond single buildings. A loose interpretation of a nanogrid is presented in [40] through the development of a road lighting system. The system consists of LEDs equipped with PVs and batteries. The LED array can be either disconnected from the utility grid, thus operating solely through their energy storage units, or connected to the utility grid, thus providing a storage and generation medium to it. In this work, the lighting control, which depends on the traffic volume through image processing, has been considered as an input parameter to the system's energy management. Moreover, in [41] a nanogrid has been implemented in an electric vehicle (EV) parking lot consisting of 20 EV charging stations, a PV system and a BESS. To overcome the limitation concerning the peak load demand and peak PV generation not coinciding, control algorithms have been applied to the BESS. Specifically, peak load shifting, minimisation of the peak period impact, limitation of the demand at fixed level, and use of all the available PV power for the charging of the BESS have been implemented. Through the control of the BESS, the nanogrid peak load was successfully shifted and the grid usage has been significantly reduced. Similarly, an EV battery has been utilised as a residential storage solution (i.e., a controllable load or a controllable source) for improving the self-consumption of the nanogrid by implementing the Vehicle-to Home technology [42]. On the other hand, the Vehicle-to-Grid technology has also been successfully implemented, by using the EV battery as a grid-connected storage device during the hours that it is connected to the grid [43]. Finally, an off-grid nanogrid has been implemented for the charging of EVs. The mission of the nanogrid is to serve as battery swapping station, by charging EV batteries through a PV system and supplying them to regional EVs [44].

In spite of the numerous advantages nanogrids can offer, as well as the key role they can play in boosting the concept of energy communities, there are a few drawbacks that are inherent in the nanogrid structure. Firstly, a significant financial capital is required for the purchase, installation and commissioning of the infrastructure. Furthermore, although the system provides the capability of energy trading with the utility grid operator, the prosumer as an individual could be in a weak bargaining position due to Time-of-Use tariffs that are offered, especially when the system is not utilised to its maximum potential. Under-utilisation of the nanogrid could occur in cases where the system size is larger compared to the load requirements of the building. Consequently, excess power is forced to be exported back to grid, often at a low price.Hence, sizing of the nanogrid system should be considered in the design phase, in order to maximise the use of RES, minimise the greenhouse gas (GHG) emissions, as well as maximise the financial gain of the initial capital investment [45]. However, for instances where 100% autonomy is required and therefore, no dependence on the grid, the nanogrid structure should be significantly oversized to cope with the peak demand without violating the comfort of the user. Thus, such system would be under-utilised for the majority of the day. Finally, the cybersecurity of a nanogrid is another aspect that should be considered. Since access is normally provided to external entities, the cybersecurity of the system should be enhanced in order increase the level of protection. An attack on the network could expose the nanogrid to major risks, such as complete control of the nanogrid deployment, control of the gateway's interactions with the remote server, and upload of malicious files to the nanogrid network, therefore, resulting in significant financial losses [46].

4. Design of PVTL Nanogrid

The premises of Photovoltaic Technology Laboratory (PVTL) at the University of Cyprus were selected for the implementation of a nanogrid. The facilities shown in Figure 9 will form a testbed for the nanogrid that will consist of PVs, a BESS and a central controller for performing DSM. In addition to these, the laboratory is equipped with smart meters, a programmable electronic load, two EV chargers, as well as numerous electrical loads, which are distributed among the offices used by researchers, the indoor testing facility for PVs and the conference room. Through the proposed nanogrid, the energy consumption of the laboratory will be met through the energy production and storage, thus resulting in the minimisation of its CO_2 emissions.

Figure 9. Aerial view of the PVTL, UCY.

A techno-economic study is not presented for the nanogrid, as this work focuses solely on its design from the hardware perspective, which will be utilised to serve the various research activities of the laboratory, without focusing on its return of investment. Hence, due the PVTL nanogrid nature and intended use, the PV system and BESS are oversized, the selected nanogrid controller can accommodate many more assets than the ones that are available at the existing nanogrid configuration.

The schematic diagram of the PVTL nanogrid is shown in Figure 10. It consists of the PV system, the BESS unit and the various electrical loads. A circuit breaker is also available for disconnecting the laboratory from the utility grid (Energy centre) and therefore, operate in islanded mode, if required. The loads of the system are mainly divided between the EV charging station, the programmable electronic load, and the various loads that exist in the laboratory facilities. It should be mentioned that additional PV systems with a net capacity of 35 kWp and a 10 kWh BESS system are also installed at the facilities of the laboratory, however, they are not part of the nanogrid, as they are used for other research activities.

The monthly energy consumption and averaged hourly and daily power of the laboratory for 2020 are presented in Figures 11–13. As shown in Figure 11, most energy is consumed primarily during the summer months, followed by the winter months. This is due to the extensive use of cooling and heating elements during that periods of the year. Therefore, the monitoring of the laboratory consumption has been divided in three distinct periods. Period A contains the months where cooling is required for prolonged periods of time within the day; namely June, July, August and September. Similarly, period B includes November, December, January and February, which are the months that require heating for extended periods. Finally, period C includes March, April, May and October, which are the mildest months with respect to the weather condition, and thus, require the least energy for cooling or heating.

As presented in Figures 12 and 13, the energy consumption of the building is a function of the personnel presence and thus. the working hours of the laboratory. In particular, most of the energy is required during the weekdays for all the periods of the year, as the laboratory mainly operates between Monday and Friday. Similarly, most of the power is consumed between 09:00 and 17:00, which is the time that most of the laboratory personnel is present. The peak load demand occurs in the morning hours for winter months and in the noun and early afternoon hours in the summer, which is strongly driven by the outdoor environmental temperature and the use of the air conditioning split units. Through the monitoring process of the laboratory consumption, which was performed via Schneider Electric PowerLogic PM8000 smart meters, an indication of the potential for DSM based on the on-site demand of the facilities can be obtained. In addition, monitoring of the existing consumption behaviour was performed for specifying the size of the PV and BESS systems, although the load demand is expected to be increased due to the expansion of the laboratory facilities and the growth of the working staff, which is also considered for the system sizing.

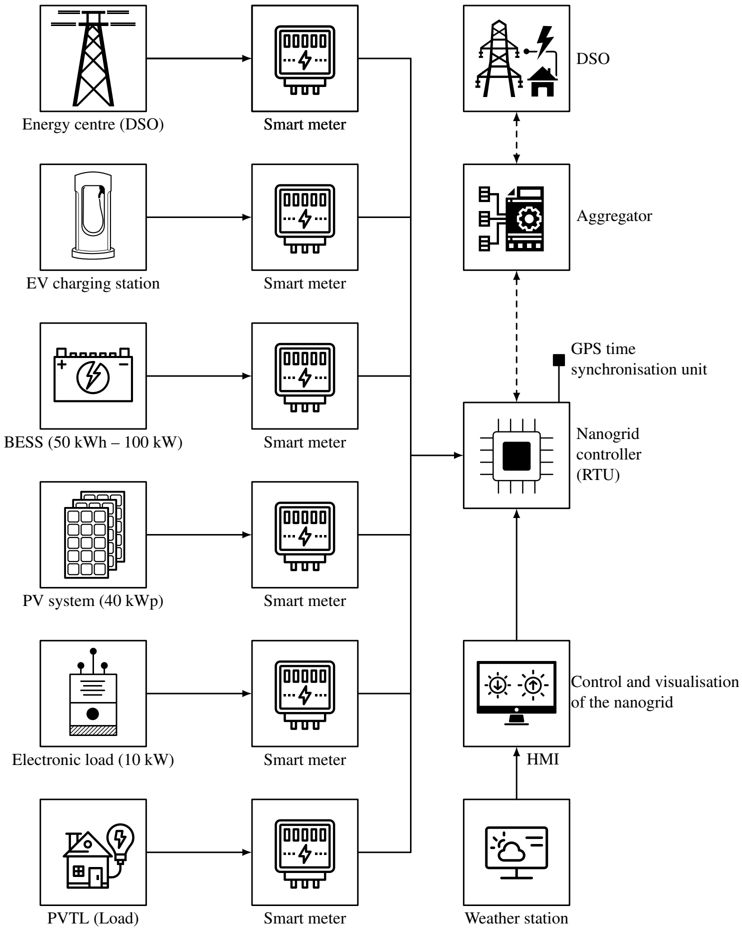

Figure 10. The schematic diagram for the pilot system.

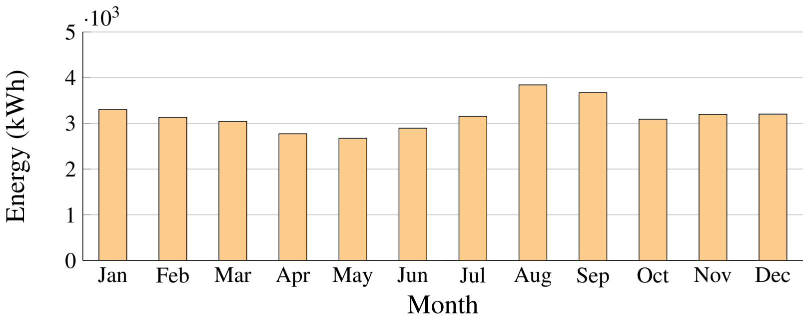

Figure 11. Monthly consumption of PVTL for 2020.

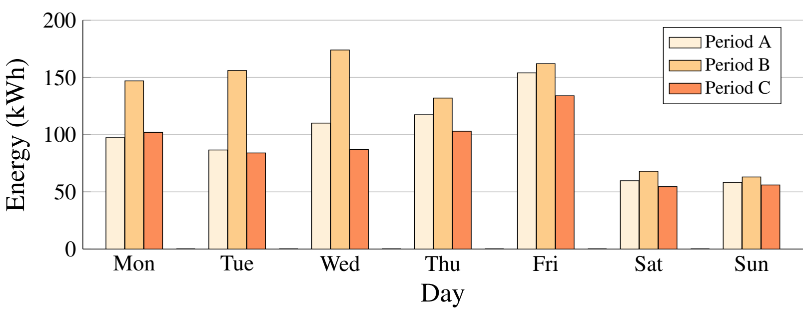

Figure 12. Weekly consumption of PVTL for three periods of the year.

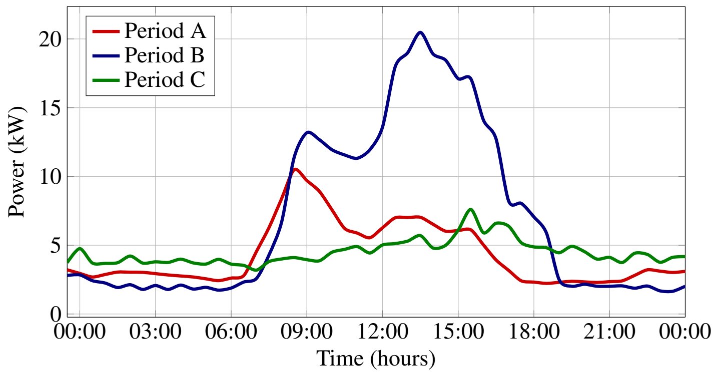

Figure 13. Averaged daily power profile for three periods of the year.

4.1. Photovoltaic System

The PV system of the new infrastructure consists of PVs with a total peak power of 40 kWp, mounted on two canopies that are installed on the outdoor corridors of the laboratory. Semi-transparent bifacial monocrystalline silicon PV modules were selected, in order to allow natural light through them. For this technology the transparency is achieved by adjusting the space between the individual cells. Another requirement for the PV modules is the type of junction boxes. More specifically, PVs with edge mounted junction boxes were selected, which allows for hiding them inside the support frame. All of these attributes of the PV system contribute to the development of a building integrated photovoltaic (BIPV) solution, where the PV modules are not used solely for power generation but are further utilised as an active component of the building envelope that replaces conventional construction materials [47].

The orientation of the two mounting structures, namely Canopy A and Canopy B, was selected based on the available installation space. Hence, Canopy A has an East–West orientation, whereas Canopy B is oriented towards the South. Moreover, the long-term operation and frequent maintenance of the PV system was considered in the design phase. Thus, despite that the PV system is integrated on the building envelope, access is provided for its cleaning and troubleshooting. A total of 104 and 20 PV modules with dimensions of 2×1 m (72-cell modules) will be installed on Canopy A and B, respectively. In addition, the PV modules are mounted at a 15° tilt angle, which is restricted by the canopies' structures and their purpose in providing shading.

4.2. Battery Energy Storage System

For the implementation of the nanogrid, a BESS based on lithium-ion technology with a usable capacity of 50 kWh is required. The BESS will be AC coupled to a 100 kVA inverter that can allow numerous functions, such as voltage control, frequency regulation, and power quality under grid connected and islanded conditions of the PVTL nanogrid.

The BESS will be installed in a temperature-controlled facility in order to be protected by high ambient temperatures, which are common in Cyprus. Nonetheless, the battery should be fully operational at 45 °C ambient temperature. The real time monitoring of the BESS is implemented through its Battery Monitoring System (BMS) that provides alarms and safety features regarding over-charge, over-discharge and over-heating of the battery, in order to prolong its lifespan. Moreover, through the BMS an estimation for the battery's SoC can be provided, as well as monitoring of the battery's voltage, current, charge power, discharge power, and reactive power.

4.3. Nanogrid Controller

A central nanogrid controller will be used for the overall management of the nanogrid and will serve as the gateway between the PVTL and the utility grid. Through the controller several functions that manipulate the operation of the nanogrid can be performed, including connection and disconnection from the grid, control of the maximum PV generation, control of the power factor, as well as charging or discharging of the BESS based on the available charge, the laboratory consumption, environmental parameters, or incoming electricity pricing signals. The utilisation of a central controller allows the performance of DSM schemes through numerous functions based on the consumption requirements and the available resources. The controller is based on a remote terminal unit (RTU) that can be utilised as a protocol converter and communicate between different devices from within and outside the nanogrid under various protocols such as Modbus RTU, Modbus TCP/IP, IEC 61850 and IEC 60870-5-104.

The nanogrid controller, as well as the PV system and the BESS are connected to a low voltage AC (LVAC) panel, which ensures that the nanogrid complies with the transmission and distribution rules imposed by the Transmission System Operator (TSO). In addition, system protection in the event of a fault or unintentional islanding is available as well. Moreover, the LVAC is equipped with smart meters that are used for monitoring the grid import and export power, the consumption power of the building, the direct PV consumption, the grid voltage and the grid reactive power.

As mentioned earlier, there are several electrical loads in the PVTL, including air conditioning split units, lighting, PCs, one video projector, one refrigerator and one microwave oven. Some of them are operating on-demand, thus, their operation cannot be altered by externals. Examples of such loads include the PCs, the video projector and the microwave oven. In contrast, some of the loads could be flexible and thus, be utilised for performing DSM. In particular, the temperature of the air conditioning units could be altered therefore, reduce their electricity consumption without violating the thermal comfort of the working spaces. Similarly, the lighting of all the laboratory facilities could be controlled based on the indoor light conditions, however, without affecting the comfort of the personnel. Finally, the refrigerator temperature could be altered without compromising its operation. However, as shown in Figure 14, production and consumption curves coincide during the day, as PVTL is a working environment and as mentioned earlier, mainly operates between 09:00 and 17:00. Therefore, in combination with all the aforementioned loads, a 10 kW programmable electronic load will be utilised for emulating various mission profiles.

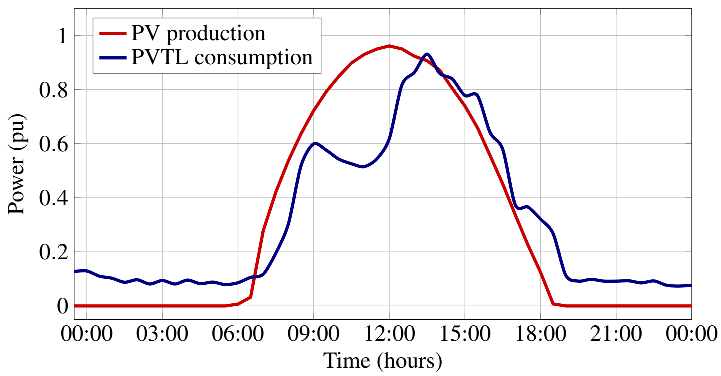

Figure 14. Production and consumption curves over a period of a day.

In addition, a weather station provides all the required environmental parameters that can be utilised by the central controller and perform actions depending on the retrieved data. Finally, the status system operation is visualised through a human machine interface (HMI). Hence, PV system parameters, such as the PV consumption and production, the load consumption, as well as environmental parameters, such as the ambient temperature, room temperature and humidity, are available through the monitoring system.

5. Conclusions

In summary, nanogrids form the backbone for energy communities and are essential for the establishment of self-sufficient buildings. In spite of the extensive work documented in the literature, there are no clear indications as to the type of nanogrid power structure and control technique that should be implemented, as each configuration has its advantages and disadvantages, as well as particularities specific to the application that should be considered in the design phase. For example, in a new building DC loads should be considered, which in combination with a PV system and a BESS that are also based on DC power, would result in increased conversion efficiency. On the other hand, for a nanogrid implemented on an existing building, an AC or a hybrid structure would be more economical, as the existing loads would be utilised. In the case of control technique, both central and distributed controllers have been used in a wide range of applications, depending on the nanogrid complexity, interoperability with neighbouring nanogrids, and available equipment. Finally, extensive research has been performed on the financial exploitation of the system, as it remains on of the main drivers for the adoption of nanogrids along with the reduction of GHG emissions, exploitation of RES and minimisation of the dependence on the utility grid. Although financial gain can be achieved through simpler actions, such as control of the BESS through its management system, a nanogrid controller yields greater financial gain, as it can also perform DSM via load shifting, voltage control, frequency control etc, thus highlighting its importance. Nonetheless, even with a nanogrid controller, country and/or regional policies should also be available, in order for the system to fully exploited. Hence, the wider adoption of nanogrids does not only depends on the owners/prosumers but also on the available incentives of each country's regulatory authorities.

In this paper, the design of a distributed generation system in the form of a nanogrid is proposed for addressing the high energy consumption that is common in fossil-fuelled buildings. Through the utilisation of RES and energy storage technologies, DSM can be applied that can increase the EE of the buildings, resulting in future sustainable and innovative solutions. The deployment of a 40 kWp PV system in combination with a 50 kWh, 100 kVA BESS is proposed at the PVTL. The infrastructure aims at increasing the self-sufficiency of the laboratory, whereas the PV system will be installed in BIPV canopies, thus generating electric power while replacing conventional building materials. Finally, through the central power converter, the necessary control methods are implemented for managing optimally local PV generation, the BESS charge/discharge system and DSM of the local loads for more efficient use of the provided resources.

Author Contributions: Conceptualization, Y.Y. and G.E.G.; methodology, Y.Y., M.K., V.E. and G.E.G.; writing—original draft preparation, Y.Y.; writing—review and editing, M.K., V.E. and G.E.G.; visualization, Y.Y.; supervision, G.E.G. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded through the BERLIN project which is funded by the European Union under the ENI CBC Mediterranean Sea Basin Programme under the grant agreement number A_B.4.3_ 0034.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

RES	Renewable energy sources
DG	Distributed generation
PV	Photovoltaic
ESS	Energy storage system
DSM	Demand-side management
EU	European Union
EPBD	Energy Performance of Buildings Directive
NZEB	Nearly zero-energy building
BESS	Battery energy storage system
EMS	Energy management system

DSO	Distribution system operator
P2P	Peer-to-peer
EV	Electric vehicle
GHG	Greenhouse gas
PVTL	Photovoltaic Technology Laboratory
BIPV	Building integrated photovoltaics
BMS	Battery monitoring system
RTU	Remote terminal unit
LVAC	Low voltage alternating current
TSO	Transmission system operator
HMI	Human machine interface

References

1. Akinyele, D.; Rayudu, R.; Nair, N. Global progress in photovoltaic technologies and the scenario of development of solar panel plant and module performance estimation—Application in Nigeria. *Renew. Sustain. Energy Rev.* **2015**, *48*, 112–139. [CrossRef]
2. Venizelou, V.; Makrides, G.; Efthymiou, V.; Georghiou, G.E. Methodology for deploying cost-optimum price-based demand side management for residential prosumers. *Renew. Energy* **2020**, *153*, 228–240. [CrossRef]
3. Akizu, O.; Bueno, G.; Barcena, I.; Kurt, E.; Topaloğlu, N.; Lopez-Guede, J.M. Contributions of Bottom-Up Energy Transitions in Germany: A Case Study Analysis. *Energies* **2018**, *11*, 849. [CrossRef]
4. Shrestha, A.; Rajbhandari, Y.; Khadka, N.; Bista, A.; Marahatta, A.; Dahal, R.; Mallik, J.K.; Thapa, A.; Hayes, B.P.; Korba, P.; et al. Status of Micro/Mini-Grid Systems in a Himalayan Nation: A Comprehensive Review. *IEEE Access* **2020**, *8*, 120983–120998. [CrossRef]
5. Nejat, P.; Jomehzadeh, F.; Taheri, M.M.; Gohari, M.; Abd Majid, M.Z. A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries). *Renew. Sustain. Energy Rev.* **2015**, *43*, 843–862. [CrossRef]
6. D'Agostino, D.; ZangheriI, P.; Paci, D. *Final Report Transition towards NZEBs in Cyprus (D2.5)*; European Commission: Ispra, Italy, 2017.
7. Burmester, D.; Rayudu, R.; Seah, W.; Akinyele, D. A review of nanogrid topologies and technologies. *Renew. Sustain. Energy Rev.* **2017**, *67*, 760–775. [CrossRef]
8. Kumar, S.; Krishnasamy, V.; Neeli, S.; Kaur, R. Artificial intelligence power controller of fuel cell based DC nanogrid. *Renew. Energy Focus* **2020**, *34*, 120–128. [CrossRef]
9. Bouchekara, H.R.A.H.; Shahriar, M.S.; Javaid, M.S.; Sha'aban, Y.A.; Ramli, M.A.M. Multi-Objective Optimization of a Hybrid Nanogrid/Microgrid: Application to Desert Camps in Hafr Al-Batin. *Energies* **2021**, *14*, 1245. [CrossRef]
10. Kumar, N.; Vasilakos, A.V.; Rodrigues, J.J.P.C. A Multi-Tenant Cloud-Based DC Nano Grid for Self-Sustained Smart Buildings in Smart Cities. *IEEE Commun. Mag.* **2017**, *55*, 14–21. [CrossRef]
11. Roncero-Clemente, C.; Roanes-Lozano, E.; Barrero-González, F. A Multi-Criteria Computer Package-Based Energy Management System for a Grid-Connected AC Nanogrid. *Mathematics* **2021**, *9*, 487. [CrossRef]
12. Goikoetxea, A.; Canales, J.M.; Sanchez, R.; Zumeta, P. DC versus AC in residential buildings: Efficiency comparison. In Proceedings of the Eurocon 2013, Zagreb, Croatia, 1–4 July 2013; pp. 1–5. [CrossRef]
13. Gelani, H.E.; Dastgeer, F.; Siraj, K.; Nasir, M.; Niazi, K.A.K.; Yang, Y. Efficiency Comparison of AC and DC Distribution Networks for Modern Residential Localities. *Appl. Sci.* **2019**, *9*, 582. [CrossRef]
14. Shahidehpour, M.; Li, Z.; Gong, W.; Bahramirad, S.; Lopata, M. A Hybrid acdc Nanogrid: The Keating Hall Installation at the Illinois Institute of Technology. *IEEE Electrif. Mag.* **2017**, *5*, 36–46. [CrossRef]
15. Wu, W.; Wang, H.; Liu, Y.; Huang, M.; Blaabjerg, F. A Dual-Buck—Boost AC/DC Converter for DC Nanogrid with Three Terminal Outputs. *IEEE Trans. Ind. Electron.* **2017**, *64*, 295–299. [CrossRef]
16. Shamshuddin, M.A.; Thanikanti, S.B.; Ramachandaramurthy, V.K.; Kennel, R. Implementation and design of an autonomous residential DC nanogrid. In Proceedings of the PCIM Europe 2019, International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, Nuremberg, Germany, 7–9 May 2019; pp. 1–8.
17. Goud, P.C.D.; Gupta, R. Solar PV based nanogrid integrated with battery energy storage to supply hybrid residential loads using single-stage hybrid converter. *IET Energy Syst. Integr.* **2020**, *2*, 161–169. [CrossRef]
18. Ebrahim, A.F.; Youssef, T.A.; Mohammed, O.A. Power Quality Improvements for Integration of Hybrid AC/DC Nanogrids to Power Systems. In Proceedings of the 2017 Ninth Annual IEEE Green Technologies Conference (GreenTech), Denver, CO, USA, 29–31 March 2017; pp. 171–176. [CrossRef]
19. Shahnia, F. Hybrid Nanogrid Systems for Future Small Communities. In *Sustainable Development in Energy Systems*; Azzopardi, B., Ed.; Springer International Publishing: Cham, Switzerland, 2017; pp. 19–38. [CrossRef]
20. Burgio, A.; Menniti, D.; Sorrentino, N.; Pinnarelli, A.; Motta, M. A compact nanogrid for home applications with a behaviour-tree-based central controller. *Appl. Energy* **2018**, *225*, 14–26. [CrossRef]
21. Javaid, S.; Kato, T.; Matsuyama, T. Power Flow Coloring System Over a Nanogrid with Fluctuating Power Sources and Loads. *IEEE Trans. Ind. Inform.* **2017**, *13*, 3174–3184. [CrossRef]

22. Wang, L.; Yang, Q.; Yan, W. Residential thermostatically controlled appliances for smoothing tie line power based on multiple state-queueing model. In Proceedings of the 2017 29th Chinese Control Furthermore, Decision Conference (CCDC), Chongqing, China, 28–30 May 2017; pp. 3195–3200. [CrossRef]
23. Liu, A.L.; Ledwich, G.; Miller, W. Single household domestic water heater design and control utilising PV energy: The untapped energy storage solution. In Proceedings of the 2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Brisbane, Australia, 15–18 November 2015; pp. 1–5. [CrossRef]
24. Wang, D.; Ge, S.; Jia, H.; Wang, C.; Zhou, Y.; Lu, N.; Kong, X. A Demand Response and Battery Storage Coordination Algorithm for Providing Microgrid Tie-Line Smoothing Services. *IEEE Trans. Sustain. Energy* **2014**, *5*, 476–486. [CrossRef]
25. Bae, J.; Lee, S.; Kim, H. Comparative study on the economic feasibility of nanogrid and microgrid electrification: The case of Jeju Island, South Korea. *Energy Environ.* **2021**, *32*, 168–188. [CrossRef]
26. Asif, A.A.; Singh, R.; Alam Majumder, A.J. The Paradigm Shifting Role of Solar Powered DC Nano-Grids in New Electrification and Replacement for Traditional Grid Distribution. In Proceedings of the 2020 Clemson University Power Systems Conference (PSC), Clemson, SC, USA, 10–13 March 2020; pp. 1–6. [CrossRef]
27. Salazar, A.; Berzoy, A.; Song, W.; Velni, J.M. Energy Management of Islanded Nanogrids Through Nonlinear Optimization Using Stochastic Dynamic Programming. *IEEE Trans. Ind. Appl.* **2020**, *56*, 2129–2137. [CrossRef]
28. González-Romera, E.; Romero-Cadaval, E.; Garrido-Zafra, J.; Florencias-Oliveros, O.; Ruiz-Cortés, M.; Moreno-Munoz, A.; González-de-la Rosa, J.J. Demand and Storage Management in a Prosumer Nanogrid Based on Energy Forecasting. *Electronics* **2020**, *9*, 363. [CrossRef]
29. Borland, J.O. Residential Island Nano-grid for 100% Renewable Clean Energy. In *Accelerating the Transition to a 100% Renewable Energy Era*; Uyar, T.S., Ed.; Springer International Publishing: Cham, Switzerland, 2020; pp. 507–528. [CrossRef]
30. Lee, S.; Vecchietti, L.F.; Jin, H.; Hong, J.; Har, D. Power Management by LSTM Network for Nanogrids. *IEEE Access* **2020**, *8*, 24081–24097. [CrossRef]
31. Burmester, D.; Rayudu, R.; Seah, W.K.G. Use of Maximum Power Point Tracking Signal for Instantaneous Management of Thermostatically Controlled Loads in a DC Nanogrid. *IEEE Trans. Smart Grid* **2018**, *9*, 6140–6148. [CrossRef]
32. Ghiani, E.; Garau, M.; Celli, G.; Pilo, F.; Marongiu, G. Smart integration and aggregation of nanogrids: Benefits for users and DSO. In Proceedings of the 2017 IEEE Manchester PowerTech, Manchester, UK, 18–22 June 2017; pp. 1–6. [CrossRef]
33. Parizy, E.S.; Bahrami, H.R.; Loparo, K.A. A Decentralized Three-Level Optimization Scheme for Optimal Planning of a Prosumer Nano-Grid. *IEEE Trans. Power Syst.* **2020**, *35*, 3421–3432. [CrossRef]
34. Zhang, Z.; Tang, H.; Wang, P.; Huang, Q.; Lee, W. Two-Stage Bidding Strategy for Peer-to-Peer Energy Trading of Nanogrid. *IEEE Trans. Ind. Appl.* **2020**, *56*, 1000–1009. [CrossRef]
35. Liu, N.; Yu, X.; Fan, W.; Hu, C.; Rui, T.; Chen, Q.; Zhang, J. Online Energy Sharing for Nanogrid Clusters: A Lyapunov Optimization Approach. *IEEE Trans. Smart Grid* **2018**, *9*, 4624–4636. [CrossRef]
36. Arboleya, P.; Gonzalez-Moran, C.; Jorge, P.G.; Mohamed, B. Hierarchical coordination of a hybrid AC/DC smartgrid with central/distributed energy storage. In Proceedings of the 2016 IEEE Energy Conversion Congress and Exposition (ECCE), Milwaukee, WI, USA, 18–22 September 2016; pp. 1–7. [CrossRef]
37. Nasir, M.; Zaffar, N.A.; Khan, H.A. Analysis on central and distributed architectures of solar powered DC microgrids. In Proceedings of the 2016 Clemson University Power Systems Conference (PSC), Clemson, SC, USA, 8–11 March 2016; pp. 1–6. [CrossRef]
38. Farzaneh, H.; Shokri, M.; Kebriaei, H.; Aminifar, F. Robust Energy Management of Residential Nanogrids via Decentralized Mean Field Control. *IEEE Trans. Sustain. Energy* **2020**, *11*, 1995–2002. [CrossRef]
39. Talapur, G.G.; Suryawanshi, H.M. A Modified Control Scheme for Power Management in an AC Microgrid with Integration of Multiple Nanogrids. *Electronics* **2019**, *8*, 490. [CrossRef]
40. Yoomak, S.; Ngaopitakkul, A. Investigation and Feasibility Evaluation of Using Nanogrid Technology Integrated Into Road Lighting System. *IEEE Access* **2020**, *8*, 56739–56754. [CrossRef]
41. Novoa, L.; Brouwer, J. Dynamics of an integrated solar photovoltaic and battery storage nanogrid for electric vehicle charging. *J. Power Sources* **2018**, *399*, 166–178. [CrossRef]
42. Giordano, F.; Ciocia, A.; Di Leo, P.; Spertino, F.; Tenconi, A.; Vaschetto, S. Self-Consumption Improvement for a Nanogrid with Photovoltaic and Vehicle-to-Home Technologies. In Proceedings of the 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), Palermo, Italy, 12–15 June 2018; pp. 1–6. [CrossRef]
43. Skouros, I.; Karlis, A. Design Methodology of a DC Nanogrid incorporating the V2G Technology. In Proceedings of the IECON 2019—45th Annual Conference of the IEEE Industrial Electronics Society, Lisbon, Portugal, 14–17 October 2019; Volume 1, pp. 5777–5782. [CrossRef]
44. Ban, M.; Yu, J.; Shahidehpour, M.; Guo, D. Optimal sizing of PV and battery-based energy storage in an off-grid nanogrid supplying batteries to a battery swapping station. *J. Mod. Power Syst. Clean Energy* **2019**, *7*, 309–320. [CrossRef]
45. Dahiru, A.T.; Tan, C.W. Optimal sizing and techno-economic analysis of grid-connected nanogrid for tropical climates of the Savannah. *Sustain. Cities Soc.* **2020**, *52*, 101824. [CrossRef]

46. Dafalla, Y.; Liu, B.; Hahn, D.A.; Wu, H.; Ahmadi, R.; Bardas, A.G. Prosumer Nanogrids: A Cybersecurity Assessment. *IEEE Access* **2020**, *8*, 131150–131164. [CrossRef]
47. Sechilariu, M.; Wang, B.; Locment, F. Building Integrated Photovoltaic System With Energy Storage and Smart Grid Communication. *IEEE Trans. Ind. Electron.* **2013**, *60*, 1607–1618. [CrossRef]