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Review

A Widespread Review of Smart Grids Towards Smart Cities

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Abstract: Nowadays, the importance of energy management and optimization by means of smart devices has arisen as an important issue. On the other hand, the intelligent application of smart devices stands as a key element in establishing smart cities, which have been suggested as the solution to complicated future urbanization difficulties in coming years. Considering the scarcity of traditional fossil fuels in the near future, besides their ecological problems the new smart grids have demonstrated the potential to merge the non-renewable and renewable energy resources into each other leading to the reduction of environmental problems and optimizing operating costs. The current paper clarifies the importance of smart grids in launching smart cities by reviewing the advancement of micro/nano grids, applications of renewable energies, energy-storage technologies, smart water grids in smart cities. Additionally a review of the major European smart city projects has been carried out. These will offer a wider vision for researchers in the operation, monitoring, control and audit of smart-grid systems.

Keywords: smart city; smart grid; solar; wind; energy storage; smart water grid

1. Introduction

Nowadays, considering the development of smart devices, there is a keen interest in linking interfacing items through available networks [1]. The aim of smart devices is to share/access information to/from other devices for taking smart decisions by having the capability of being integrated into current infrastructures as much as possible [2]. On the other hand, currently people move to cities to improve their life quality and the United Nations expects that by 2050, 70% of the world's population will be settled in cities [3]. It is evident that urbanization has its own challenges including resource shortage, energy and waste management, aging of the existing infrastructures, human health problems etc. [4,5]. The smart city idea has been the spotlight during last decade and is suggested as an optimal solution of overcoming urbanization problems by researchers. Herein, smartness is defined as the desire of improving the quality of life within cities and residents living there from several points of views by utilizing information and communications technology (ICT). However, employing ICT in city setups does not construe a smart city [6]. For a smart city concept, there are many definitions and a widespread one describes a smart city as the connecting environment of physical, social, business, and ICT infrastructure for elevating the intelligence of the city [7] by balancing the demand and supply of different functionalities [8]; 75–80% of world energy consumption is attributed to cities [9,10], which leads to the generation of 80% of the total greenhouse gas emissions [11]. Bearing this in mind, besides the scarcity of fossil energy sources and increasing populations of cities, the renewable essence of renewable energy sources best fits the recent global energy demands of sustainable smart cities [12]. Smart grids (SGs) or the updated version of traditional "dumb" energy infrastructures stand as the key and vital items supporting the concept of a sustainable future city [10]. They merge the non-renewable and renewable energy resources into each other, reducing the environmental problems. Meanwhile they carry the benefits of lower power cost and a reliable energy service [13–16]. There is a lack of monitoring/real-time control in the traditional non-smart systems, which creates a challenging opportunity for SGs to act as a real-time solution. In case of a smart city, the new generation of smart energy systems and grids have the capability to manage the energy of buildings which are on their way of modernization, by linking the smart grids and buildings to each other for efficient energy consumption/generation [17]. In fact, the smart grid provides new services for the inhabitants of smart homes (SHs) by the exploitation of available resources [18] and demonstrates a major potential from the viewpoint of economic and business value [19]. Making an allowance for the smart grids and taking into consideration their indispensable service to other infrastructures make them an exemplary guide for the implementation of the smart cities. By 2020, it is predicted that the smart energy sector will reach its highest development within the smart city territory. It is expected that 15.8% of the global smart energy market valued approximately US $248.36 billion will be devoted to smart energy [3].

In short, the smart city perception addresses the arising challenges of urbanization issue, which is and is going to be challenging in the future. Suryadevara and Biswal [20] published a comprehensive review of smart plug technology as a potential contributor to green energy and the smart grid/micro-grids and smart cities. Hernández-Callejo [21] reviewed four major aspects of smart grids by going through 316 applications of smart grids. Uslar et al. [22] conducted an inclusive overview of state-of-the art and related work for the theory, distribution, and usage of the smart grid architecture model. Espe et al. [23] re-read some research papers issued in the period 2009–2018 and grouped them based on their research contribution into the categories of prosumer smart grid classification. Fallah et al. [24] focused on the current state-of-the-art of computational intelligence (CI) techniques employed for advance intelligent load forecasting in energy smart grids besides classifying different CI techniques.

However, there is a lot of work to be carried out due to technological, economical, and governing barriers. The aim of this paper is to provide an impression of the role of smart grids towards smart cities since they play a major role in this regard. Firstly, we will define SGs in more detail and demonstrate their importance in smart cities, which will be followed by stating the roles of micro/nano grids, solar energy, wind energy, energy storage and smart water grids by smart cities. Lastly, a review of the major European smart city projects will be carried out. To the best of the authors' knowledge, although several papers have been published in this field and have discussed various aspects of smart grids, such a review report covering all the aforementioned issues altogether at the same time has not been conducted.

2. The Importance of Smart Grids in Developing Smart Cities

Based on the roadmap of American Reinvestment and Recovery Act, the president of the US in 2009 devoted $3.4 billion for 100 smart grid projects [25]. Currently, the energy distribution system is unidirectional, possesses static consumer tariffs and typically employs simple meters, which are not capable of two-way data exchange (Figure 1). Of course, in some cases, they are designed for remote reading purposes, but still most of them lack bio-directional digital communications network.

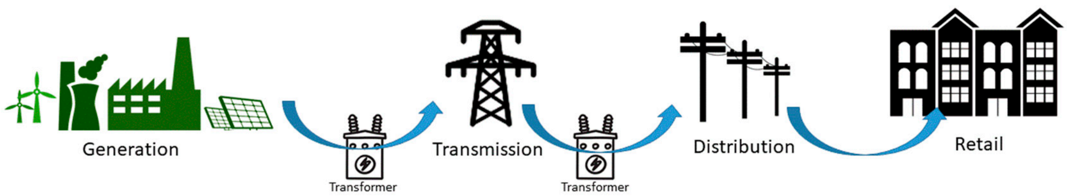


Figure 1. Traditional energy distribution systems.

Advanced metering infrastructure (AMI) fills this gap through linking the power generation grid and consumers by bidirectional exchange of information. Applying smart meters enables the users to monitor the exact and real-time electricity usage by affording dynamic price information, and their contribution on the carbon emissions, and assisting them to make more intelligent decisions [17,25]. On the other hand, managing energy demand and supply will be easier for energy suppliers. Additionally, the consumers will have the freedom to manage their high wattage appliances such as air conditioning, electric water heaters, pool pumps, clothes dryers etc. by means of peak demand management. Electric vehicles (EVs) are becoming more and more popular and this enables smart grids to detect and accept the produced/stored energy from consumers' side for overcoming the "spinning reserve" of wind turbines for example. Changing "dumb" infrastructure into smart infrastructure lies beneath adaptive feedback loops as a result of smart grid digital communications [25] (Figure 2).

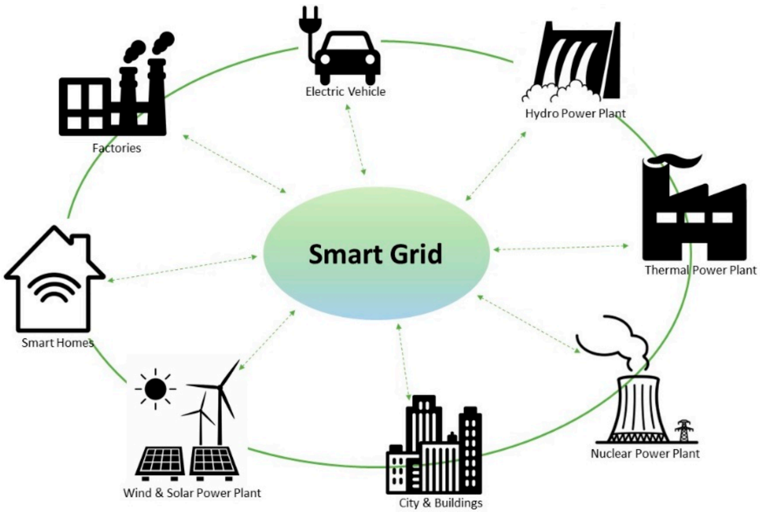


Figure 2. Smart future infrastructures.

The main functionalities of SGs start with modernizing power systems by means of real-time monitoring, automation and self-controlling issues. Next to that, updating consumers from the viewpoint of energy consumption, the real-time cost and making smart decisions stand as the second ranked target. Finally is the provision of reliable and sustainable energy resources as a combination of renewables and non-renewable [10]. By producing and distributing energy through intelligent energy systems, some main problems such as energy losses of long-distance transportation [26], and their corresponding costs are minimized. This is done as a result of smart load and building automation which leads to the increase of energy efficiency, safety and comfort both in domestic and industrial scales [27–29]. Rising energy efficiency in well-organized cities is a direct way of accomplishing ambitious environmental goals [10]. The smart city project of Malaga, Spain, started in 2009 and is assumed as the largest energy-smart city demonstration of Europe following the European Union's (EU) policy to reach 20-20-20 objectives [10]. Utilizing advanced smart meters by the capability of remote management for improving the energy efficiency, forward-looking demand management systems, employing a light-emitting diode (LED) street lighting network, micro/nano generation and high-technology energy storage setups have major roles within the project. Another major project that is currently ongoing is Triangulum Project [30], an ongoing EU lighthouse project started 2015 with the overall objective of demonstrating, disseminating and replicating solutions and frameworks for Europe's future smart cities. Within the framework of the project, three lighthouse cities, Eindhoven (Netherlands), Manchester (UK), and Stavanger (Norway), served as testbeds, while the outcomes are to be replicated in the follower cities, Leipzig (Germany), Sabadell (Spain), and Prague (Czech Republic) [31]. In each lighthouse city, a district has been selected to apply different technological solutions that will decrease the use of energy, reduce carbon emissions, and improve air quality in cities. The technologies used vary from local renewable power generation and energy storage, geothermal pumps or storage batteries integrated into the electricity grid, to the use of electric mobility (e-cars and e-bikes) as well as refurbishment of over 100,000 m^2 of housing. Almost all the activities are currently being developed in the cities. Some of them are described as follows: Stavanger municipality has installed a renewable energy plant for three of its municipal administration buildings including Stavanger swimming pool. This Central Energy Plant (CEP) heats and cools the buildings using energy generated from the city's waste and rainwater from a large sewer tunnel underground. The target reduction of CO_2 emission relies on the range of 80% in comparison to the earlier plant. It is obvious that smart homes play a major role in modernizing Stavanger into a smart city. For instance, 100 domestic dwellings have been equipped by smart generic gateways by Lyse AS which provides the services of controlling heating and lighting, charging EVs, security issues and advanced video solutions. On the other hand, some new electrical buses are employed by Rogaland County Council aiming at CO_2 discharging reduction on nationwide and worldwide level. A new Building Energy Management System (BEMS) have been installed in the Manchester Art Gallery for optimization measures. Optimization measures have been applied to improve the operation of air-handling units, and hot and chilled water systems. The results demonstrates a reduction of gas consumption by 24%, electricity by 12% and CO_2 by 15%. Gungor et al. [18] presented a widespread review on the major actors of SG characteristics and smart homes. The foremost encounters of SGs in terms of consistency, strength/flexibility, convenience, safety and supply/demand management issues were deliberated. Paaso et al. [3] emphasized the fact that grid modernization is flattening the path of constructing smarter cities leading to remarkable business opportunities for utilities. They pointed out the potentials of electric utilities and their importance in executing smart city agendas promoting electrification and environmental justice. Additionally, the recent activities of Commonwealth Edison Company (ComEd, Chicago, IL, USA) as a global leading company in Chicago area and northern Illinois were discussed and the significance of a smart grid as a fundamental element of achieving smart cities was highlighted. Li et al. [32] investigated the new challenges of cities and stressed the need for developing intelligent grids. They reported that smart grids would bring to the table the benefits of solving the energy crisis, the sustainable development of cities, minimizing energy consumption, flexible electricity market mechanism and extensive client contribution. Employing numerous sources of renewables at any building and city spot, the capability of managing distributed systems [33] and local microgrids [34–37] were considered as the main advantages of SGs while organizing and processing the grids interaction with volatile inputs and two-way power flows were the challenging issues of them [38]. Pirbazari et al. investigated the various feature selection techniques of a household load prediction problem by means of different clusters of load profiles. They found out that there was a significant relationship between the model accuracy and household load profile volatility [39].

Despite technical issues of the SGs, one can find an appropriate solution by the aim of predictable technologies. The other imperative challenges are mainly the institutional, market, and social engagements that would go along with setting out increasingly intelligent grids. Masera et al. [19] inspected a wide-ranging outline of analyzing extended cost analysis of smart cities and considered a comprehensive set of factors and concluded that the actual complications are unifying the all aspects in a conjoint outline. Bulkeley [40] indicated that energy transition mostly relies on geographies and physical infrastructures.

3. Micro/Nano Grids

The microgrid, as defined by the U.S. Department of Energy, is "a group of interconnected loads and distributed energy resources (DERs) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island modes". Parhizi et al. [41] reported that DER setups are assumed to be microgrids if they obey three criteria including owning obviously specified electrical boundaries, possessing a main controller, and the power generation capacity would be higher than that of peak load besides having the capability of island mode operation. It is evident that microgrids

(MGs) are more flexible than those of purely backup systems and act in both self-supply and islanding manners for generating, distributing and controlling the demanded electricity.

As reported in [41], control and automation systems, protecting devices, main controller, smart switches, and loads comprise the major components of microgrids. MGs are divided into two main categories, dispatchable or controllable and non-dispatchable or uncontrollable. The function of controlling in dispatchable MGs are carried out by means of the main controller depending on several parameters while non-dispatchable units do not have the capability of being controlled. This is because of the uncontrollable nature of the input source that are mostly renewable energies such as solar and wind and lead to unstable and alternating power output.

In the islanding mode, by taking benefit of smart switches and protective devices, an energy storage system (ESS) plays the chief role. Additionally, in problematic situations, smart switches connect/disconnect the power flow and stops proceeding of the fault within MG. The function of master controller is based on safety and financial principles, which determines the connection/disconnection of the MG to the grid, acting at island or interconnected mode and optimizing the operation of DERs. This will assure continuous, operative and consistent communication among MG elements.

Although islanding mode is not the only application of MGs, it stands as the most important characteristics of a MG which enables it to act independently for instabilities or voltage fluctuations. In 2017, a market prospect of $17.3 billion was witnessed while the engaged MGs capacity boosted from 1.1 GW to 4.7 GW within a five-year period [42]. As concluding remarks, it can be stated that MGs cover the three main goals of smart cities in terms of reliability, toughness progresses, and the integration of renewables and is a great importance in establishing future sustainable cities.

Smaller-scale MGs usually providing the load of a single construction are called nano-grids (NGs). By utilizing an NG within a building, it gains its own dependency from the viewpoint of generating and consuming power [43] and actual independency could be targeted at the ideal situations (Figure 3). Additionally, there is the possibility of reducing setup losses, which would lead to more sustainable systems. NGs can provide consistent energy, which still stands as a major problem. As mentioned before, at the campus of the Illinois Institute of Technology, ComEd desires to establish a nano-grid pilot [3]. The controlling and energy management attitude of MGs are of great importance. Jiang et al. [44] suggested a control method consisting of two layers consisting of schedule and dispatch layers. By considering a satisfactory amount of active power within the schedule layer followed by assigning the same quantity in dispatch layer, the deviations between predicted and real-time data were minimized. The load allotment between a house standing apart and a small office block utilizing a microgeneration system consisting of a ground source heat pump (GSHP) and a hybrid GSHP/photovoltaic (PV) was investigated by Entchev et al. [45]. They concluded that the perception of SG, demand side management and load flattening decrease the necessity of relying buildings purely to the grid.

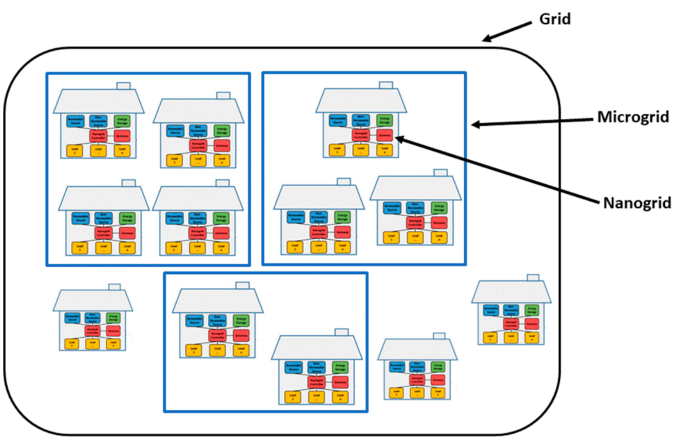


Figure 3. An overall comparison between micro- grid and nano-grid.

4. Solar Energy in Smart Grids

Due to global warming, the growth of greenhouse gas emissions, fossil fuel scarcities and considering the renewable essence and plentiful amount of solar energy, it has gained extensive attention. Nowadays, not only there is a need for utilizing solar energy, but also there is a huge demand for storing and integrating it into smart power grids for improving energy management systems through demand-side management strategies [46]. Liu et al. [47] proved that solar PV systems could act as the actuators in improving the inter-area oscillations and diminishing undesirable impressions of large scale interrelated power setups. A novel dispatch scheme for resolving the low-frequency power fluctuation of a central PV-grid arrangement beside of its main task was proposed by Wandhare and Garwal [48]. The suggested plan modified the constancy of the system without the necessity of integrating any supplementary devices or other arrangements which showed the potential to be utilized in SG uses.

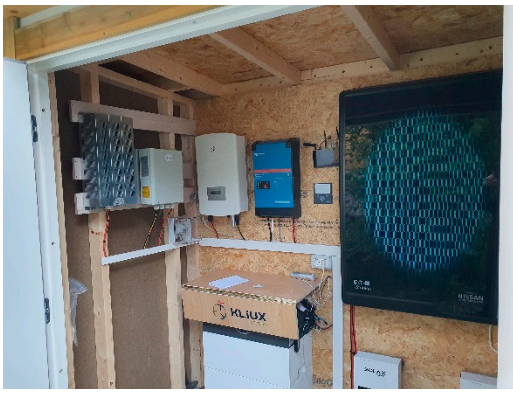
Another work [49] proposed a scheme where an auxiliary circuit was added to the PV-grid, which boosted the reactive power recompense of the system up to three times more than that of the original PV invertor. An innovative control scheme of a multi-generation setup consisting of PVs, storage components and a micro gas turbine was suggested by Kanchev et al. [50]. The management arrangement comprised two sections including the microgrid chief energy management sector and costumer power supervision section. The managing scheme was based on the PV power production and the load predicting permitting bi-directional grid communication. A control strategy investigation of an active PV system (APS) encompassing of ultra-capacitors, batteries and PV was presented by Choudar et al. [51]. Preserving the grid control petition from the operator side was carried out by power flow management between the convertor and grid by means of a direct current (DC) link. The simulation results demonstrated the most favorable use of storage components, flattened power and fast dynamic compensation. The capability of a PV micro-inverter microgrid functioning on both island and grid-connected modes through a management procedure was explored by Rodríguez et al. [52]. For the grid-linked type, they employed micro-inverters owning the supplementary facilities of functioning in the island mode while the control algorithms were kept the same. They concluded that reorganization of micro-inverter control in the island style could act as a voltage source utilizing droop schemes. A building integrated photovoltaic (BIPV) approach incorporated into a storage system for metropolitan applications was designed by Sechilariu et al. [53]. The initial aim of the system was self-serving the buildings while, by employing a DC network distribution, several energy transfers were abolished. The system demonstrated the potential for feeding a tertiary building and simultaneously the PV setup generated electricity and a classified management through bidirectional data swap was undertaken. Another project for energy management of a DC distribution within a building was undertaken by Byeon [54]. The DC production of systems such as PVs and fuel cells besides the DC loads were considered on the proposed management system. It was proved that controlling the energy costs of the constructions is the basis of launching an energy management system which is beneficial for the contributors. One-day in advance functional forecasting and online regulation for an active-generators based PV setup of an urban microgrid was studied by Kanchev [55]. Multi-objective tasks including minimizing CO_2 discharge and economic costs were performed by a dynamic algorithm. In a similar study, the joint setup of a combined heat and power (CHP) and PV prosumers considering the interior expense-based demand response cooperative management was investigated by Ma et al. [56] and was demonstrated that the difference between predicted and actual power curves was huge enough. A novel energy management algorithm for a photovoltaic customer grid supply system (PCGSS) acting on a two-way power demand/response arrangement was suggested by Guichi et al. [57]. A battery system was also included in the setup to guarantee the ongoing energy provision. They observed that during the nighttime, the quantity of power input to the grid was approximately the same as taken out amount while the battery charge level was just about unchanged.

5. Wind Energy in Smart Grids

Integrating wind energy into upcoming smart grids in possible regions and cases increases the efficiency and reliability of them. The two-dimensional synergy of this process comprises two benefits. First, a wind turbine performs as a source of energy and besides that, the other components of the setup can control and protect it throughout grid instabilities. Therefore, integrating wind energy into SGs will enhance the control degree of the power system. An efficient and end-to-end strategy for a feasible wind-based setup was proposed by Glinkowski [58], which brought about a well-organized electricity consuming and producing smart grid beneficial for both the sides and environmental issues. The mybox platform in University of Stavanger as a part of Invade Project, which is an EU project [59], intends to employ a wind turbine integrated into PVs, batteries and a central control unit in a smart home for load shifting and electricity trade purposes (Figure 4).

(**A**) Wind turbine and photovoltaic (PV) setup

(**B**) PV arrays



(**C**) Central control unit and battery

Figure 4. Mybox platform, University of Stavanger.

Based on the new energy strategy of the Danish government, 50% wind energy will be penetrated into the Danish power system by 2025 [60]. Guo et al. [61] developed a fully distributed economic dispatch algorithm (ED) based on finite-time average harmony and predicted gradient of smart grid systems with random wind power. The suggested ED algorithm enabled the communication process of the neighboring agents by preserving the equality and inequality restrictions and the overall financial cost of the arrangement was minimized. Minimizing the wind power fluctuations and expenditures used for charging and discharging electric vehicles was suggested to be modified by Ghofrani et al. [62] through a stochastic-based algorithm and vehicle-to-grid (V2G) service. He et al. [63] carried out a numerical study for dispatching and forecasting one-day in advance planning and real-time arrangement to overcome the unstable nature of the power generated from wind connected to the grid. They concluded that the proposed planning strategy worked well from the viewpoint of demand response indecisions. In another work [64], they targeted the integration of wind power into SGs and considered multi-period setting up and pricing by old-fashioned and adaptable end-users. They revealed that the optimal arrangement and price setting were branded strictly for persistent and non-persistent cases.

An agent-based simulation was developed and verified for a SG by Broeer et al. [65]. Moreover, the addition of the wind power to the earlier validated model was also investigated and the possibilities of stabilizing the oscillations of the power system comprising of several intermittent brokers by a smart grid were proven. The monitoring and energy management of buildings encompassing photovoltaic and wind energy setups by means of open access by ZigBee equipment were carried by Batista et al. [66]. The results confirmed the capabilities of ZigBee tools in distributed renewables and smart-metering coordination. A harmonized V2G regulator and controlling the frequency of a vigorous load-frequency control (LFC) of a SG employing wind power generation arrangement was presented in [67]. The strength and synchronized controlling impacts of the projected V2G control and proportional integral (PI) controllers of LFC alongside the altered variables and functioning settings were presented.

6. Energy Storage in Smart Grids

If renewable energy does not have the possibility to be stored in extensive quantities, it would not be feasible [68]. Balancing the volatile load of renewable sources through controlling strategies is the main task of smart grids. The "balancing act" of SGs can be simplified by storing smaller quantities of energy by the grid. It is worth mentioning that in a real SG scheme, all the design parameters starting from demand supply procedures of buildings to the dynamic loading of transmission lines depending on the wind speed and temperature are to be considered [69]. The energy storage as a part of energy planning at large scales has been the target of nations such as Japan and Germany. The percentages of energy storage within grids as the near-term objective of Japan and Germany are 15% and 10%, respectively, while it is only 2% for the US [70]. There is an essential difference between the power storage and the energy storage and it is strategic in numerous applications. The use of energy storage is part of demand management, while power storage is engaged in the speed of feedback, frequency adjustment and spinning reserve. Several engineering applications employ energy storage technologies such as compressed air, battery, pumped hydro storage plants, super capacitors and flywheels. An interesting example of energy storage is the idea of engaging minor quantities of energy storage for (1–2 h) on the feeders of residential zones. The perception of community energy storage (CES) sets out 25 kW low-voltage elements guarding small building clusters [71].

Some innovative equipment such as electric springs have been developed and have shown the effectiveness in alleviating SGs by considerable participation of renewables facilitating the harmonizing of power demand-supply [72]. Venkataramani et al. [73] reviewed different dimensions of compressed air energy storage (CAES) and concluded that adding CAES to multi-generation systems will play an important role in improving the sustainability and renewables in company with SGs. A storage control strategy for huge dimensions was planned by Koutsopoulos [74] and sounded compatible with small scales also. A novel and quite spread algorithm for service renovation by the provision of distributed energy storage accomplished by error detection and isolation was presented by Nguyen and Flueck [75]. Two algorithms acting as the power flow controller of a grid-connected source as a subset of SG energy storage stabilizing the voltage setting was offered by Ivanovi'c et al. [76]. Mohd et al. [77] emphasized that there is an essential necessity to examine the feasibility and efficiency of coupling several energy-storage arrangements into distributed energy resources besides the influence of employing renewables on the electric grid and common power stations. Sbordone et al. [78] designed and integrated an energy storing setup comprising a Li-polymer battery into an EV fast-charging station and demonstrated that it functioned quite satisfactorily in peak shifting task within a distribution grid. Pang et al. [71] demonstrated the potential benefits of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) as dynamically configurable dispersed energy storage acting in a vehicle-to-building (V2B) operating mode. The possible dynamic energy storage/management by means of V2B and applying BEVs and PHEVs was explored by Pang et al. [79]. The results showed that by employing BEVs/PHEVs through via peak load shifting, the purchase price of the electricity for the client and vehicle owner would decrease. The weaknesses of battery technologies such as broad approval, inclusive expenses, inadequate lifetime, discharge deepness, short energy concreteness and sustainability of the employed resources were claimed to be alleviated by vanadium redox flow batteries (VRFB) [80].

Carrying demand-response contrivance or smart grid setup, the importance of end-user energy storage and its mutual impact on the hybrid distributed arrangement was investigated by Granado et al. [81]. They revealed that storage adjudicate decisions increases the cost saving up to 5–7% in comparison to fixed retail price. An innovative setup of building integrated photovoltaic (BIPV) convoying a storage system for urban regions was proposed by Sechilariu and Wang [53]. It was concluded that the setup has the possibility of functioning devoid of grid power fund while it was connected to the grid. Hybrid AC/DC microgrids comprising of renewables and hybrid energy storage arrangements consisting of super capacitors (SC) for ultra-fast load matching and lithium-ion batteries for moderately long-term load buffering was explored by Mohamed et al. [82] and a real-time energy management algorithm was proposed. The function of the suggested algorithm relied on minimizing the effect of pulsed (short period) loads on the power system stability. By demand-side management and peak hour loads into off-peak, an average yearly saving of around 7% was achieved. Ru et al. [83] studied a grid-connected PV containing battery setup targeting the battery size determination. They developed a well-organized algorithm for obtaining a principle aimed at assessing the feasibility of batteries in comparison to electricity acquisition from the grid and suggested lower and upper restraints.

Young et al. [84] proposed a single-phase multilevel inverter with battery balancing wherein any battery was directly allied into a separate inverter. The battery-balancing action of the whole system was conducted by regulating the voltages. For validating the brilliant function and viability of the arrangement, a prototype was also designed and built. By the aim of minimizing the line loss of supply coordination integrated into sizeable PV generation systems (PVGSs) a genetic algorithm (GA)-based scheme for optimizing the charging/discharging scheduling of battery storage systems (BSSs) was proposed by Teng et al. [85]. Arefifar and Mohamed [86] defined a new probabilistic index approaching for unifying the active supply arrangements into a group of microgrids by improved consistency and supply-capability indices. They learned that by systematic scheme plan and coupling distributed sources and storage systems, the index could be improved up to 54% and 70% for simple microgrid using distributed generators and all other resources respectively.

An optimal predictive control method was developed by Torres and Bordons [87] for renewable based microgrids complemented by hybrid energy storage system. The objectives of the optimization method were minimizing the dreadful conditions originating in each storage system besides maximizing the economic profits simultaneously considering several system restrictions. The study conducted by Lucas and Chondrogiannis [80] reported a model to demonstrate how a vanadium redox flow batteries-based storage device could afford multi-functions emphasizing on frequency regulation and shifting peak hour loads. A comprehensive and novel perception of building predictable and flexible energy management making an allowance for employing smart grids, optimum anticipated occupancy outlines, financial and environmental state of affairs, smart regulating and utilizing high-density latent heat storage was proposed by Lizana et al. [88]. Aiming ay upcoming energy demand estimation and electricity price growth, the model was implemented for a Scottish case study and a bill reduction of 20% for the end user and 25% for the retailer was achieved. On the other hand, the total energy consumption boosted by 8% which was acceptable due to lower CO_2 emissions of power generation.

7. Smart Water Grids

The existing water infrastructure lies in the huge and central setups while managing the functionalities are very limited. Water scarcity and distribution stand as the two main challenges of municipalities [89]. It is evident that because of the latter restrictions, some real-time strategies are to be employed. This means that since the current water systems are one-directional [90], there is an actual necessity for the online and in-network supportive and monitoring systems. That will be the base of smart water grids (SWGs), which allow the water utilities to modify and optimize the system performance, controlling water leakage in an efficient way, and minimizing the maintenance period [91]. Considering the fact that the current water supply/demand infrastructures are not monitored/measured by real-time data and bearing in mind the definition mentioned earlier, the water distribution system of municipal regions is not precisely grid-based. It is evident that the essence of grid based management system is measuring the real-time data and from this point of view, it can be categorized in smart-grid classification. On the other hand, since water-related issues in terms of separation, heat integrated distillation, purification, process water removal/treatment, pumping and distribution are energy-intensive processes [92–94], then they are intimately connected to energy management systems such as smart grids.

Data from several applications of an area such as potable water, washing and flushing uses, agricultural and industrial consumption etc. would be unified, processed and managed in a unique setup by means of ICT methods, networks of sensors and smart meters are required to satisfy the criteria of grid definition and to be recognized as SWG [95,96]. As reported by several researchers the main final goals of SWGs are using water in a more efficient way, providing end-users real- time data, detecting leakages and contamination [97–99]. For example, as reported by Hauser using sensors within water systems incorporated into communication and networking opens the door to valuable insights on the Internet of Things (IoT) [98]. By taking benefit of SWG technology, the rainfall dependency of South East Queensland, Australia dropped from 95% to 75% in just four years [90].

Kim et al. [100] reported that the useful consequences of SWGs could be considered as advanced water generation, treatment and management methods besides providing water security. Cheong et al. [97] examined the process of SWGs growth and difficulties and proposed some interesting solutions for overcoming existing problems. They introduced cost, security, anxiety and complexity as the major barriers of SWGs and suggested that updating the knowledge of consumers to be aware of SWG advantages, dynamic pricing, vigorous contribution of the private sector and merging smart water grid with sustainable water management as the solutions of SWG challenges solutions.

For solving the water shortage problem of an airport located at the Yeongjongdo Island in Korea, Byeon conducted a research [101] and implemented it in an artificial environment. They did their best to minimize the demanded changes of the standing infrastructure. They used a pressure "signature" technology propagating through the entire piping system for detection and modifying the water supply management. A similar technology named HydroSense, merely by using a single sensor, is capable of recognizing each signature at the domestic appliances [102]. This means that if there is any leakage at the system, it would be identified as a noise and the rotating devices such as pumps and valves will function manually and automatically based on the sensors signals and ecological situations. It is clear that on SWGs, there is a direct dependency between water and energy consumption, which cannot be separated from each other [90], Spinsante et al. [103] carried out prototype experiments and numerical simulations assessing energy consumption and system performance by employing wireless metering bus protocol to be adapted in upcoming smart water grids.

A prototype of self-feeding smart water meter gaining energy from supercaps and micro-turbine and utilizing Wireless Metering Bus capillary network technology was manufactured by Gabrielli et al. [104] and the sustainability of the setup from energy point of view was demonstrated. In another work [105], they implemented the wireless metering bus protocol on a real Hot Water (HW)/SWG platform and studied the energy consumption. They concluded that the wireless metering bus N modes represented the best transaction for the setup [91]. For detecting and predicting gas and water leakage, Fagiani et al. [106] went through the existing techniques and determined that the wide and novel monitoring arrangements mostly rely on low-power wireless strategies simplifying to collect large quantities of data. The same group in another work [107] attempted to estimate the feeding gas and water quantity based on data exploiting for achieving trustworthy results. Their outcomes demonstrated that genetic programming and extended Kalman filter-genetic programming (EKF-GP) achieved quite satisfactory for the Energy Information Administration (EIA) datasets while artificial neural networks (ANN) and support vector regression (SVR) techniques performed marvelously for both long/short-term forecasts. In their third work [108], they developed an algorithm for detecting the leakages of smart water/gas grid circumstances. They claimedthat the system identified both normal and irregular actions by executing an on-line tracking. It is introduced as a novel approach of spotting leakage at the beginning and end whereas the entire system is monitored through a real time process. Targeting the chief challenges of water distribution structures including real-time monitoring, Allen et al. [91] introduced an end-to-end platform and reported that it acts to improve the functioning efficiency of the water supply system in the city center of Singapore. A theoretical distributed control outline for regulating the wind/solar grid integrated Reverse-Osmosis (RO) water desalination energy setup was proposed by Qi et al. [109]. The aim of the propose was to manage, predict and regulate the combined scheme for short-term purposes respects. The function of same setup was for long-term optimal management purposes on the basis of a dual-time-scale decomposition was examined through a computationally proficient supervisory control method [110].

8. European Projects/Case Studies

Considering the fact that smart energy city has emerged as the latest urban development strategy in European countries, this section provides a review to the major European smart energy city projects and the application of previously mentioned technologies by them.

STEEP (Systems Thinking for Efficient Energy Planning) [111] was a European project carried out in 2013–2015 in the three cities of San Sebastian (Spain), Bristol (UK) and Florence (Italy). The possibilities of employing PVs, cogeneration setups, geothermal and hydrothermal heat pumps, short and long-term thermal energy-storage systems, waste heat recovery from industry and smart meters were investigated. STEP UP (Strategies Towards Energy Performance and Urban Planning) [112] comprising four cities Ghent (Belgium), Glasgow (Scotland), Gothenburg (Sweden) and Riga (Latvia) was an EU project in 2012–2015. Employing CHP, renewables in terms of biomass, geothermal and solar thermal was a major section of the project. PLEEC (Planning for Energy Efficient Cities) [113] was conducted in 2014–2016 among six mid-sized European cities including Eskilstuna (Sweden), Turku (Finland), Santiago de Compostela (Spain), Jyväskylä (Finland), Tartu (Estonia) and Stoke-on-Trent (Estonia). The used technologies were water management, electrical power grids, heating and cooling grids and renewables. ZenN (Nearly Zero Energy) project [114] (2013–2017) covering four cities of Oslo (Norway), Malmö (Sweden), Eibar(Spain) and Grenoble (France) aimed to reduce energy use in existing buildings and neighborhoods. Photovoltaic and solar thermal panels besides ground, air and solar source heat pumps and cogeneration units had major roles in the project. In another project R2CITIES [115] (2013–2018) three cities of Valladolid (Spain), Genoa (Italy) and Istanbul (Turkey) were the candidate cities for achieving nearly zero-energy cities. Photovoltaic energy, solar thermal, storage systems and distribution systems were among the utilized technologies for achieving the project targets. READY [116] running in Aarhus (Denmark) and Växjö (Sweden) in the period of 2014–2019 proposed and developed integrated smart city electric grid systems and mobility solutions. They employed integrated PV power and heat generation, batteries for electricity storage, district heating and electricity systems, and intelligent control (by Power Hub) of energy consumption and production for optimizing the utilization of renewable energy resources more efficiently and reducing fuel consumption.

There are similar projects that have been completed or soon will be all over the Europe such as mentioned in [117–125]. There are some huge running projects presently on European cities. IRIS [126] is an ongoing project on Goteborg (Sweden), Utrecht (Netherlands) and (Nice France). The three main smart solutions of the project are smart thermal grid, smart electricity grid and e-mobility besides energy management and ICT. The EOn Smarter Together project [127] arranged for the targets of Lyon

(France), Munich (Germany) and (Vienna Austria) on energy and climate protection to be achieved in an integrated way and by using modern technologies based on smart energy solutions.

9. Future Works

According to the literature, there are several suggestions/recommendations regarding smart grids. For instance as stated on [21], there is a serious need for developing new software/hardware technologies particularly for metering systems besides applying renewables more and more on SGs. As another subject, investigating the prosumer related issues such as roles, market design, provider-consumer relationship, consumer engagement and socio-economic-technological, are of great importance [23]. However, as the authors studies show [17], studying the psychological reactance concept [128] regarding smart grids is very important. It means that when people feel their freedom is threatened, they act to restore their freedom. If people believe that the smart technologies prohibits them from living the way they desire, they override the programmable appliances/grids to set points manually higher than before installation. This may sound illogical to engineers, but it is certain that it would be considered in future studies.

10. Conclusions

The current paper demonstrated the importance of smart grids as a major component of founding smart cities by giving an overview to the key constituents of the smart grids in terms of micro/nano grids, applications of solar energy, wind energy and energy-storage technologies besides smart water grids in smart cities. For any sector, the imperative challenges/barriers were introduced and the major potential solutions as well as available technologies were brought together. Several experimental/theoretical case studies as a demonstration/application of smart grids targeting smart cities were reviewed. The importance of smart water grids in forming smart cities by the aim of using water in a more efficient way, providing end-users real-time data, detecting leakage and contamination has been pointed out via several case studies. Additionally a review of the major European projects in this regard was done and the latest urban development strategies were presented. Finally, some suggestions/recommendations for future studies have been proposed. Hopefully this article will open the doors to valuable insights on smart grids and offer a superior vision to the chief features and challenges of smart grids for future research.

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