Community Connected Microgrids

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Renewable energy systems in the form of community microgrids, and grid-connected solar PV-storage are considered primary solutions for powering residential developments. The primary objectives for commissioning such systems include significant electricity cost reductions and carbon emissions abatement. Despite the proliferation of renewables, the uptake of solar and battery storage systems in communities and multi-residential buildings are less researched in the literature, and many uncertainties remain in terms of providing an optimal solution.

Keywords: rapid review ; microgrid ; community ; solar PV ; battery storage

1. Introduction

Electricity produced from non-renewable power plants can experience power disruptions because of extreme weather conditions, which may sometimes result in huge financial losses [1], estimated at USD 44 billion annually, as reported in the US [2]. At the same time, the recent upsurge of solar photovoltaic (PV) penetration worldwide, coupled with the climate agenda of carbon emissions mitigation, have also disrupted the monopoly of fossil fuel-based power plants, thus transitioning towards a new renewable power regime.

Following the suppression of socio-economic activity induced by COVID-19, there was a decline of 6.4% in global greenhouse gas (GHG) emissions in 2020 relative to 2019, equivalent to 2.3 billion tonnes [3]. Although this reduction is promising, GHG emissions are expected to surpass previous figures when the ongoing pandemic situation comes to an end. Of the reported 33 billion tonnes of global GHG emissions for the 2019 season [4], along with other active sources of emissions, the building sector is a key contributor; it has been reported that the building sector is responsible for 19% of carbon emissions, 51% of global electricity consumption and 32% of global energy consumption [5][6].

It is commonly acknowledged that the main drivers of electricity consumption of buildings are heating and cooling appliances. Although modification in construction design can modulate these loads, such high consumption offers an excellent opportunity for the abatement of GHG emissions and costs by utilising distributed renewable energy sources (DRESs).

It is financially difficult to accomplish net zero energy in existing residential buildings, but there are approaches to offset grid-imported electricity, with innovative building construction designs emerging. The concept of net zero energy buildings (NZEBs) has been adapted widely in the research community and projects. NZEBs generate the energy they consume from DRESs, mainly PV and battery storage. Today, the utility network offers dynamic tariffs for scheduling consumers' electricity usage. Energy management systems (EMSs) and arbitrage allow users to charge their electric vehicle (EV) during low-tariff periods. These innovative measures contribute to net zero sustainable buildings. It is, however, equally important to identify which building type (detached houses, multi-residential communities or high-rise apartments) requires an identified mode of technology if the energy transition is to accelerate.

Though attractive in theory, “net zero” as such is not the cornerstone of an ideal sustainable building; rather, this lies in the combined specifics of maintaining smooth electricity supply, frequency and voltage stability, backup generation during blackouts and meeting peak demand that must be contemplated in the selection process of DRESs. For instance, diesel generators are still regarded in many applications as the most orthodox backup option to provide electricity during outages and are often combined with battery storage. However, rapid infrastructure transformation and increasing tariffs foster the need for a new electricity paradigm to deliver power, with microgrids being the product of this new required distributed transformation. Microgrids contain a group of loads and poly-generation sources (e.g., PV and battery storage) operating in a single management system connected to the grid or isolated.

The increased penetration of DRES, principally PV, into utility grids poses various challenges such as the management of excess energy flow, voltage fluctuation, frequency distortion, system stability and protection issues [7]. Further, the efficient utilisation of renewable energy is also imperative on both residential and commercial scales. Microgrids offer various benefits when integrated with the grid, including (i) energy quality, (ii) system reliability, (iii) peak power reduction, (iv) ancillary services provision such as voltage and frequency regulation, (v) reactive power support through the injection of power into the grid, (vi) backup supply in case of grid failure, (vii) electricity infrastructure replacement, (viii) contribution to GHG abatement and (ix) providing autonomy to consumers by giving them control over modifying their energy use through demand response strategies.

The massive rollout of small-scale distributed microgrids with PV and battery storage systems can curtail the levelized cost of energy and, in some cases, cause grid parity situations [8]. The deployment of battery storage from static packs to mobile EVs can also minimise energy costs and ensure the smooth supply of power.

Indeed, various multi-objective control and optimisation techniques can be applied to model microgrids [9]. In the same manner, several forms of DRESs can be integrated with microgrids, such as fuel cells, hydrogen, wind turbines and various forms of energy storage. Technological developments and decreasing costs of DRESs favour microgrid deployment globally; however, many regulatory and policy barriers across certain domains exist, which should also be surveyed. It appears that multi-residential buildings, communities and apartments have received less attention when it comes to the applicability of DRESs, in line with their complexity in design, regulations and scalability.

After the careful review of scientific articles on the topic, it appears that there are several ways of implementing a microgrid for multi-residential buildings and communities; we define such microgrid schemes as community connected microgrids (CCMs). It is worth noting that the terms community grid, community microgrid and multi-residential communities are used interchangeably with CCM in this study without the actual meaning being affected.

2. The Rapid Review Methodology

Rapid review methodology and manuscripts accelerated over the year 2020, partly due to the emergence and prevalence of COVID-19 around the world. The principles of this methodology are based on the systematic review method, which seeks to identify the conclusions and analyses of multiple research resources, but so that the results obtained can be implemented for policymaking within shorter timeframes. To keep the research predefined and well organised, certain inclusion and exclusion criteria are set with the aim of extracting only published literature reviews from authentic and reliable resources for further evaluation.

Rapid reviews differ from standard literature reviews as such studies can be completed within shorter timeframes as compared with traditional systematic literature reviews (SLRs), which are often conducted within one to two years [6][10]. They have been predominantly conducted in the medical science research, and there is not much evidence that they have been applied in the field of renewable energy. Rapid reviews, much like SLRs, minimise the risk of bias [6]. Factors such as specific database selection, set timeframes and review article proclivity confines the length of rapid reviews. Rapid reviews implicitly synthesise a wide literature through original reviews without these being singularly studied. Consequently, the conclusions are much shorter; the findings, however, are substantial and unbiased as compared with narrative reviews.

We take the example of the “AGILE” model used in Lagisz et al. [11] to describe the rapid review process, in which each step is recurrent and interconnected to the following step. Although AGILE was originally developed drawing on a different motivation, it is still appropriate for use in this study, which follows the steps as shown in Figure 1. To expedite the process, we have excluded the team communication step, which often requires stakeholder consultation and interviews, from the AGILE model.

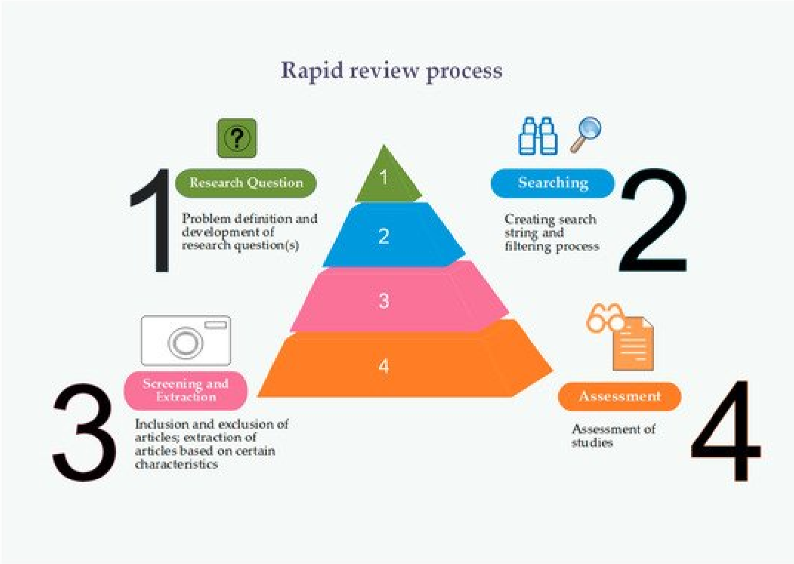

Figure 1. Rapid review process diagram.

3. Energy Storage for Community Microgrids

A community microgrid configuration necessitates the adoption of ESSs as this offers various benefits. From a technical perspective, load demand aggregation generates fewer spikes in load profile in comparison with an individual house, which reduces the battery discharge rate and also decreases the optimum battery capacity. Most importantly, energy storage becomes crucial when the primary source of power is from DRESs, and therefore, to cover the rest of the night demand, more storage is needed if grid consumption is to be avoided [12]. In the case of off-grid CCMs, this implies a large amount of storage. ESSs can address the issue of intermittent generation; hence, efficient storage is still a significant challenge for future microgrids.

The adoption of CES provides power quality, stability to the grid, voltage control, peak demand management and demand load management. From a socio-economic point of view, and along with distributed wind and solar power resources, CES addresses issues of energy efficiency, affordability and mitigation of GHG emissions linked to individual households and communities [13]. Further, utility companies can optimise CES systems for the benefits of the electricity network and wholesale electricity markets. However, the existing CES models (through battery) are costly. CES can open new approaches for energy transition as the community scale introduces electrochemical technologies such as batteries and can increase the awareness of users and communities regarding energy usage and environment.

Several energy storage technologies are discussed by the selected reviews. Conventional lead–acid batteries are the most widely available storage in the market and mainly used in automotive applications and in uninterrupted power supplies for residential and commercial purposes [14][13][15][16]. The major benefits of lead–acid are low cost, high efficiency (70–80%) and long lifetime (5–10 years). However, cycle-lifespan is short (i.e., 500–2000 cycles), which limits the charging capability and provides poor temperature handling [13][15].

Lithium-ion (Li-ion) technology is by far the most rapidly growing and adoptable technology for stationary applications [15][17][16]. The success factors are high efficiency (90–95%), high energy density (75–200 Wh/kg), long life and operating cycles, low maintenance, high power capability and better temperature management (−25 °C to 55 °C) [14][18][15][17][16]. The most common identified downside of Li-ion technology is high cost [13][18]; however, this is estimated to drop within next decade in line with massive manufacturing. Similarly, flow batteries are used in high-power, large-scale commercial-based systems and offer better efficiency (80–85%) [13].

Thermal storage systems offer efficient storage with 30–60% efficiency, better energy density (80–250 Wh/kg) and low energy consumption and GHG emissions [19][14][13][18][15][16]. Thermochemical heat storage systems have high energy density with minimal loss; however, thermochemical materials incorporated in storage systems for buildings have the drawback of high cost, unsuitable temperature and discharge power [19][15][16].

Hydrogen is also considered a promising technology for mid- to long-term storage because of its high specific energy density (33kWh/kg) and energy and power ratings [13]. The process usually involves converting surplus electricity into hydrogen and oxygen through electrolysis; hydrogen can then be used to charge fuel cells. Higher costs of electrolysers and supporting material are disadvantages of this technology [13][20][16]. Moreover, water needed, and logistics costs make it an expensive investment. For short-term standby applications, flywheels are also considered promising [15]; these can stabilise intermittent generation from solar and wind.

Further storage technologies such as compressed air energy storage and pumped hydro storage, regardless of their poor efficiency, carry high capacities with longer lifespans [14][15][16]. Superconducting magnetic energy storage yields high efficiency; however, it is still in the demonstration and testing phase [14].

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