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An Investigation into Energy Communities

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***Abstract*: This research presents an economic evaluation for determining the ideal size of a battery energy storage system (BESS) for usage in an energy community. It is based on data from UK based communities, the research tries to establish the appropriate size for the BESS to manage the community's power cost and increase PV self-consumption within the community. A research is conducted, taking into account the Economy 7 and Tide Tariff systems, and evaluating the financial benefit if community BESS is used.**

***Keywords*: Energy communities, battery energy storage system, tariff, consumption, PV, generation, consumption profile, battery sizing, economy 7, TIDE tariff.**

1. Introduction

The world is gradually shifting towards low carbon economy which focuses on net zero carbon emissions in the near future. The major sources of energy used to date are known to be fossil fuels, which are non-renewable and finite in quantity, hence will be exhausted eventually in the near future [1]. Alongside that, fossil fuels are considered as one of the major contributors to the greenhouse gas (GHG) emissions, which are the primary contributor to pollution and global warming.

As the population increases, humankind is technologically transitioning, which is projected to make the world more connected, intelligent, efficient, dependable, and sustainable, which in turn increases electricity requirements [2]. With the increase in electrical requirement, more fossil fuel is required, which in turn increases carbon emissions and global warming. In order to curtail this, in 2015, the Paris Agreement was signed, where countries agreed to make plans to limit their emissions of GHG. This agreement explicitly states that a rise in 2°C is the limit for global warming, but 1.5°C is a more desired objective since it minimises the likelihood of the worst climate change outcomes, like extreme heat waves, droughts, water stress, and extreme weather conditions, across the majority of the earth. Therefore, according to its most recent report in 2018, the Intergovernmental Panel on Climate Change (IPCC) now cites 1.5°C as the target rather than 2°C. [3], [32].

Renewable energy has various benefits: they are less expensive, plentiful, have good economic performance, have lesser carbon footprints and are readily available [4]. However, they are costly in terms of initial investment is concerned, but presently due to increase in generation quantity, renewable energy's cost has dropped dramatically in recent decades, making it a more affordable alternative for additional capacity practically everywhere on the planet. According to 2019 research from the International Renewable Energy Agency (IRENA), between 2010 and 2019, the Levelized cost of electricity (LCOE) for solar photovoltaic panels decreased by roughly 82%. Solar power costs continued to decline in 2019, because of reduced equipment and balance-of-plant expenses. Utility-scale solar PV electricity costs fell 13% year over year in 2019, to USD 0.068 per kilowatt-hour (kWh). Despite the COVID-19 pandemic, renewable energy generation has increased in 2020. However, new capacity additions in 2020 is lower than the previous high-water mark. Nonetheless, when governments and communities consider economic stimulus choices, renewables continually rising competitiveness, as well as their modularity, fast scalability, and potential for job creation, make them very appealing. Importantly, increasing renewable energy investment can help to integrate short-term recovery efforts with medium- and long-term energy and climate sustainability goals [5].

If the UK is to meet its climate and energy objectives, renewable power would need to expand considerably by 2025, from 41% to 60% of the UK's energy supply [7]. In the UK, energy communities are becoming increasingly popular. They are essentially "community-led renewable energy, energy demand reduction, and energy supply initiatives," which are either wholly owned or controlled by communities, or are managed by communities in collaboration with commercial or public sector partners [9]. Members of energy communities are encouraged to self-produce the energy they use by installing solar PV panels on their own rooftops. As a result, each kilowatt-hour (kWh) of energy consumed does not require production or transmission across the grid, nor does it necessitate purchase from energy merchants. It also entails lower tax rates and network charges, as well as a lower reliance on the grid [13].

Customers gain from community energy, which enables people to participate in democratic climate action by understanding, generating, owning, consuming, and saving energy. It focuses on empowering, transparent, and egalitarian energy systems through explicit accountability and participatory governance. Energy communities are primarily concerned with transitioning to a carbon-free energy system while also enhancing community resilience [9]. Therefore, building energy communities are beneficial. The energy communities have Battery Energy Storage System (BESS), which are beneficial for storing any surplus generation

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throughout the day, so as to increase grid independency.

BESS is widely regarded as a useful strategy for addressing overvoltage issues, meeting load demand, improving power quality, and regulating power grids [22], [23]. BESS has both load and power resource properties. It has the potential to smooth and stabilise the output of PV systems, peak load shifting, operational reserve, and scheduling flexibility of PV-MG due to its variable charge and discharge characteristics. As a result, appropriate BESS size with an acceptable volume may considerably increase PV system efficiency and boost local PV consumption rate [23], [24]. There are several techniques to optimising BESS size in the literature.

According to [22], the study provides a BESS and SI size optimization approach that incorporates the schedule optimization method of linked facilities including BESS, PV system SI, and on-load tap changer (OLTC). Various power rates are also compared to discuss the effects of BESS investment. Due to the complexity and dimensions of the suggested dual-loop optimization structure, unique electrons drifting algorithm (e-DA) is presented to overcome the problem and improve overall performance. The suggested strategy incentivizes PV system owners to invest in BESS voluntarily, that not only increases their earnings but also aids DSO in improving distribution networks [22]. A convex programming framework for optimising battery size in a smart house with a BESS and PV system was described in [26]. Home energy management systems (HEMSs) were articulated as a mixed-integer nonlinear programming framework in [27] and [28] to optimise the BESS size and operating strategy in a smart house. Reference [29] developed a mixed-integer linear programming framework for scaling additional distributed generation and energy storage devices in a smart house under demand response while accounting for seasonal load and PV generation trends. An integer programming framework was proposed in [30] for calculating the necessary amount of PV modules and battery capacity for stand-alone PV systems in residential buildings. The focus of [25] will be on how electricity pricing dynamics influence the appropriate size of renewable energy production systems and BESS in households. This paper focuses on determining the best battery size by considering PV panel orientations on rooftops of houses, as well as the various tariff rates used by consumers, in order to find the best suited battery sizing, which reduces grid dependency while also lowering the import and export tariff of the generated energy. This method is useful for selecting the ideal PV panel orientation, which helps generate excess electricity during the restricted daylight hours. Comparisons of alternative tariff rates can assist customers in determining the optimum tariff structure for them and how it will benefit them.

The household PV and solar farms are connected at the distribution level and there are notable arguments that it is better to connect the energy storage nearby to the energy communities. Since renewable resources are distributed in nature and often not close to the demand sites, therefore there is more reliance on long transmission lines to get power from where it is created to where it is needed the most [7], which in turn increases the I^2R loss in the transmission system. This in turn increases the energy cost in the system [8]. Alongside this, transmission lines become "congested" at times of peak demand or generation, implying that sending more power through the line would cut customer bills, but the line is unable to do so owing to technological constraints. Scaling renewables to the levels necessary to satisfy the UK's climate ambitions might cause significant grid congestion unless further investments are made to maintain the infrastructure. Indeed, bottlenecks in just one part of the UK grid may result in up to 14.8 terawatt-hours (TWh) of renewable energy being curtailed each year, losing about 20% of the energy [7].

The fundamental problem in integrating renewable sources, such as solar into large scale energy systems, is the intermittent nature of their output and it does not match demand profile. As a result, it is critical to plan for appropriate storage devices to store surplus generated power in order to ensure that the generation matches demand at all times, and maintain an uninterrupted power supply to consumers. Energy storage systems (ESSs) are critical for the smart community's energy management system [11]. To reduce the energy tariff, microgrid with BESS can be implemented by the local communities along with the distributed renewable energy systems. Additionally, communities aid in the creation of local markets, which are aided by Time of Use (ToU) Tariffs, which allow local "prosumers" to meet their consumption demands by installing energy storages rather than from the national grid. In ToU, customers are encouraged to utilize energy at off-peak periods via ToU pricing. When demand and energy prices are at their lowest, the ToU flexible tariff provides individuals discounted power bills. The smart meter in a home monitors the costs, and this information may be used to shift some forms of energy usage to less expensive times of day, avoiding high peak rates. It's a situation where everyone benefits. Off-peak pricing allows energy firms to better control demand while also helping customers save money [31]. As a result, customers become less reliant on the grid, and the cost of energy export decreases [10].

The micro-storage systems, which are shared by multiple households in a neighborhood, allow users to retain a small quantity of energy on hand to cover demand spikes and smooth out the fluctuation of their own renewable energy source [12]. The proper sizing of the storage device is crucial to achieving a balance between the initial and operational expenses of the battery, as well as the power import and export costs when utilizing the battery. Residential applicants can now participate in rescheduling their loads, lowering the expenses connected with it. A smart grid framework that incorporates effective demand-side management (DSM) and flexible operation of energy efficient controlled appliances requires an efficient energy management strategy [15]. Due to recent changes such as deregulation of electricity markets, distributed generation, accommodation of intermittent renewable energy sources, DSM, and increased usage and pricing, traditional electrical networks are experiencing various issues [16], [17]. Smart metering, real-time pricing, DSM, and enforcing additional demands are some of the fundamental elements of smart grid technology, which may help increase the capacity and efficiency of current electric power networks [18], [19]. Peak shaving is the process of smoothing out peaks in power use. Typically, the solution is viewed as a technique to influence electricity purchase costs. Electricity rates for industrial and commercial customers are generally determined by the claimed maximum peak-load. Reduced power consumption, on the other hand, benefits not just an organization or institution from an economic standpoint, but also the National Power System's functioning in terms of grid stability during peak hours [6]. Grid power peaks and grid-imported electricity were reduced thanks to a PV and battery control technique. The PV system first supplies the load in self-consumption mode, according to the control strategy. Only the PV surplus is stored in the batteries, which are then drained to satisfy the load. Between BESS and the grid, there are power transfers only during the night time, i.e., the low tariff period [14]. Additionally, constructing an optimized BESS guarantees that generated electricity is not wasted. The major purpose of this research is to obtain an appropriate battery capacity strategy for storing and exploiting surplus energy created by residential PV panels during peak hours, while taking into account the tariff systems, such as Economy 7 and TIDE Tariff structure, utilized in the UK.

This paper aims to develop an energy management system that takes into account the demand and supply sides of a microgrid for domestic residences of the "near future" and use it to figure out how a group of five to ten houses may efficiently operate as an "energy community." The goal of this study is to find the appropriate battery sizing to meet the community's energy demands, as well as how it may be operated to take advantage of local PV power and ToU tariffs.

2. Community Architecture

This paper presents case studies based on localities in the United Kingdom for determining battery capacity and power over a year. This will examine the behavior of an ideal battery in a community over the course of several seasons, and help in determining the best value for battery sizing. The months of January and June are included in the analysis since they have the lowest and highest daylight time, respectively. The amount of sunshine is important since the PV panels will generate power as long as the sun shines. The generation will be significantly lower during the winter months owing to fewer daylight hours and a colder, cloudier environment, whereas the generation will be significantly greater during the summer months due to more daylight hours and a warmer temperature. This study requires weekly per-minute generating and consumption data.

The case studies shown in this paper are UK based communities comprising of 5 houses and 10 houses versus a single house. The houses have distributed rooftop Photovoltaic (PV) generation and the community can be considered to have a centralized Battery energy storage system (BESS). This centralized BESS is considered to be formed of several household batteries operating together as if they were a single battery. In this case, there is no requirement for land or infrastructure for a single big battery. The PV generation profile is a recorded historical data of PV systems installed in Nottingham, UK, with one-minute sample time obtained from the website pvoutput.org [20]. This is the actual power measured at the generation meter. The consumption profile also recorded with a one-minute sample time and has been obtained from a study based in Milton Keynes, a town in the Midlands of the UK [21]. The communities are assumed to be connected to the main national grid and guarantees a secured supply and a suitable path for excess generation. Isolated microgrids are not considered here. The communities are formed by considering the orientations of the PV systems based on least average difference between the generation and consumption, so that a more appropriate size of battery can be chosen, which in turn reduces the battery installation, operations and maintenance costs. Therefore, a comparison is made accordingly, taking into account a five-house community, a ten-house community, and

Table 1
PV installations based on South and South – East PV orientations

S. No.	Name of PV installation	System size (W)	Orientation	Array tilt (Degree)
1	Wiimad	3952	S	1
2	Matt and lottie's home solar	3840	S	45
3	Pumphollow	4000	S	1
4	Davo- Grantham	3800	SE	32
5	CCCXXIX-eco-eye real time	3920	SE	1

Table 2
PV installations based on East and West PV orientations

S. No.	Name of PV installation	System size (W)	Orientation	Array tilt (degree)
1	The Bowlers	3800	E	30
2	Mason-CB	3600	W	40
3	Straws	4000	E	40
4	Frostys-Pause	7500	E/W	22
5	Ross Fronius Inverter	6600	E/W	1

Table 3
PV installations based on mixed PV generations

S. No.	Name of PV installation	System size (W)	Orientation	Array tilt (Degree)
1	Davo- Grantham	3800	SE	32
2	CCCXXIX-eco-eye real-time	3920	SE	1
3	Mason-CB	3600	W	40
4	Mason-CB	3600	W	40
5	Frostys-Pause	7500	E/W	22

a single residence. The choices of solar panel orientations are based on PV system installations, i.e., on the south and south-east side, east or west side and mixed orientation based on generation potential. PV systems are chosen based on PV orientations to demonstrate a comparison between which orientation is most suited for PV panel installation as well as which orientation helps to minimize import and export tariff rates, decreasing grid reliance. The PV systems are grouped as follows. Table 1, 2 and 3 lists the 3 PV groups, respectively. All the PV systems chosen have no shading.

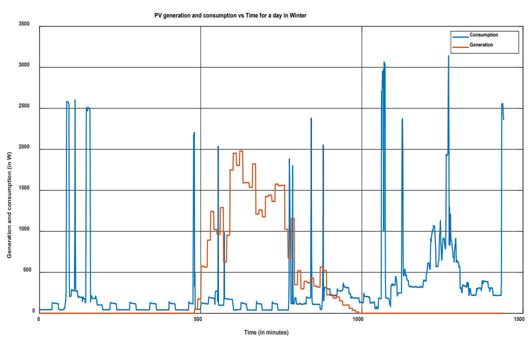

Fig. 1. Load and PV generation vs. Time for a day in winter

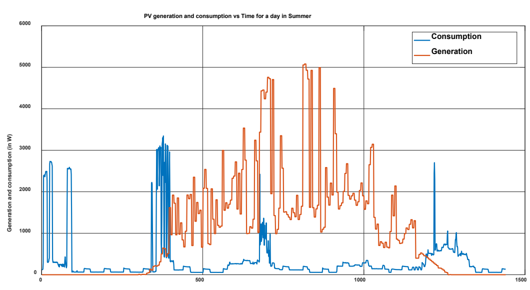

Fig. 2. Load and PV generation vs. Time for a day in summer

From the Fig 1 and 2, we can see the comparison between load and PV generation vs time (for a day consisting of 1440 mins) in the winter and summer month for a typical house in the dataset, and generation from south oriented panels. It can be seen that, the generation (i.e., graph in red) is much lesser, in the average scale of 2 KW during winters, whereas, has a peak of 5 KW during summer months. Along with that, it can be seen that the generation during winter month is spanned over a much shorter interval during the day, than during the summers and therefore has lower generated daily PV energy in winter months. This is because, the UK experiences sunny and longer daylight hours during summers than that of winters. In case for consumption profile (i.e., graph in blue), we can find that the consumption during winter months is much more than during summer months. This may be because of rising utility of home heaters, water geysers etc., is in much more use for the customers.

Figure 3 and 4 shows the performance of a battery, using a TIDE Tariff system during a typical winter and summer day when it is charging, discharging and also the net import and net export during the day. A battery is so designed to minimize the export potential during the day and store any excess generation after feeding the load.

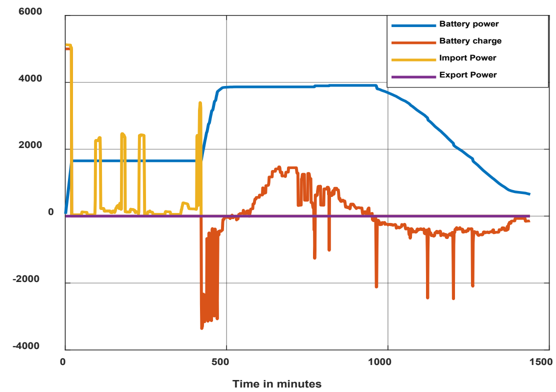

Fig.3. Performance of a battery during a typical winter day in January

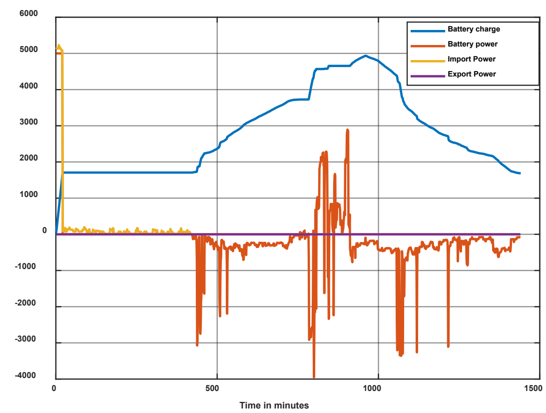

Fig. 4. Performance of a battery during a typical summer day in June

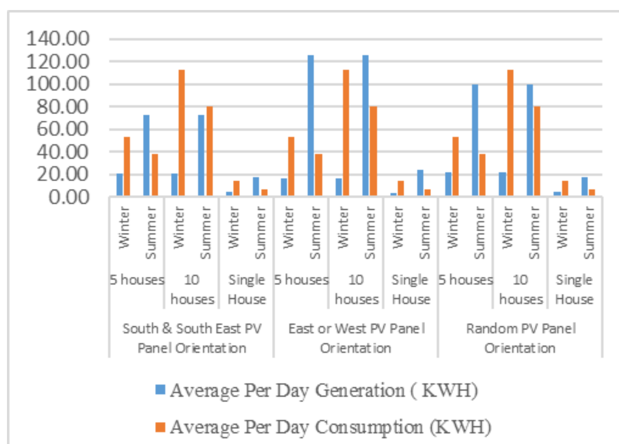

Fig. 5. Weekly average summer and winter energy Generation (kWh) and Consumption (kWh) for 5 Houses, 10 Houses and single House Community from the PV systems installed on various orientations

As mentioned earlier, the communities are grouped, taking five houses and ten houses in consideration. The houses are chosen based on their consumption patterns, so as to tally between the PV generation and the consumption, so that there is less import and export of power. In case for five houses, each house has an installed rooftop PV system, whereas, in case for ten houses, five houses have rooftop PV system installations. This will provide a comparison to determine how smaller number of PV system installations are used, and help to supply uninterrupted power to all its community customers. This will also help to determine the minimum size of the BESS required in order to fulfil all its requirements. The PV systems for the communities are grouped together based on system location. The three usual system orientations include south and south east, east or west and mixed orientations. In the Fig. 5, the y-axis indicates the generation/consumption power in kWh.

From the Figure 5, we can see that the average generation and consumption for the PV panels oriented on the South and South east sides, East or West side of the homes and for mixed orientations, considering communities of 5 houses and 10 houses and individual house, respectively.

The generation is maximum in the east and west residences during the winter months, but it is much lower during the summer months, as seen in Figure 5. During the summer months, south and south-east oriented PV panels create more PV generation, however during the winter months, PV output decreases significantly. As a result, in both circumstances, battery size will be less due to the significant variance in PV generation between the summer and winter months. If the battery size is determined by the winter month, it is too large, but if it is determined by a summer month, it is fairly little. As a result, if the battery size is larger than necessary, extra installation, operation, and maintenance costs would be incurred. Furthermore, if the battery capacity is less than required, there will be less capacity for storing excess PV power during sunny days, resulting in the surplus generation being transmitted to the grid at a significantly lower export tariff, making the system much more grid reliant. As a result, consideration must be given to the PV systems as well as the houses chosen to create a community, so that maximum PV generation is utilized and minimal electricity is exported back to the grid.

The correct sizing of any BESS is a crucial consideration for proper management, usage and storage of PV generation around the year. If islanded operation is not required, then the sizing is compromise between obtaining good system behavior in all different operating conditions, whilst keeping the system capital costs low. The requirements of the BESS are seasonally dependent, for example, the aim in summer is to capture as much PV generation as possible, and use it during peak evening consumption periods. In winters, when there is lower PV generation, the battery is charged more from the grid during the cheaper tariff overnight periods. For the rest of the day, the battery is utilized to meet the consumption of the consumers. In the UK, there is significant variation in PV generation on a daily basis, so the aim of BESS design is to get good performance for each day of the year for a low installation, maintenance and operational costs. The system does not need to be able to capture all generation on the sunniest day or meet all high tariff consumption demands on a cold winter day, it aims for a good average performance which is cost effective. Therefore, a key challenge is to determine the best values of battery power rating used (KW) and battery capacity rating (kWh) of a grid-connected BESS to meet year-round demands.

3. Methodology

The main aim of incorporating BESS into a system, is to reduce the consumption cost for the customers. The ideal way is to capture all the free PV generation throughout the day and utilize it during the peak consumption period. However, it is not always possible. Therefore, the next best objective is to use the battery to "move" cheap electricity to high tariff periods to minimize the electricity drawn from the grid at this time. Initially, per-minute data is obtained from the PV generation and consumption on a daily basis. Then, net import power and net export power are calculated. Power is imported from the grid when the generation is less than the consumption. This commonly happens at night, but it may also happen on overcast, wet days when the sun is not shining brightly. Power is exported back to the grid, when the generation exceeds consumption and battery storage capacity. This mostly happens on sunny days during the summer months. The battery is operated by considering the import and the export power of the battery on a per-minute interval. During the night as there is no PV generation, the consumption is supplied by the main grid. The main grid also charges the battery to its required capacity overnight as the tariff rates are lower at night. The battery is not charged to its maximum capacity overnight, so that it can capture any surplus generation during the day. This is beneficial as the import cost during the day is far greater than during the night, whereas the export rate is much lower. Hence, if there is surplus generation, it is beneficial to store the excess generation in the battery, and minimize any export back to the grid. In this way, the community becomes more independent from the grid. Also, consumers can save money, by maximizing its use of local PV generation and by importing less power overnight to charge the battery to its maximum capacity.

The import tariff rate is usually higher during the daytime, beginning at 7 a.m. Therefore, the BESS controller prevents the battery from charging from the grid, and if appropriate, consumption is met by the battery storage until the battery hits its minimal depth of discharge level (DOD). During the daytime, PV generation is utilized to feed the load, and if there is any surplus generation, the excess is stored in the battery. If there is any surplus, it is exported back to the grid at a tariff rate significantly lower than the import rate. As a result, in ideal conditions, the major goal is to have little to no power exported to the grid. The import tariff rates for TIDE Tariff structure and Economy 7 vary throughout the day, and also has different set of rates for weekdays and weekends, respectively. The tariff rates considered are provided in Table 4.

There are various tariff structures in the UK, and this paper describes the comparison between the Economy – 7 tariff structure and the TIDE Tariff structure. The TIDE Tariff structure is divided into four parts in a day in order to encourage moving the load away from the peak consumption period (i.e., 4 pm to 8 pm). However, the Economy – 7 tariff structure is divided into two parts- daytime and night-time.

The day is divided into two halves under the Economy – 7 tariff structure. The night-time runs from 12 a.m. to 7 a.m., while the daylight runs from 7 a.m. to 12 a.m. Since the import tariff rate is significantly cheaper at night, it is utilized to charge

Table 4
System parameters and Tariff rates

Parameters	Values
DOD (minimum)	1%
DOD (maximum)	100%
ToU during Low peak [33]	4.99 p/min (from 12 am to 7 am)
ToU during TIDE weekday [33]	12.5 p/min (from 7 am to 4 pm)
ToU during High TIDE [33]	24.710 p/min (from 4 pm to 8 pm)
ToU during TIDE weeknight [33]	11.99 p/min (from 8 pm to 12 midnight)
ToU during weekend Low TIDE [33]	3.750 p/min (from 12 am to 7 am)
ToU during weekend whole day [33]	10 p/min (from 7 am to 12 am)
Economy – 7 overnight charges [34]	4.99 p/min (from 12 am to 7 am)
Economy – 7 rest of the day [34]	24.710 p/min (from 7 am to 12 am)

the battery at night. Import electricity from the grid is also utilized to provide any consumption demand in order to keep the systems working smoothly. The peak power for the Economy – 7 tariff ranges from 7 am till the entire day. The battery disconnects from the grid at 7 a.m. PV is used to meet demand during periods when there is sufficient PV generation, such as from 7 a.m. onwards. If there is insufficient generation, the battery is used to serve the load until the lower DOD percentage is reached, after which the remaining power is imported from the grid at a higher tariff rate. During periods when generation exceeds consumption, however, the surplus generation is kept in the BESS after feeding the load. Even if there is still excess generation, it is exported back to the grid at a cheaper cost than the import tariff. Tariffs on import and export are determined using data collected throughout the day.

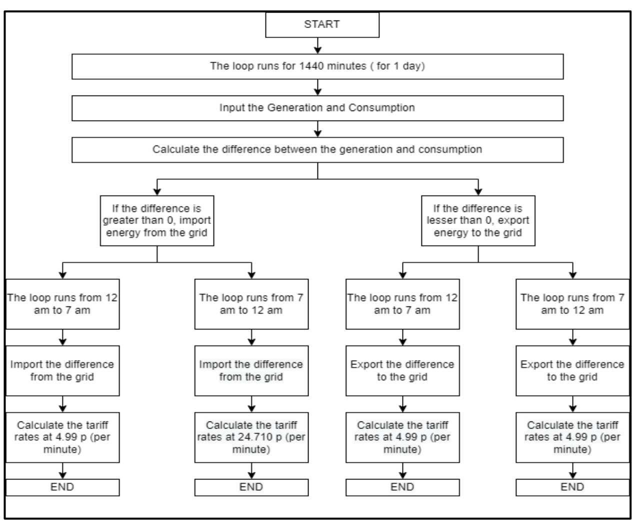

Fig. 6. Algorithm for Economy 7 Tariff model

Figure 6 depicts the Economy – 7 tariff structure, which is also applicable for the TIDE Tariff structure, which is depicted in Figure 7 and 8, respectively.

Since TIDE Tariff structure has four separate tariff rates during weekdays, the For loop runs four times throughout the day, from 12 a.m. to 7 a.m., 7 a.m. to 4 p.m., 4 p.m. to 8 p.m., and 8 p.m. to 12 a.m. The import tariff rate is significantly cheaper at night, it is utilized to charge the battery at night. Import energy from the grid is also utilized to provide any consumption demand in order to keep the systems working smoothly. At 7 am in the morning, the battery charging is disconnected from the grid, as the import tariff rises, and the PV generation is utilized to feed the consumption. If there is insufficient generation, the battery is used to serve the load until the lower DOD percentage is reached, after which the remaining energy is imported from the grid at a higher tariff rate. During periods when generation exceeds consumption, however, the surplus generation is stored in the BESS after feeding the load. Even if there is still excess generation, it is exported back to the grid at a cheaper cost than the import tariff. The export tariff rate remains fixed throughout the day. The peak tariff rate in this case is from 4 pm till 8 pm, where the battery charging from the grid is turned off in order to avoid higher tariff charges. Therefore, the peak load is “shifted” and distributed throughout the day, so that the PV generated power and also the power stored in the battery is sufficient enough to supply the load in peak periods. Costs of import and revenue of export are calculated using data collected throughout the day and the associated tariffs.

However, the TIDE Tariff system, operates the same way as the Economy 7 algorithm, during the weekends. The import tariff rate is different than that of Economy 7 tariff, which is shown in Figure 8.

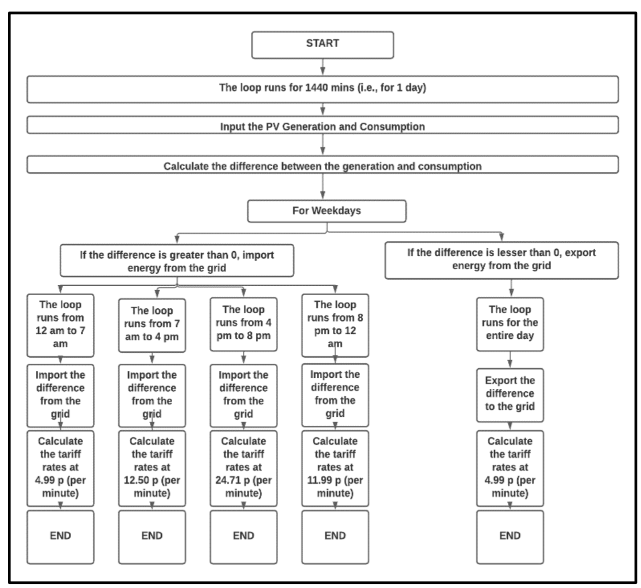

Fig. 7. Algorithm for TIDE Tariff model for weekdays

The PV systems are sized according to the peak consumption pattern of the households considered. Figure 9 and 10, shows the average daily import and export energy for the Economy – 7 (showing the two daily tariff periods) for a single house and communities with 5 and 10 dwellings, respectively, throughout the winter and summer, respectively. The figures show that there is essentially little export during the winter months, while there is a significant amount of export during the summer months. As a result, it's critical to limit export energy during the summer months to avoid wasting locally generated electricity throughout the day. As a result, incorporating a BESS is recommended, which will be able to capture and store surplus generation during the day, therefore supplying for later use. This decreases PV waste, reduces grid reliance, and reduces the requirement to export energy at a considerably reduced price to the grid.

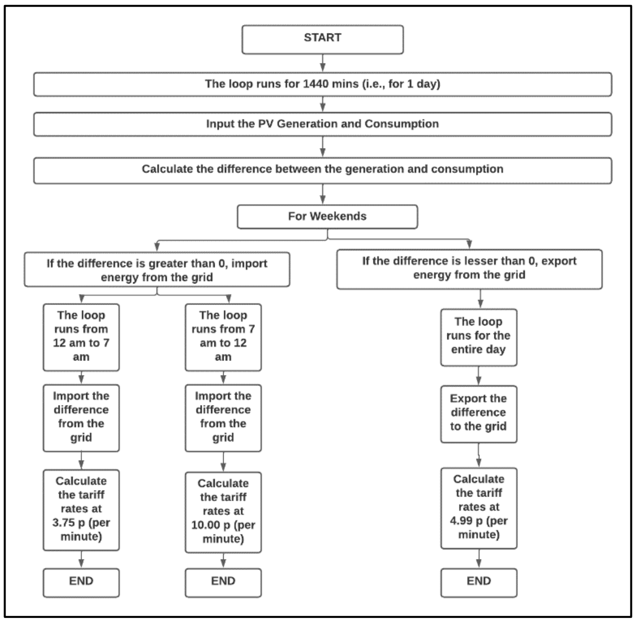

Fig. 8. Algorithm for TIDE Tariff model for weekend*s*

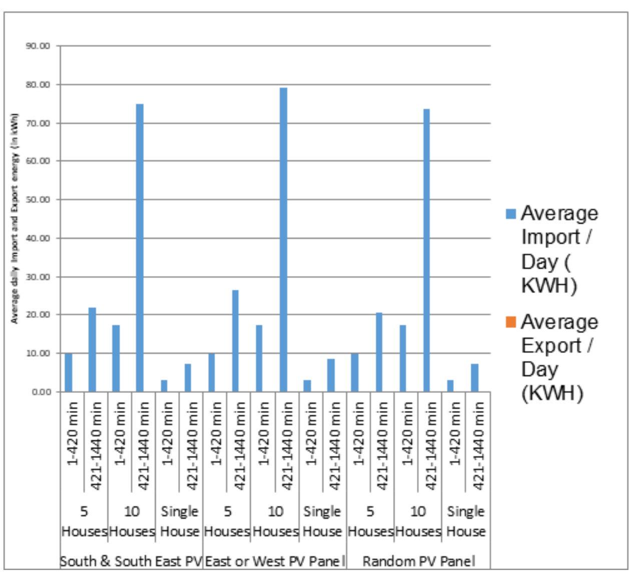

Fig. 9. A graphical representation of Import and Export power statistics for a single house and communities with 5 and 10 dwellings, respectively, throughout the winter

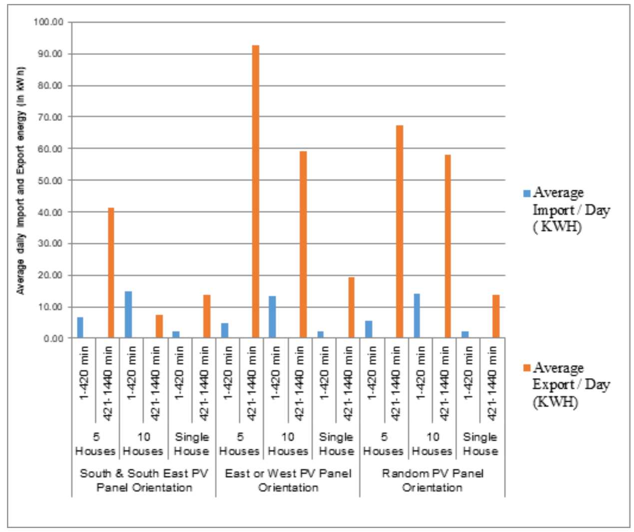

Fig. 10. A graphical representation of Import and Export power statistics for a single house and communities with 5 and 10 dwellings, respectively, throughout the summer

A. *Battery Sizing Methodology*

Battery capacity simply means how much energy can be stored inside a battery pack. The battery capacity is calculated in Kilo-watthour (kWh). The battery capacity is an important parameter, as it will determine whether the stored energy will be sufficient to feed the consumption throughout the day, without having to import any power from the grid from 7 am till midnight for Economy – 7 and from 4 pm to 8 pm (i.e., the peak time) for TIDE Tariff structure. The battery capacity is determined during the winter months by using the formula:

$$X = = \frac{\sum_1^7 Imp_{peak}}{7} \qquad (1)$$

The Imp_{peak} is basically the energy imported during the peak tariff period, $(Energy = \int_{initial\ time}^{final\ time} Power * Time)$ during the day. The Imp_{peak} for each minute is integrated with time to get the energy. For the Economy – 7 tariff system, the Imp_{peak} ranges from 7 am (i.e., 420 mins) to 12 am (i.e., 1440 mins), whereas for TIDE Tariff Structure, the Imp_{peak} ranges from 4 pm (i.e., 960 mins) to 8 pm (1200 mins). Our goal is to identify the proper battery sizing such that there is minimal to no import and negligible export during the day. The Imp_{peak} is considered to be the peak energy during the peak tariff period, and care is taken to shift the peak so that the consumers can benefit from various tariff rates and also there is less pressure on the grid. X is divided by 7, since it offers a mean value for determining an acceptable value for capacity over the week, as there is no set generation owing to the intermittent nature of solar energy.

The battery capacity for the summer months is calculated as:

$$Y = \frac{\sum_1^7 Imp_{peak} - Export}{7} \qquad (2)$$

The Imp_{peak} is the peak import energy during the peak tariff period each day. In the summer, the export power is deducted from overnight charging the battery for two reasons. The daylight hours are longer during the summer months, and the generation is significantly higher due to the warmer climate. As a result, there is a strong likelihood of exporting a big amount of power to the grid at reduced export rates. If the power is not exported back to the grid, it must be stored, which necessitates the use of bigger batteries. Because summer is short in colder countries like the UK, a larger battery merely for the sake of summer is not a viable option, as it may not be utilised to its full capacity the rest of the year. As a result, the battery's installation, operational, and maintenance costs will rise overall. Furthermore, eliminating the surplus export already overnight would aid in saving the import cost for charging the battery to its full capacity, as well as avoiding energy waste and the possibility of selling it back to the grid at a reduced export rate. As a result, the community becomes increasingly independent of the grid and attempts to find the appropriate size for the battery. The appropriate battery size is found by averaging the winter and summer months, because they record the lowest and greatest PV generations throughout the year, indicating that the battery size will be cost efficient and useful. Therefore, it is represented as appropriate battery size.

$$\text{Appropriate battery size} = (X+Y)/2 \tag{3}$$

The battery size is determined by considering the import power and export power of the battery throughout the day.

The number of repetitions of a range of power rating over time determines the battery power (in minutes) and is measured in KW or W. That is, the battery is most frequently used between 7 a.m. and midnight; so, the power range in which the battery is most frequently used can be designated as the cut-off point. The more instances are counted, and the power is assumed to be that value. In January, the power rating varies from 2.5 KW to 3 KW, while in June, the power rating ranges from 4.5 KW to 5 KW. A battery power of 5 KW is employed in the simulations.

Therefore, a BESS is incorporated to the community. Table 5, provides the battery capacity (kWh) required to minimize the export power and export cost during the summer months, in turn reducing the grid reliance. The values obtained are calculated using the Equation 1, 2 and 3 respectively.

From the above Table 5, it was observed that when the PV panels are placed on south and south-east orientation, the requirement of battery capacity per building is lower than any other type of orientation of PV panels as per Economy - 7 tariff system. Moreover, if we compare both the community along with an individual house the percentage saving in the battery capacity in case of 10 house community reduces by around 28% and 56%.

In Table 6, the optimum battery capacity calculated by using the Tide tariff system is shown. The import rate is highest during 4 pm to 8 pm. The excess generation during the peak period (from 4 pm to 8 pm) is not considered during summer and it is exported to reduce battery size and balance the generation and consumption quantity. Therefore, care has to be taken to not import any energy from the grid to supply the consumption and the battery and the entire excess generation is exported back to the grid without storing it in the battery. Thus, it can be observed that the not only the battery capacity is reduced from around 8% to 18% depending upon the generation capacity based on PV orientation but also the consumers in the community can earn the export revenue.

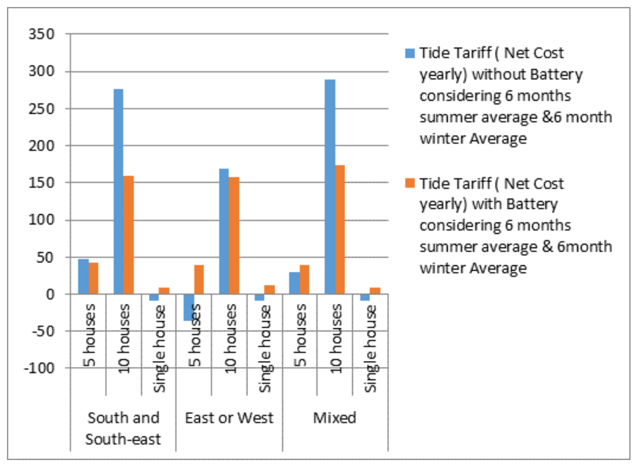

Fig. 11. Graphical representation of Net Yearly Cost per house in GBP for a single house and 5 and 10 house communities with and without a BESS for Tide Tariff System

Figures 11 and 12, demonstrate the annual net energy cost in GBP when using the Economy – 7 and TIDE Tariff systems,

Table 5
Battery capacity (kWh) for 2 communities and a single dwelling, based on the PV systems installed as per Economy 7 Tarff System

No. of Houses	South and South East		East or West		Mixed	
	Total kWh	Per House kWh	Total kWh	Per House kWh	Total kWh	Per House kWh
5	14.15	2.83	28.54	5.70	20.60	4.12
10	20.55	2.05	31.23	3.12	29.36	2.93
1	4.69	4.69	6.45	6.45	4.69	4.69

Table 6
Per House Battery Capacity (kWh) comparisons with Tide Tariff System and Economy 7 considering peak tariff limit

No. of Houses	South and South East			East or West			Mixed		
	Tide tariff system	Economy 7 tariff system	% Reduction in battery size with tide tariff system	Tide tariff system	Economy 7 tariff system	% Reduction in battery size with tide tariff system	Tide tariff system	Economy 7 tariff system	% Reduction in battery size with tide tariff system
5	2.4	2.8	14.8	4.6	5.7	19.3	3.3	4.1	18.9
10	2.1	2	-3.41	2.8	3.1	8.97	2.6	2.9	8.19
1	4.1	4.6	11	5.5	6.4	14.2	4.1	4.9	11.3

respectively, with and without a battery. The annual cost is calculated using the average of six months of summer and winter. This is because the daytime and night- time variations in the UK shift bi-annually, i.e., the UK records lower daytime range from October to March and longer daytime range from April to September. Therefore, it is observed that in case of TIDE Tariff system with BESS, the net cost of the energy reduces significantly in case of larger communities.

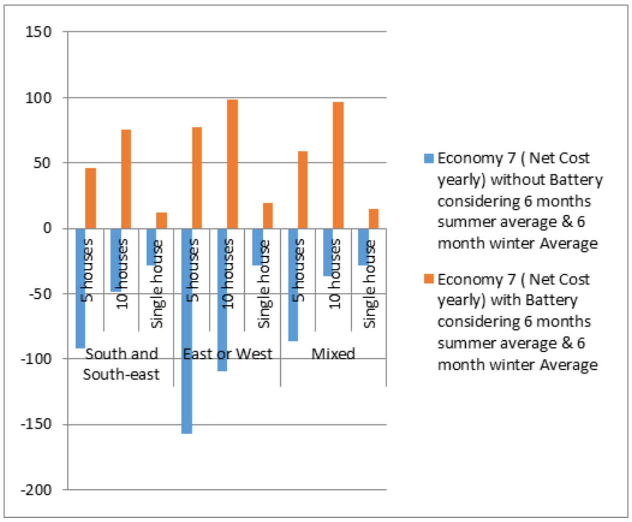

Fig. 12. Graphical representation of Net Yearly Cost per house in GBP for a single house and 5 and 10 communities with and without a BESS for Economy 7 Tariff System

4. Conclusion

This paper demonstrates the methodology for determining the appropriate battery capacity and power for a battery energy storage system (BESS). The comparison of several tariff structures, such as Economy – 7 and TIDE Tariff system is explored in this study.

Figure 1 and 2 depicts a typical PV generation and consumption requirement for a day in winter and summer months. It can be observed that, the PV generation is greater during the summer months, than that of the winter. Along with that, the daylight time is also more during the summer months.

Figure 3 and 4, shows a typical performance of a BESS system, during a day in winter and summer.

In Figure 5, weekly average of PV generation and consumption for summer and winter months are depicted for communities of 5 and 10 houses, as well as a single dwelling. This is compared on the basis of PV panel orientations. It can be observed that the PV panels orientated on the East/West side has the highest generation, followed by south and south east facing PV panels and mixed oriented PV panels. The gap between generation and consumption is least when the PV panels are placed on the based on mixed orientations. This in turn help to determine that mixed orientations are the best possible direction for PV panel orientation. This is because, battery storage system of less capacity is sufficient to store the excess PV generation, which in turn reduces the installation, maintenance and operational costs of the battery over a longer period of time.

In Figure 9 and 10 shows graphical representation of import power and export power of communities comprising of 5 and 10 houses, along with an individual house, for summer and winter month. When PV panels are oriented based on the amount of PV generation, the difference in import and export power is fairly small.

The battery capacity is greatly lowered when PV generation is taken into consideration while orienting PV systems with relation to consumption to minimize net import and export power, as shown in Figures 8 and 9. From Table 5, it is observed that a 10-house neighborhood will require roughly 21 kWh battery capacity, with each home utilizing around 2.1 kWh of battery capacity during the day. When the difference between PV generation and consumption was not effectively managed, the battery capacity was about 31 kWh, and each family required 3.1 kWh battery capacity during the day. As a consequence, it is found that properly situating PV systems leads in a significant reduction in battery capacity, down to around 32%.

Table 5 shows that 14.15 kWh battery is sufficient for a community of five houses, 20.55 kWh is sufficient for a community of ten houses, and 4.69 kWh is necessary for a single residence. For a community of five houses, ten houses, and a single house, we may say that each house requires 2.83 kWh, 2.05 kWh, and 4.69 kWh of battery, respectively. When a community of ten dwellings is compared to a community of five houses and a single household, a reduction of 28% and 56% of total battery capacity is noted, respectively. As a result, we may infer that the more people in a community, the more effective the battery will be. As presented in table V, we can say that battery sizing gets more precise as the gap between import and export power is narrowed by selecting the proper PV panel orientation based on PV generation. The net installation, maintenance, and operational costs are greatly lowered when the battery size is suitable with a larger community.

From Figure 11 and 12 we observed that in case of TIDE Tariff System with a larger community, net yearly cost is reduced with the inclusion of the Battery in the system versus without Battery Energy Storage system (BESS).

We may deduce that in the case of Economy 7, the net cost to the customer is significantly lower than in the case of TIDE Tariff. Since the TIDE tariff is designed by the supply provider to regulate peak load conditions by dispersing net consumption and reducing peak time pressure, users may choose their viable operating times without having to increase installed generation capacity. However, for the beneficiary of the suppliers, the customers are insisted in distributing their load, in turn losing the flexibility of operation as per their needs. On the other hand, in case of Economy 7, the day is divided into two halves, and the supply provider will need to develop a greater capacity producing system to meet peak load circumstances. As a result, the installation and the operational cost of the generating station increases.

Therefore, by adding the BESS in the communities, we can observe that the net cost for TIDE Tariff system has reduced significantly in case of larger community which helps consumers greater choice to meet their needs without much rationing in their requirement. On an above the supply providers can install lower capacity generating stations, which helps both the consumers and the supply providers. Hence, we can infer that by incorporating a Battery energy storage system (BESS) in a larger community is beneficial for both the consumers and the service providers.

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