

Grid-interactive rooftop photovoltaic clusters with third-party ownership

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Abstract

Irrespective of having a variety of policies and competitively lower costs of solar panels, rooftop photovoltaic (PV) systems have not been attractive to the majority of stakeholders because a perfect integration of the technologies and policies is yet to evolve. In this context, the power purchasing agreement (PPA) scheme under third-party ownership is becoming an attractive financing option available for residential PV applications. This paper elaborates on an innovative concept for the development of a centralized unit commitment management system for grid-interactive rooftop PV systems that are integrated with energy storage systems, under a PPA scheme. It is technically feasible to expand the energy storage of distributed PV systems and link together to operate as a cluster, where there is a huge potential in achieving a number of grid supporting operations including peak shaving and load shifting. This paper emphasizes that economic feasibility of the proposed concept depends on the accuracy of demand prediction and smart monitoring of system parameters and thus, an artificial intelligence (AI)-based monitoring approaches, which have a greater potential in real-time handling of operations, are required to achieve the best results. The implementation of this concept will be beneficial for almost all stakeholders involved in the business-as-usual and simultaneously, act as a catalyst in popularizing PV systems in developing countries

Keywords: Battery energy storage, centralized monitoring and unit commitment management, demand prediction, residential solar systems, third party ownership

1. Introduction

Globalization, industrialization, ever-growing population and complexity of living styles are the main contributors to the drastic increase of the global electrical energy demand. The more stringent environmental standards unfolded in the aim of protecting the earth system, the higher rate of depletion of fossil fuels and the demand for energy security, have compelled the world to move towards sustainable solutions, resulting renewable resources to penetrate the energy market. Among the other renewables, PV systems have shown a remarkable presence in global energy generation, accounting for about 55% of the newly installed renewable power capacity in 2017 [1].

In comparison to centralized solar utilities, distributed rooftop PV systems have the advantage of minimized distribution loss in transmission and distribution lines. Moreover, it has become a perfect application on rooftops because of silent technology, non-moving parts in the system and efficient space management. One of the key parameters for promoting rooftop PVs, especially in the residential sector, is allowing consumers to sell their excess generation after self-consumption, which has become comparatively more popular in most of the developed economies. However, roadblocks for the popularity of solar still exists. These include; uncertainty in markets due to inconsistent policies, prolonged and restrictive permitting processes, grid integration issues, potential grid instability due to the intermittent

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nature of solar irradiation, comparatively higher upfront costs of solar technologies, unaffordable funding schemes and inadequacy of skilled labor in most of the developing economies.

Therefore, it is crucial that an innovative scheme integrated with the advancements of technology be made available for rooftop PV systems to increase their share in the energy market. According to the 2018 REN21 global status report, with the fast evolution in the renewable technologies and the market maturity, the challenge of integrating variable renewable energies into power systems have been thought of, and thus, existing policies require necessary amendments. Furthermore, in order to get the maximum share of renewables in the energy market, modifications into the policies, standards, and mechanisms are required without compromising the reliability and the energy security. In this backdrop, this paper discusses the concept of developing a centralized unit commitment and management system for rooftop PV systems that are integrated with energy storage systems, under a PPA scheme.

The remainder of the paper is organized as follows: Section 2 reviews and assesses the existing policies for residential PVs. Based on this assessment, the techno-economic potential of PPA for grid support is analyzed in section 3, followed by a study into the emerging advanced technologies for demand monitoring and prediction for optimum battery usage in section 4. Finally, the key findings of the study are summarized and highlighted in the last section.

2. Residential Solar Schemes

Supporting policies for renewables have always been instrumental in increasing the market share of renewables as they act as boosters to overcome institutional, technical and economic barriers. In an analysis carried out in India, the prevailing bottlenecks for solar energy projects, namely; high-interest rates, investment barriers, financial issues of distribution companies and lack of access to long-term debt financing have been discussed [2]. Financing becomes even more demanding due to the higher upfront capital investment for solar-based technologies irrespective of the drastic reductions in the cost of PV panels. Furthermore, it highlights the impacts caused by the cost, tenor and the nature of debts over the levelized cost of electricity (LCOE), and therefore, on the necessity of innovative financial instruments and policies to support rooftop PVs. There is an extensive literature available on off-grid and grid-tied rooftop PVs covering a vast area including optimization, implementation, and policies in different regions of the world. Emerging policies such as virtual net energy metering (NEM) are expected to attract more stakeholders in solar-based electricity generation, as it is possible to claim NEM to identify the most attractive choice, which caters the requirements of the conceptual design.

2.1. Feed in Tariff (FiT)

Feed-in Tariff (FiT), is a policy instrument, which has a purchase obligation, where a grid operator purchases electricity produced from the solar PV and the producer is guaranteed to get back a fixed unit rate over a long period of time, usually 15 to 20 years. FiTs, as shown in Figure 1 (a), are well known for their successful implementation in a variety of renewable sources such as wind, biomass and solar, and have become the popular policy in many countries including Japan [3], Europe [4], [5], China [6], Thailand [7] and New Zealand [8]. However, FiTs often demand regular revisions, and thus, highly depend on strong renewable energy policy, as well as high-level of government support, leading to investor diffidence.

2.2. Net Energy Metering (NEM)

NEM allows the utility customers to offset the electricity consumption over the self-generated electricity. Under NEM, as illustrated by Figure 1 (b), if the energy generation is higher than the consumption, provision is given to have energy credits in the account of the customer towards the next billing cycle. The time of use (TOU) metering and market rate metering are two types of NEMs available. The NEM of TOU consists of a reversible smart meter, which determines the electricity consumption throughout the day. It allows the charges and utility rates to be assessed based on the time because peak

and off-peak hours are specified. For a PV system, TOU metering is more important since it produces power during the daytime.

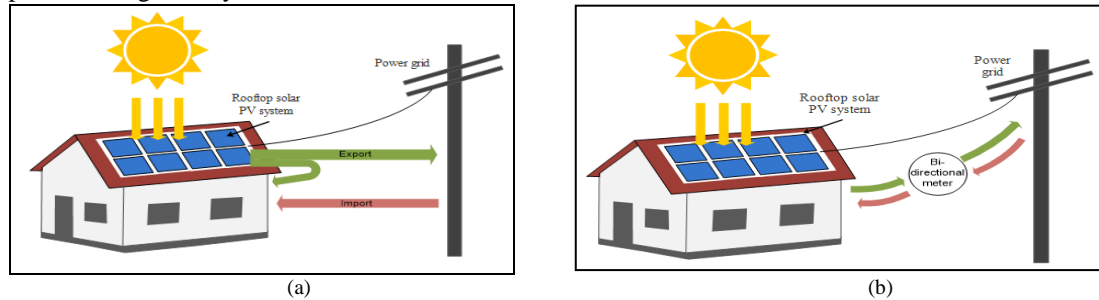


Fig. 1. Main residential solar schemes: (a) FiT scheme and (b) NEM scheme.

A comparative analysis in [9] has shown that NEM performs better than FiT for the residential applications, in terms of energy policy since green tax reduction is expected, as well as for the household owners due to a significant reduction in their final bills. However, inappropriate design and implementation issues with respect to NEM have found to be the reasons for its lower popularity in the applications of residential rooftop PVs, which will lower the public support for the technology. Furthermore, the public utility commissions have identified a regulatory issue in NEM, because when a customer sells surplus electricity back to the utility at the existing retail rate, it provides a subsidy for the residential solar installations, whereas this subsidy is paid for by all ratepayers. Furthermore, the study has revealed that, although the investors will have adequate incentives in residential PV to continue in the NEM scheme if overage electricity is credited at a rate equal or above the LECO, there will be a substantial reduction in the profitability of these investments [10]. A study carried out in California has found that the NEM policy has minor impacts on future PV adoption if the impacts of the TOU rate are assumed to be cost-neutral [11]. This is because, California has imposed a low non-refundable charge, which is comparatively less than the high retail rates. Furthermore, this study has suggested the requirement of modelling methods, with a detailed sensitivity analysis to derive more robust forecasts.

2.3. Investment Tax Credits (ITC)

ITC scheme supports solar technology deployment, which has been a substantial boost in the field. ITCs reduce the tax liability for solar project owners based on the capital investment of the project. However, since there is no maximum incentive that can be claimed for solar energy projects under ITC, the owners must maintain a mandatory project ownership period, irrespective of their discretion [12].

2.4. Value of Solar (VOS)

VOS tariff is another policy for the purchase of distributed PVs. It aims to pay off the disparities between the real value of solar that has been taken up by the utility. If the LCOE is lower than the retail electricity rate, rooftop PVs become economical to the customers. Gradually, when the cost of rooftop PV systems continues to reduce, solar generation becomes highly cost-competitive against the retail electricity rates because the incentives for solar also will be phased out with time. On this backdrop, VOS appears to be an effective scheme since the VOS rate is calculated based on the benefits and costs imposed on the solar provider. However, the benefits will be once again limited since the TOU has not been taken into consideration, and it follows the 'buy-all sell-all' concept, where the customer purchases the electricity demand at the retail rate and sells all solar generation to the utility at the VOS rate [13].

2.5. Third Party Ownership (TPO)

There are two major business models of distributed rooftop PVs; namely, customer-owned and third-party ownership (TPO). Incentives are available for households to install residential rooftop PV in many countries. However, under the customer-owned business model, owners make a huge upfront investment

initially, with the risk of knowing that there are variable and uncertain returns.

Irrespective of many policies in existence, market penetration in rooftop PVs on residential applications were not much popular prior to the emergence of TPO into the industry, approximately a decade ago in developed countries. Under TPO, homeowners benefit because of avoiding the high upfront costs and distributing this cost over a long period, typically 15-20 years, instead. There are two popular such schemes; namely, solar leasing and PPA. Figure 2 (a) and (b) depict the involvement of main stakeholders in these TPO schemes.

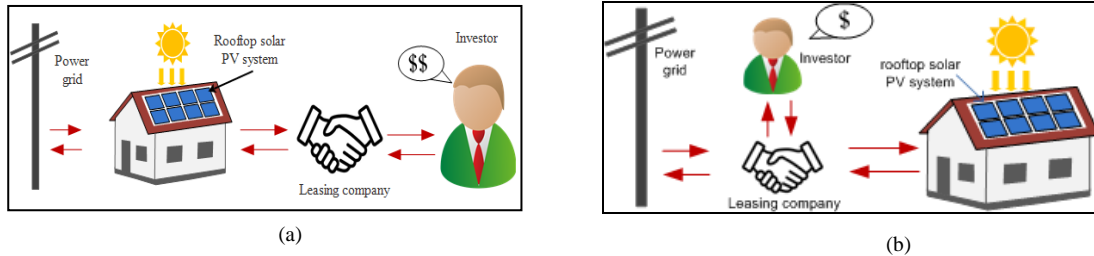


Fig. 2. Involvement of main stakeholders in TPO: (a) Solar leasing and (b) Power purchasing agreements.

2.5.1. Solar leasing

Under the solar-leasing mechanism, the owner of a household enters into a contract with a company (the lessor) of a PV system to install a rooftop PV system and agree to pay scheduled, pre-determined installments at a flat rate to the lessor. The homeowner, whilst consuming generated solar power, gets renewable energy certificates (RECs) for the excess electricity that is supplied to the grid. Similar to all other leases, homeowner pays retail utility rate if consumption exceeds the generation. Whilst breaking the barrier of high upfront costs, solar leasing also relieves the household from the operation and maintenance, because it becomes the responsibility of the lessor. In most of the cases, neither the households are capable to pay for high upfront costs nor do they become eligible to apply for a loan, where solar lease might be the financing choice. There are two main types of solar leasing based on the type of payment; namely, fixed or adjustable. Homeowners mostly get overall bill savings, whereas the tax benefits and rebates will be received by the lessor, which is a ‘win-win case’ for both parties.

2.5.2. Power Purchasing Agreements (PPAs)

Under this mechanism, solar finance company purchases, installs and maintains a PV system on a resident’s roof. Homeowner purchases solar power at a fixed per-kilowatt-hour rate, which is competitively attractive than utility electricity rates. Similar to solar leasing, this also avoids high upfront costs, operation, and maintenance burden and permitting and interconnection delays. The disparities in the leased and purchased price of solar also have disappeared over the years, mostly influenced by increased market competition among leasing companies [14].

A report prepared by the National Renewable Energy Laboratory (NREL) has earmarked solar lease option for residential PV systems as the most attractive financial structure amongst other available sources of financing [15]. This study has compared three alternative financial schemes; namely, cash purchase, home equity loan and solar lease program (both running for 15 and 20 years), for residential PV systems have been compared (while keeping all other system parameters such as the maintenance expenses, cost, and frequency of inverter replacement, retail electricity savings and revenue from selling solar RECs constant) under a solar leasing program in US, named ‘Connecticut’. The LCOE is calculated by dividing the total expenses (i.e., the cost of the system, its maintenance, REC revenue, tax credits, and cash flows) from the total kWh production over the period. ‘Implied net price of electricity’ represents the retail utility bill savings owing to self-generation. Derived results depicted in Table 1 and show that the solar lease is the cheapest and the most attractive financing option available for residential solar applications.

Another study reveals the financial attractiveness of solar leasing and PPA for rapid deployment of

distributed PVs in developing countries, whilst identifying the solutions for unaffordability of high upfront costs through the availability of abundant solar irradiance in most of the developing countries [17]. A study in Thailand has compared business models of solar PPA and solar leasing, in the aim of accelerating adoption of rooftop PVs, and also has analyzed the drivers, barriers, and risks in different perspectives [18]. Issues in existing energy policies for the slow growth of distributed PVs have been identified by a study carried out in China and has suggested employing policies such as TPO to attract investors in the business [19]. Another study has revealed the necessity of having innovative business models and financing mechanisms including solar leasing in China's energy policy as an important driver and discusses the importance of addressing challenges exist in China for implementation [20]. Through a scrutiny done on the existing barriers that restrict PV systems, a study has attempted to develop community shared business model and insists the necessity of national level identification and addressing them separately, even for the TPO mechanisms [21].

Table 1. Electricity prices with different types of financing (in \$) [16].

Type of financing	LCOE in 2008 [\$ / kWh]	Implied net price of electricity in 2008 [\$ / kWh]	Upfront payment [\$]	Monthly load/lease payment [\$]	LCOE in 2008 [\$ / kWh]	Implied net price of electricity in 2008 [\$ / kWh]	Upfront payment [\$]	Monthly loan/lease payment for years 1-15 [\$]	Monthly loan/lease payment for years 16-20 [\$]
Period	15 years				20 years				
Cash	0.30	0.18	19,500	0	0.32	0.17	19,500	0	0
Loan	0.22	0.093	195	190	0.22	0.073	195	190	0
Solar leasing	0.20	0.072	0	97	0.20	0.055	0	97	29

3. Techno-economic Potential of the PPA Scheme for Grid Support

The cost-competitiveness of PV with the anticipated changes in energy policies and technological boosts imply a higher market share of solar in the energy sector in the near future. However, due to the over-generation in high insolation periods, if solar power dominates in the total energy mix, it would result in unfavorable condition between the existing TOU prices and the pattern of solar power generation. With this backdrop, the application of battery energy storages with rooftop PVs becomes essential to store the unused energy. Nevertheless, with the current technology, distributed rooftop PVs and battery storage systems will operate as individual units. If they are linked together to operate as a cluster, there is a huge potential in achieving a number of grid supporting operations including peak shaving and load shifting, which is not possible with individual systems.

Apart from that, [22] reveals that PPAs give provision for the developers to sign a long-term agreement with special tariffs, which provides a considerable incentive for the developers. However, it is an intense load for the power distribution companies. In most of the cases, they are bound to purchase power from the developer at the FiT rate and sell it at a lesser rate. However, this study further highlights that most of the distribution companies have failed in meeting the targets; thus, losing an opportunity to attract investors in the renewable energy sector, specifically in terms of solar energy. Therefore, the application of battery storage systems with rooftop PVs creates a unique cluster that can become an attractive answer to the existing issues.

The literature on integrating battery storage with residential PVs under different policies have different focuses. Techno-economic analysis on integrating battery storage with residential PV that are supported by FiT revealed no added benefits in the UK [23]. A study in Oman highlights that due to the extensive government subsidy, the electricity price in Oman is extremely low and the benefits envisaged from PV investment are hardly enough to outweigh the costs, making a huge challenge for Oman to shift towards renewables. Thus, renewable energy policies must be incorporated in aiming at successful implementation [24]. Three selling scenarios (NEM, wholesale pricing, and no payback) for excess PV energy have been analyzed under a situation where the LCOE is considerably higher than retail electricity

rates, and the results yield the addition of energy storage beneficial only with no payback policy. Apart from that, the study also has assessed the impacts of excess PV generation on a distribution system, because there might be phase voltages and the nominal voltage rises causing instability of the distribution system [25]. The mitigation to this can solely be achieved through the integration of battery energy storages with the PV systems.

Stability of the grid should not be compromised while adding up renewable energy sources. Integration of battery storage in PV systems is quite common in the grid-connected PV systems. Various studies have been carried out in aspects of battery control, management and prediction for optimal battery usage, related to grid-connected PV systems. An algorithmic approach followed by one study has resulted in optimal forward trading and battery storage management plan having detailed and strategic optimization feasibility [26]. The use of a distributed storage system to mitigate the voltage swell in rooftop PVs has studied [27] where the surplus power is utilized to charge the energy storage. This system uses an intelligent control strategy for charge/discharge operations to make an effective use of battery capacity. Another study into the residential PV battery system has concluded that PV system and battery size are crucial factors affecting the self-consumption rate and the degree of self-sufficiency [28]. A typical rule-based battery energy management system is shown in Figure 3, which has been proposed by [29] to control the state-of-charge dynamically for the protection of the battery and extend the life span.

With the use of a stackable battery design, multiple batteries can be connected to the rooftop PV systems to supply additional capacity. For the optimized usage, the condition of the batteries is to be monitored, including its voltage, state of charge and number of charge/discharge cycles, which gives an indication of the amount of energy stored in the battery and its health. Based on this information, the solar developer can decide on the amount of energy it can safely deliver to the grid.

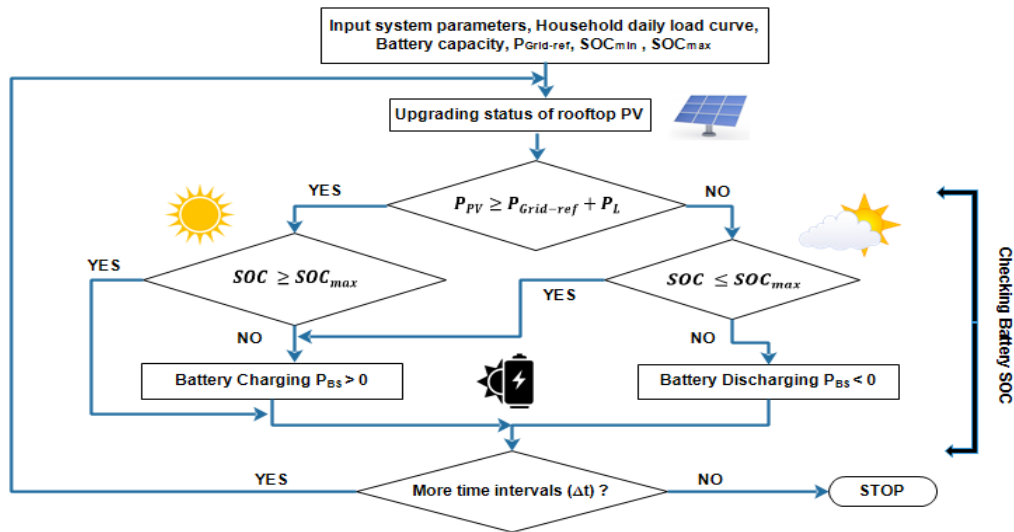


Fig. 3. Flowchart showing a typical battery energy management system.

4. Demand Monitoring and Prediction for Optimal Battery Usage

Drastic changes anticipated in grid-connected rooftop PV systems demand their integrating capability considering the uncertainties and fluctuations of power output. In order to optimize the planning and modelling of PV systems, reliable forecasting is essential, on which the designers and operators manage the demand and supply. Furthermore, accessing real electricity utilization data and the load profiles of major energy consuming appliances in the residential sector is no more challenging with the advancements of communication technologies and the availability of smart load monitoring devices. Electricity consumption and net load monitoring have been key factors in various studies carried out in the past because the integration of smart monitoring and control systems into households provides real-

time energy consumption feedbacks, as well as standby power consumption information.

Wireless communication has appeared in many studies and has resulted in benefiting the operators by using real-time data with respect to the energy demand of households [30]. Behavioral research into consumer energy management has revealed that they manage it best when appliance-by-appliance consumption is provided, whereas smart meters provide the entire consumption only [31]. Therefore, energy disaggregation, a computational technique, is used to solve this issue, which has become an active area of research [32]. Energy disaggregation has been utilized to build a data set in support of researchers who seek access to large data records [33].

Issues in dispatch planning, both day-ahead and real-time operation, have been addressed by a study through the application of a control architecture and a multi-scale hierarchical controller [34]. An optimization-based algorithm has been used in [35] to schedule the battery storage of a residential PV. Another study has used a real-time control strategy based on load forecasting and dynamic programming methods for load shifting of the battery energy storage system [36]. In this system, online regress forecasting has been used to update the predicted load curve. Linear and quadratic program-based algorithms have been utilized to schedule battery storage in residential PV in Australia and have revealed elimination of the reverse power flow under the quadratic program-based battery schedule [37]. Likewise, [38] has assessed the impacts of distributed PVs in smart grids through an integrated real-time platform, which consists of a PV simulator and a real-time distribution network simulator, interconnected over the Internet through a communication software adopter. This integrates the real-sky solar radiation on rooftops, generation, and consumption as well. Another study has focused on minimizing the prediction interval for solar power due to its higher variability and has reduced the prediction interval more than three times by using an improved bootstrap method [39].

A comprehensive analysis of different prediction methods has concluded that AI approaches are widely accepted as the most reliable forecasting method, because they can solve the non-linear and complex structure of data with least error, compared to other statistical methods [40]. In the aim of increasing revenues for all stakeholders in PV business, precise data are important. Use of big data, cloud analytics, and AI techniques in order to get better predictions and real-time management of grid load through PV have now emerged. Integration of distributed PVs into the grid can be achieved through network operators, which produces accurate, as well as updated, data for forecasting. Large scale energy storages allow optimized injection of excess generation into the grid, which becomes beneficial to the lessor in terms of TPO scheme. Predicting optimal sizing and tilting of a hybrid generator system done through AI in India was successful, and the system has been validated for their results [41].

Probabilistic load forecasting has been one of the common tools in the renewable integration projects to forecast electricity consumption through PV systems, which can be used for system planning and operations [42], [43]. These studies have employed dynamic Gaussian process and quantile regression to produce probabilistic forecasts on data. Reinforcement learning, which is an agent-based AI algorithm is used in [44] as a new and effective electricity demand modelling technique, in a vast variety of applications including distributed generation. Agents of this technique learn the optimal set of actions and preferences of the user through their interactions with the environment, and also have proven potential in addressing the complex and real-world applications. Moreover, energy yield prediction has been conducted using machine learning in [45], in which the established mathematical model can predict the output power from the PV panels under varied environmental conditions and cloud covers.

5. Conclusions

The emergence of PPA has created many opportunities in the residential sector as it offers an attractive financial mechanism to have a rooftop PV system, breaking the affordability barriers. Due to the ever-growing expansion of rooftop PV systems, innovative system integration is anticipated to assure the benefits to all stakeholders. PV integration demands a high capability in handling uncertainties and fluctuations of power. Furthermore, when the distributed generation and storage systems are linked together, so as to operate as a cluster, there is a huge potential for achieving a number of grid supporting

operations including peak shaving and load shifting.

Therefore, it is required to develop a centralized management system for rooftop PV systems integrated with battery storage systems, under a PPA scheme. By using a stackable battery design, multiple batteries can be connected to the rooftop PV system to supply additional capacity. For the optimized usage, the condition of the batteries, including voltage, state of charge of the battery and number of charge/discharge cycles are to be monitored closely. This allows the unit commitment, where the solar developer decides on the amount of energy that can be safely delivered to the grid. Moreover, depending on the agreement with the distributor, grid support can also be achieved once the real-time information of these distributed energy sources is known.

Economic feasibility of the system thoroughly depends on the data precision, and thus, AI techniques can be utilized to get better predictions and real-time management of grid load through PV. In order to earn more through the proposed concept, more energy storage systems could be installed at customer sites, since higher the energy storage capacity, the higher the amount of energy that could be promised to the grid operator. Therefore, once the proposed system becomes popular, it will lead to an increase in battery purchasing which impacts the energy storage market. This, in turn, reduces battery prices. Besides, the cost of additional hardware and software required to implement this feature is very low compared to the amount of money that can be earned by agreeing to deliver grid support. This is beneficial for almost all stakeholders involved, i.e., the solar leasing company, grid operator, as well as the end users. Moreover, this introduces a novel way of operating and making an additional profit in the solar leasing market.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

KN Amarawardhana and SDG Jayasinghe developed the conceptual framework and KN Amarawardhana drafted the manuscript, SDG Jayasinghe and Farhad Shahniah critically revised the paper and all authors had approved the final version.

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