Design of Battery Storage System for Malaysia Low Voltage Distribution Network with the Presence of Residential Solar Photovoltaic System

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Abstract: The recent proliferation of residential solar photovoltaic systems has prompted several technical challenges to the operation of low voltage (LV) distribution networks. More specifically, the mismatch of the solar generation and demand profiles, particularly during the midday when the demand is low and solar generation is high, can lead to network overvoltages and increased network losses. In addition, the solar photovoltaic system is not able to reduce the system’s maximum demand, given the residential LV network would normally have an evening peak when the sun goes down. In this regard, this paper examines two different control strategies in designing the battery energy storage system. One aims to eliminate reverse flow caused by the surplus solar energy and the other aims for peak demand reduction.

Keywords: grid-connected PV system; battery energy storage system; distribution network

1. Introduction

Over the last decade, residential rooftop photovoltaic (PV) systems have gained popularity in many countries [1]. This is mainly driven by its low upfront investment, coupled with strong government-led support schemes, such as feed-in tariffs and net metering [2,3] to achieve a low carbon future in the respective countries. The proliferation of residential solar PV is expected to continue in the years to come. However, the increasing penetration of residential PV systems has started to witness technical challenges in the low voltage distribution network, particularly overvoltages and frequent voltage fluctuations [4–7]. The residential PV system is also unable to reduce peak demand since the maximum solar output at midday does not coincide with the evening peak normally experienced by the residential household [8].

One of the promising ways to address the these issues is by utilizing an on-site battery energy storage system (BESS) in which surplus PV power can be stored locally [9]. This avoids reverse power flow occurrence when PV generation exceeds local demand. In addition, residential BESS can be controlled to achieve different aims, such as reduce peak load [10,11], mitigate the volatility of renewable energy sources [12,13], and minimize the electricity cost based on economic incentives [14]. The high costs for the integrated PV–BESS system still remain as the main barrier for adoption amongst the residential prosumer [15,16]. Nevertheless, several studies have suggested that with the advancement in the battery technology, BESS could become profitable in the future [14,17]. This stimulates interest in developing methodologies that can support the quantification of BESS benefits, and its associated technical impacts to the system under various operating strategies.
The benefits of integrated PV–BESS have been well reported in the literature, given its superior ramping speed and flexibility in managing the solar output intermittency [18]. Recent studies [19,20] examined the technical benefits of BESS without considering any network topology. Instead, simplified network models have been utilized as the test case in [14], where these idealized network models have the limitation on representing the consumers’ diversity and network characteristics adequately. In addition, a limited number of BESS studies have considered multiperiod load and PV generation profiles at the final user level. The authors in [21] proposed a control strategy to increase the penetration of solar power with proper control of BESS. The Monte Carlo simulation performed in [22] only considers a fixed time horizon of 24 h without the influence of demand diversity. An enhanced probabilistic load forecasting technique was proposed for optimal energy storage system operation; however, the authors did not consider simultaneously the presence of PV generation in their optimization model [23]. Analysis in [24] that apply annual solar irradiation data suggests that the output from the solar PV system is highly uncertain and able to be broadly categorized into five variability days. Averaging the multiday PV profiles into a typical PV profile for a case study may underestimate the BESS capacity requirement. Thus, considering the wide spectrum of PV variability is of paramount importance in designing the BESS system. Furthermore, it is also worth noting that none of these papers consider the concept of battery-autonomy days in determining the optimal BESS capacity. This is important as the solar PV generation varies in consecutive days. This phenomenon is particularly acute for tropical countries that experience frequent cloud passing. This will result the state of charge (SoC) of the BESS system, which will vary significantly over the days.

In light of this, the BESS design approach developed in this paper is based on the real residential low voltage (LV) distribution network in Malaysia [8]. Moreover, the residential PV system’s rating is based on the actual PV installation statistics as provided by the Sustainable Energy Development Authority (SEDA) Malaysia [25]. More importantly, each house is assigned with an individual load profile with actual annual solar generation profiles. This allows the PV–BESS studies to be carried out more realistically, as compared to the abovementioned papers, which only consider a simplistic network model with daily or weekly profiles.

An optimal operation of centralized control of battery energy storage in low voltage networks with a few hundred nodes is computationally infeasible [19]. This is because the optimization problem becomes too complex to be solved efficiently. Furthermore, these centralized control strategies would normally require advanced communication infrastructure at the LV distribution substation or end user level, which is scarcely available nowadays. Hence, this paper proposes the design of a BESS system with two practical operation strategies for a typical residential LV network in Malaysia. The first strategy aims to effectively avoid the occurrence of reverse power flow incident at an LV distribution substation when the solar output is higher than the aggregated demand, thus eliminating the adverse impacts of reverse power flow on the operation of the distribution network. The second strategy utilizes all of the generated solar energy to minimize the maximum demand at the substation level. Subsequently, both strategies were evaluated and compared in terms of the required BESS power and energy ratings, maximum demand reduction, and the smoothness of the load profiles. It is also worth noting that annual demand and generation profiles were considered in this paper.

The paper is organized as follows. Section 2 presents the modeling approach for a low voltage distribution network, as well as the associated demand and solar profiles. The formulation of battery control strategies is presented in Section 3. Section 4 provides the results with detailed discussion, followed by concluding remarks in Section 5.

2. System Modeling and Analysis

2.1. Network Modeling

This paper focuses on LV network integration with solar PV and a BESS system. A typical residential area in Malaysia, called Taman Impian Putra and located at Port Dickson, was considered
as the reference LV network in this work, as shown in Figure 1. The network data were obtained from the local power utility, TNB [8]. Tables 1 and 2 show the types of cable used and the loading among the distribution feeders. An open distribution system simulator (OpenDSS) was utilized in this work for the network modeling that considers the self-impedance, neutral wire, and mutual impedance of the network. The network is supplied by three main LV feeders with a distribution transformer (11 kV/0.4 kV) rated at 500 kVA with a different number of residential houses. As identified from the site visit, two types of houses were considered, terrace and single story, with after-diversity maximum demand (ADMD) of 3 kW and 1.5 kW, respectively [26]. Previous study that utilized a similar LV distribution network as shown in Figure 1 suggested no voltage violation issues to the network even with 200% of solar PV penetration, driven by the high cable rating used and relatively short feeder. In this regard, voltage violation is assumed not to be a primary concern for this study.

![Figure 1. Single line diagram of residential LV distribution networks at Taman Impian Putra (BESS, battery energy storage system).](image)

Table 1. Size and types of cable used in the network.

| Branch Section          | Type of Cable                  |
|------------------------|--------------------------------|
| From                   | To                             |                                  |
| 500 kVA transformer    | Bus 2 × 500 mm² PVC/PVC Al     |
| Bus 2                  | 185 mm² PVC/PVC Al             |
| Piecing connection A,B,C,D | Aerial Bundle Cable (ABC)      |
| Node                  | Node 3 × 185 mm² + 120 mm² Al |
| House                 | 16 mm² PVC/PVC Cu             |

Table 2. Feeder loading condition.

| Type of House | Single Story | Terrace | Total loading (kW) | Total feeder loading (%) (185 mm²) | Total loading (kW) | Total feeder loading (%) (185 mm²) |
|---------------|--------------|---------|--------------------|-----------------------------------|--------------------|-----------------------------------|
| Feeder A      | 37           | 15      | 101                | 43.7                              | 125.6              | 54.6                              |
| Feeder B      | 64           | 0       | 96                 | 41.7                              | 120.0              | 52.2                              |
| Feeder C      | 0            | 33      | 99                 | 43.0                              | 123.8              | 53.8                              |

The proposed BESS system will be centrally installed at the LV substation level, as shown in Figure 1. In this regard, only a central controller is needed to manage the charging and discharging strategies of the BESS system. The battery management system can utilize the historical aggregated
load profile, as seen from the substation side for peak load reduction strategy. A monitoring device can be installed to detect the occurrence of reverse power flow and subsequently trigger the BESS charging operation. The requirement of communication infrastructure for this centrally managed BESS is much lower compared to the distributed BESS system.

2.2. Consumer Demand Profile and Modeling

The typical aggregated residential load profile in Malaysia that was utilized in previous studies [27] was utilized in this paper. The load profile as shown in Figure 2 is an aggregated residential profile of 149 Malaysian households that was generated in ten minute intervals for a day (144 min). The individual load profiles are generated by utilizing the approach that was presented in previous work [27]. Figure 3 shows the individual and aggregated household load profiles for seven consecutive days. The load profiles were saved in a TEXT file for OpenDSS LV load-shape modeling. A power factor of 0.95 was assumed for all case studies. The aggregated load profiles and energy consumption of the houses can be written as Equations (1)–(3), as follows:

\[
P_{\text{Agregated}}^{(t)} = \sum_{i=1}^{nh} P_i^{(t)} \quad i \in \{1, 2, \ldots, 149\}, nh = 149
\]

\[
E_{\text{Agregated}}^{(d)} = \frac{\sum_{i=1}^{ntps} P_{\text{Agregated}}^{(t)}}{(ntps/24)} \quad t \in \{1, 2, \ldots, 144\}, ntps = 144
\]

\[
E_{\text{Total}} = \sum_{d=1}^{nd} E_{\text{Agregated}}^{(d)} \quad nd \in \{1, 2, \ldots, 365\}
\]

Figure 2. Typical daily residential load profile in Malaysia.
The capacity of the PV system installed for each house was assigned randomly based on the statistics Therefore, this paper utilizes the yearly PV profile data sets that were extracted from a weather station profiles were recorded and saved in a txt file, which served as the input data for the PV system installed. Energies 2020, 13, x FOR PEER REVIEW 5 of 21

2.3. Solar Variability Profiles and Modeling

There are five different types of PV profiles that might happen based on Malaysia’s weather conditions, based on the recorded and analyzed site data [24,28]. The authors clustered the data sets of a year as clear day, overcast day, moderate variability, mild variability, and high variability. In order to have proper design for BESS, the whole probability of weather conditions needs to be considered. Therefore, this paper utilizes the yearly PV profile data sets that were extracted from a weather station located on the rooftop of the Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, UTeM (2.32° N, 102.3° E). The PV generation data are real data that were recorded from the solar inverter’s AC output data, located in the UTeM’s Solar PV System and Smart Grid Research Laboratory. Figure 4 shows the PV generation profile with a five minute interval for five different solar variability types recorded during the year 2016. Meanwhile, the aggregated PV generation profile of the houses that can be seen from the transformer side is written as Equations (4)–(6). The PV generation profiles captured for 365 days of the year 2016 are shown in Figure 5.

\[ PV_{Aggregated}^{(t)} = \sum_{t=1}^{nh} PV_{i}^{(t)}, \quad PV_{Aggregated}^{} \geq 0 \]  

(4)

\[ PVE_{Aggregated}^{(d)} = \frac{\sum_{t=1}^{ntps} PV_{Aggregated}^{(t)}}{(npts/24)} \]  

(5)

\[ PVE_{Total}^{(d)} = \sum_{d=1}^{md} PVE_{Aggregated}^{(d)} \]  

(6)

The PV system was modeled in OpenDSS as a grid-tied PV system. The data of PV generation profiles were recorded and saved in a txt file, which served as the input data for the PV system installed. The capacity of the PV system installed for each house was assigned randomly based on the statistics obtained from the Sustainable Energy Development Authority (SEDA) Malaysia. Figure 6 shows that the two highest residential PV system capacities installed in Malaysia are 4 and 12 kWp, respectively, followed by 6 and 8 kWp.

![Normalized Load Profile](image.png)

**Figure 3.** Normalized load profile of 149 households for 7 days in sequence.

**Figure 4.** Agregated Profile

Time (7 days, 10 minutes interval)
3. Formulation of Battery Control Strategies

Various battery control strategies can be considered to allocate BESS in the distribution network, depending on the aims of the BESS installation. The following subsections describe the proposed strategies that were utilized in this study for BESS charging, namely reverse power flow strategy (RPFS) and PV generation strategy (PVGS). Subsequently, different BESS sizes (kW) and capacities (kWh) were determined under various BESS integration scenarios. Furthermore, the following battery

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Figure 4. PV generation profiles for five different solar variability types.

Figure 5. PV generation profiles and aggregated PV generation profile for the 365 days in 2016 that were captured at the Universiti Teknikal Malaysia Melaka (UTeM).

Figure 6. Probability of residential PV system capacity installed in Malaysia.
parameters and factors were considered. These factors were determined based on datasheets from battery manufacturers such as Tesla [29].

- Depth of discharging (DOD), 80%;
- Battery charging efficiency (Eff_c), 90%;
- Battery discharging efficiency (Eff_dc), 90%;
- Autonomy days (AD), 0–100%;

3.1. Reverse Power Flow Strategy (RPFS) for Charging BESS

The reverse power flow can adversely affect the operation of the distribution network. When the PV system generated power is greater than the demand, the surplus solar power will reverse back to the upstream grid. This will lead to network voltage rise and increased of network losses. Hence, the utility company will normally encourage the consumer to self-consume their PV generated energy instead of exporting it to the grid. Accordingly, the BESS can play an important role in this regard. This section introduces a strategy to store the amount of surplus PV generation into the BESS. This could avoid reverse power flow as well as utilize the stored energy for peak demand reduction. The main concept of RPFS strategy is shown in Figure 7. The total amount of stored energy in BESS can be calculated as in Equation (7). The BESS sizing is calculated based on the daily maximum stored energy. Equation (8) expresses BESS capacity in kWh and Equation (9) indicates the formulation of BESS power rating in kW.

\[
\text{BESS}^{(d)}_{SE} = \frac{\sum_{t=1}^{npts} \left( |\text{PV}^{(t)}_{\text{Aggregated}}| - |\text{P}^{(t)}_{\text{Aggregated}}| \right)}{(npts/24)} \times \text{Eff} \times \text{AD} \quad (7)
\]

\[
\text{BESS}_{\text{Capacity}} = \max \left( \text{BESS}^{(i)}_{SE} \right) \quad (8)
\]

\[
\text{BESS}_{\text{rating}} = \max \left( \frac{\max \left( \left| \text{PV}^{(i)}_{\text{Aggregated}} \right| - \left| \text{P}^{(i)}_{\text{Aggregated}} \right| \right)}{(npts/24)} \right) \quad (9)
\]

3.2. PV Generation Strategy (PVGS) for Charging BESS

The second strategy proposed for BESS charging is completely based on the total amount of PV generation power. Hence, it can be expected that the size and rating of the BESS unit will be larger than the previous strategy. Nevertheless, the amount of energy that can be delivered during the peak demand duration will be higher. Figure 7 shows the concept of BESS charging for this strategy. The amount of BESS stored energy is equal to the total PV generation of the day, as expressed in Equation (10) with its power rating calculated as in Equation (11). Similarly, the capacity of the battery is the same as in Equation (8).

\[
\text{BESS}^{(d)}_{SE} = \frac{\sum_{t=1}^{npts} \left( |\text{PV}^{(t)}_{\text{Aggregated}}| - |\text{P}^{(t)}_{\text{Aggregated}}| \right)}{(npts/24)} \times \text{Eff} \times \text{AD} \quad (10)
\]

\[
\text{BESS}_{\text{rating}} = \max \left( \frac{\max \left( \left| \text{PV}^{(i)}_{\text{Aggregated}} \right| \right)}{(npts/24)} \right) \quad (11)
\]

It is worth noting that the AD value in Equations (7) and (10) are adjusted in an iterative manner with a 10% increment for every iteration. The higher value of AD might result in oversizing the BESS.
Conversely, a lower value of AD might result in BESS charging and discharging failure. Hence, it is important to determine the suitable AD value for safe BESS operation.

3.3. Peak Reduction Strategy (PRS) for Discharging BESS

The amount of stored energy in the BESS can be discharged based on different objectives. This paper considers discharging the BESS based on the peak reduction strategy (PRS). The main aim is to reduce the network peak demand by discharging the BESS stored energy for both RPFS and PVGS strategies, as discussed in the previous sections. The amount of energy stored in the BESS can be discharged equally with respect to the demand at peak hours. For this purpose, the first step is to find the day ahead equilibrium peak demand based on the amount of energy stored in BESS. Figure 8 shows the proposed algorithm to find this equilibrium peak demand. The formulation of equilibrium peak demand with BESS stored energy is shown in Equation (12). This equation determines the amount of energy that can be discharged to reduce the peak demand. It is based on the summation of power for day-ahead load profiles (DALP) above the equilibrium threshold line. DALP can be obtained from the methods and approaches that were presented in other research, e.g., [30,31]. The algorithm continues...
in an iterative manner to find the adequate threshold and equilibrium energy, which is equal to the BESS stored energy. The value of damping is set as 0.999 per iteration.

\[
\text{PeakDemand} = \begin{cases} 
\sum_{i \in \text{ppts}} \left( \text{DALP}_i \geq \text{threshold}_i \right) & \text{if } (\text{PeakDemand} \geq \text{BESSSE} \times \text{Eff}_{dc}) \\
\text{DALP}_i - \text{threshold}_i & \text{otherwise} \\
\text{else} & \text{else} \\
\text{threshold} = \text{threshold} - 1 & \text{otherwise}
\end{cases}
\]  

(12)

![Figure 8. Peak reduction strategy algorithm (discharging algorithm).](image)

Figure 9a shows the concept of RPFS charging strategies that stores the solar surplus energy during the reverse power flow period. The stored energy is then released during peak hours to reduce the network peak demand. It clearly indicates that the small amount of stored energy from reverse power flow could significantly help to reduce the daily peak demand. On the other hand, Figure 9b illustrates the PVGS charging strategy. The amount of energy that was generated from the PV system is stored at BESS and released back to the grid at peak hours. It can be observed from the figure that the battery size in PVGS is significantly larger than the one in RPFS. Hence, this study investigates both proposed charging strategies to determine the most effective strategy under various PV penetration scenarios.
Figure 9. BESS operation for peak reduction strategy (PRS) concept under (a) RPFS and (b) PVGS.

Figure 10 shows the implementation of a rooftop PV system and BESS allocation. The process begins with initial data entry for load and PV profiles for each consumer (149 households) for a one year period with 10 min data intervals (144 samples). The test network under study is modeled in OpenDSS to establish base case characteristics with power flow simulation. The PV system is then integrated to the network with different penetration levels (25% to 100%). The results of power flow calculation after PV integration are obtained and stored in common-separated values file (CSV) format. The sizing and power rating of BESS are determined based on applied charging and discharging strategies. The obtained results of power flow calculations for before and after BESS, and PV integration are compared with the base case. This is to determine the most effective and adequate BESS sizing for each PV penetration level.
4. Results and Discussion of BESS Allocation

These strategies proposed for BESS integration are demonstrated through a residential LV distribution network in Malaysia. The proposed BESS is centrally installed at the distribution substation level. The case study aims to compare the BESS power rating and capacity, in the presence of residential PV systems. The time resolution of the sample data and duration of the study are the two important factors that significantly influence the design of BESS, which are demonstrated in the following analysis. Figures 11 and 12 show the BESS design with the case study of PVGS and RFPS for seven consecutive days, 1–7 January 2016. The results show that the BESS capacity and power rating vary throughout the duration of the study. These can be seen in Table 3. Additional simulation days resulted in a more accurate BESS design. Hence, this paper utilized one year’s data from 2016 to design the optimum BESS for the test network with different PV penetration levels. Figure 13 shows the monthly BESS sizing for both RPFS and PVGS strategies. As expected, the BESS rating requirement
for PVGS strategy is much higher than RPFS strategy. However, when the PV penetration increases, the BESS rating between these two strategies become less obvious. This is because the occurrence of reverse power flow will become more intense during high PV penetration levels.

Table 3. Comparison of the duration of study for BESS design.

| Item                | One Week | One Month | One Year |
|---------------------|----------|-----------|----------|
| BESS Capacity (kWh) | PVGS     | RPFS      | PVGS     | RPFS      | PVGS | RPFS |
|                     | 2070     | 895       | 2554     | 1126      | 2600 | 1150 |
| BESS Power Rating (kW) | 245       | 185       | 255      | 190       | 260  | 220  |

Table 4 shows the strategies applied for charging (PVGS/RPFS) and discharging (PRS) of BESS design for 25% to 100% of PV penetrations. It shows that the BESS capacity and power ratings very much depend on the strategy and PV penetration levels that were considered. In addition, selecting higher resolution data sets is very important for designing the BESS ratings. Figure 14a shows
the comparison of the BESS size with RPFS charging for two different time resolutions, i.e., 10 and 60 min. Figure 14b shows the PVGS charging and BESS size for different PV penetration level. It can be observed that the higher time resolution of input data resulted in a more accurate BESS sizing. Hence, this paper utilizes 10 min resolution data for the case studies.

![Figure 13. Comparison of BESS sizing within the year 2016: (a) PVGS and (b) RPFS.](image)

**Table 4.** BESS capacity and power rating for both strategies with a one year simulation period.

|                | 25%  | 50%  | 75%  | 100% |
|----------------|------|------|------|------|
| BESS Capacity  | PVGS | 1300 | 2600 | 3800 | 5000 |
| (kWh)          | RPFS | 150  | 1150 | 2300 | 3450 |
| Difference (%) | 88   | 56   | 40   | 31   |
| BESS Power     | PVGS | 150  | 260  | 370  | 500  |
| Rating (kW)    | RPFS | 60   | 220  | 360  | 500  |
| Difference (%) | 60   | 15   | 3    | 0    |

![Figure 14. Comparison of BESS sizing for different time resolutions for strategies: (a) PVGS and (b) RPFS.](image)
Therefore, increasing the AD would address this problem satisfactorily. In this regard, this paper proposes optimum AD utilization to size the BESS. Figure 17 shows a similar case study as the one in 2020 that PVGS reduces the SI index more significantly than RPFS. 

Reduction of the net imported energy is 88.343 to 68.576 MWh with PVGS and 68.940 MWh with RPFS under 25% PV penetration scenario. Figures A1–A4 in Appendix A show the results for all of the scenarios considered.

Figure 15 illustrates the MD reduction in kW with different PV penetration level. It can be observed that the month of March has the maximum MD reduction for months during the year, approximately from 220 to 58 kW with RPFS and to 46 kW with PVGS.

![Figure 15. Maximum demand reduction in kW for both scenarios: (a) PVGS and (b) RFPS.](image)

The other important factor for designing BESS is the consideration of autonomy days (AD) to cope with the weather uncertainty. Figure 16 shows the BESS failures (blue line) due to inadequate BESS capacity. Discharging the BESS below its allowable limit is detrimental to its technical lifespan. Therefore, increasing the AD would address this problem satisfactorily. In this regard, this paper proposes optimum AD utilization to size the BESS. Figure 17 shows a similar case study as the one in Figure 16, but with increased AD from 20% to 40%. This helps the BESS to prevent sudden charging and stop discharging defects (spikes). In this case, by adjusting the AD to 40%, the capacity of the BESS increased from 3.45 to 4 MWh. The BESS power rating still remains the same at 500 kW. The results obtained show that the BESS successfully smoothes the load profile (LP) and lowers the peak demand.

This paper further proposes a smoothness index (SI) as an indicator to quantify the smoothness of the load profile. The SI is driven by the rate of changes of the load profile and can be written as Equation (13). Lower SI would indicate more smoothness load profile. The SI value for the flat load profile is equal to zero, which means there is no fluctuation in the load profile. More fluctuations in the load profile result in a higher SI. Figure 18 shows the SI comparison for the case study ranging from 25% to 100% of PV penetration for both PVGS and RPFS strategies. As can be seen from the figure, the SI for the base case remains constant with all of the PV penetration levels. It is interesting to observe that the SI index increased quite substantially after including the PV system. This mainly was caused by the intermittency of the PV system. After the BESS was integrated, the SI index reduced significantly due to the effects of BESS removing the PV intermittency. As expected, the results show that PVGS reduces the SI index more significantly than RPFS.
The main findings of the paper can be summarized as shown in Table 5. The BESS design for different PV penetration levels for both PVGS and RPFS are determined. The energy to power ratio of the BESS (Table 5) indicates that the battery is designed adequately based on the battery manufacturer requirements and range as reported in [25]. In general, it can be observed from the results, in terms of MD reduction, that the PVGS with 1300 kWh BESS can achieve 36.8% of MD reduction as compared to RPFS, with a significantly higher BESS of 3450 kWh, can only achieve a comparable 39.9% of MD reduction. In other words, the results show that PVGS is more suitable for lower PV penetration, and that RPFS has a reasonable MD reduction for higher PV penetration with a smaller battery size.
which was installed with rooftop solar PV systems. Two BESS control strategies are considered, the first
writing—review and editing, W.H.T.; supervision, C.K.G. All authors have read and agreed to the published
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Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

nh Number of households
nd Number of studied days
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Appendix A

Figure A1. Comparison of PVGS and RPFS with 25% PV penetration level (January 2016).

Figure A2. Comparison of PVGS and RPFS with 50% PV penetration level (January 2016).

Appendix A

![Figure A1. Comparison of PVGS and RPFS with 25% PV penetration level (January 2016).](image)

![Figure A2. Comparison of PVGS and RPFS with 50% PV penetration level (January 2016).](image)
Appendix A

Figure A1. Comparison of PVGS and RPFS with 25% PV penetration level (January 2016).

Figure A2. Comparison of PVGS and RPFS with 50% PV penetration level (January 2016).

Figure A3. Comparison of PVGS and RPFS with 75% PV penetration level (January 2016).

Figure A4. Comparison of PVGS and RPFS with 100% PV penetration level (January 2016).

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Figure A3. Comparison of PVGS and RPFS with 75% PV penetration level (January 2016).

Figure A4. Comparison of PVGS and RPFS with 100% PV penetration level (January 2016).

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