Conference Proceedings

ASES National Solar Conference 2018

Boulder, Colorado August 5-8, 2018

ASES National Solar Conference 2018

Comparative Analysis of Energy Storage for Photovoltaics: Electrical vs Virtual

Orthi Sikder[1] , Camille Torres[2] and Peter Mark Jansson[3]

[1] Bucknell University, PA (United States)

[2] Polytech Tours, Tours (France)

[3] Assoc. Professor ECE, Faculty Director BCSE, Bucknell University, PA (United States)

Abstract

The recent successful deployment of 100+ MWhr battery in South Australia by Tesla to solve grid problems with the intermittent generation of renewables places an economic stake in the ground for energy storage. Virtual energy storage at the Bucknell University Residential Microgrid testbed has demonstrated that multiple kWhrs of electricity can be successfully shifted during utility heating and cooling peaks at a fraction of the cost of batteries. While load management and pre-cooling and pre-heating of residential dwellings have been discussed historically as potential solutions to intermittent generation from photovoltaics (PV), our work in a live test bed definitively demonstrates that load shifting can be the electrical equivalent of battery energy storage while maintaining occupant comfort and satisfaction. It is our hope to reinvigorate the discussion about these options because they are not only more economic than physical electrochemical batteries but they represent a much more sustainable pathway to meet utility near term electricity storage needs.

Keywords: energy storage, microgrid, residential photovoltaic system, battery, virtual storage

1. Introduction

Photovoltaic (PV) systems are recognized as promising renewable energy resources to meet the world's growing electricity demand. After evolving over the last two decades, PV has proven to be a mainstream source of electricity. Today the world is experiencing rapid growth of solar electric technologies. As a matter of fact, some power grids across the world are struggling to keep up with the technological advances, increased penetrations and growing cost-competitiveness of renewable energy sources like PV.

The United States, China, Germany, Japan, United Kingdom and India are currently leading installers of PV [1]. Annual new additions of photovoltaics to world electric grid are shown in Figure 1.

doi:10.18086/solar.2018.01.11 Available at http://proceedings.ises.org

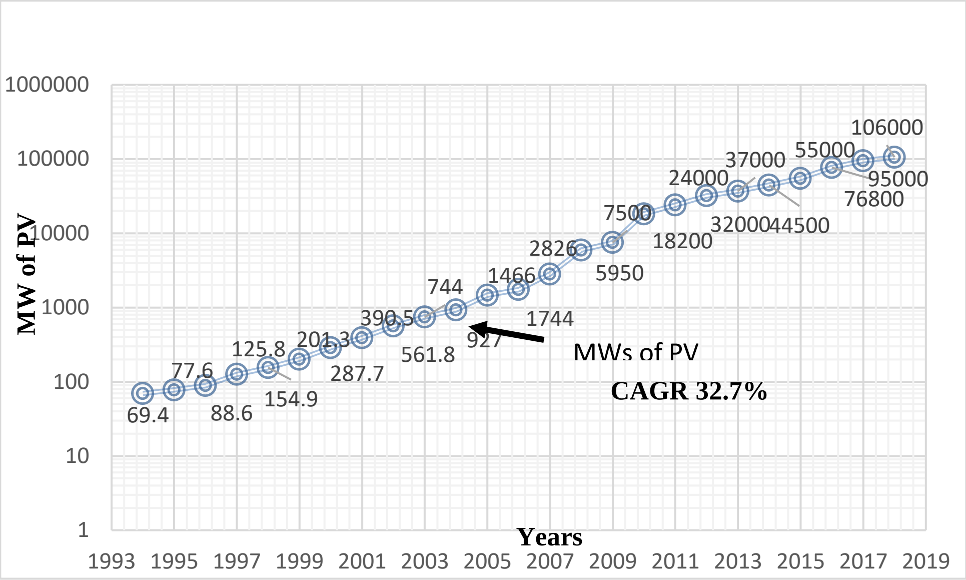


Fig 1: Annual new addition of photovoltaics to global total installed PV

Figure 1 shows the annual addition of new PV to the world's grids (in MW) over the last 25 years. Here, the plot is in logarithimic scale and it is linealy increasing at the same time. From the plot, we can see that every 5 to 6 years the new PV capacity has increased an order of magnitude. The compound annual growth rate CAGR) represented by grid-tied photovoltaics averaged nearly 33% per year over the last 25 years as costs of this technology plummeted. PV in 2018 is projected to be as high as 106 GW [2-3].

Since PV is clearly an intermittent source of electrical energy due to its diurnal cycle and susceptibility to poor weather (cloude cover), electrical energy storage has now become a fast growing sector in the solar marketplace. According to market research; the electrical energy storage market exploded to annual installation size of 6 gigawatts (GW) in 2017 and it may grow to over 40 GW by 2022 ($6.8B) – from an initial base of only 340 MW installed in 2013 ($400-$600/kWh in 2015) [4-5].

2. Problem Statement

To help illucidate the temporal problem associated with PV generation, we will begin by discussing some typical load profiles and usage trends. Let us pick a typical summer day with an average outdoor temperature profile [shown in Fig 2 (a)]. For a typical residential home with a PV system as its renewable energy resource, the net load profile and PV generation profile will look as graphed below [in Fig 2 (b,c)].

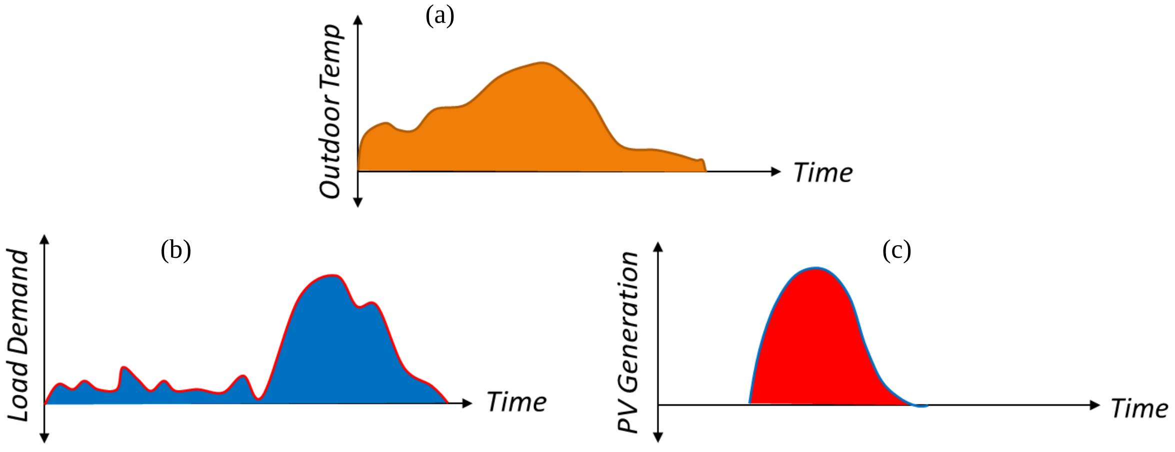
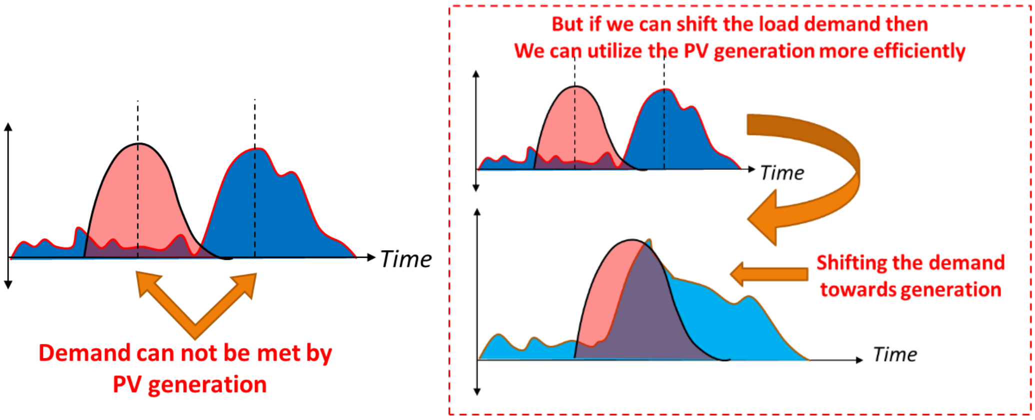


Fig 2: A typical day's (a) temperature profile; (b) load profile; (c) PV generation profile.

Fig 2(b) and 2(c) clearly illustrates that the peak load demand and peak PV generation are not occurring simultaneously. More clearly, if we superimpose the demand over generation, we will get the result as in Fig.

3(a). This Impllies that, the peak generation from PV system is not being used to meet the peak load in a typical day. There exists a time gap between these two. In order to meet the peak demand by PV generation we can either store the generated PV energy with electrical storage systems and dispatch the energy later when usage is high. Otherwise, we can simply sell the energy to the main grid at a low price and draw energy from the main grid when the peak demand hits again at the cost of higher energy prices.



(a) (b)

Fig 3: (a) Superimposition of a typical day's load profile over PV generation profile (b) Demand shifting can help optimize PV energy utilization

For decades, the most popular form of enegy storage has been batteries. In a battery, we store energy in the form of chemical energy. Later, that energy is turned back into electricity for usage. There are some other forms of energy storage available such as: flywheels, hydrogen systems, pumped hydro, compressed air energy storage etc. However, almost all kinds of conventional energy storages come with several limitations. They are often very expensive, have limited capacity, require timely maintenance, use natural resources and have adverse environmental impacts. Hence, with all these inadequacies, scientists continue to think about an alternate form of energy storage over the troublesome and expensive conventional ones.

3. Research Motivation

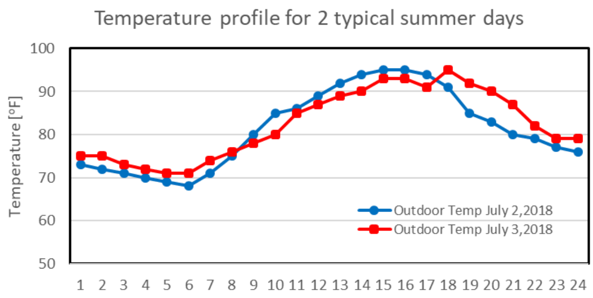
A load management system can create more load if more power is available from a PV system than is being used currently to make sure no energy is wasted [Fig 3(b)]. For example: a load management can adjust a smart thermostat (if available) to store more energy in the dwelling thermally. Various techniques enable a load-management environment and can be classified into six categories: peak clipping, valley filling, load shifting, strategic conservation, strategic load growth and flexible load shape [6]. Therefore, it is possible to shift load from peak periods to off peak periods in a way that can potentially provide cost savings both to the consumer and utility grid operators. However, to carry out the load shifting and peak clipping without changing consumer preferences, some form of energy storage is necessary. Such storage acts as a conduit between peak and off-peak loads. To perform load shifting, peak clipping, valley filling and flexible load shape techniques in cost-effective ways, a possible and potential candidate is virtual energy storage (VES) systems.

The ability to shift load and store energy thermally internal to a house as well as activate diversion loads as necessary to store excess energy gives the Microgrid a form of virtual energy storage [7-8]. It is considered virtual, because the energy stored cannot be recovered as electricity to be used in grid. The energy is instead consumed at the time of generation as is done in the utility power grid. The difference is that the energy consumption is controlled by the microgrid to be done at the most beneficial time. If selling solar energy back to the main grid is not desired due to unfavorable conditions, the energy can rather be stored in the thermal mass of the house through use of the heating,ventilation and air-conditioning (HVAC) system. This energy is recovered later by not using the HVAC system as much and allowing the internal temperature to float back to a normal set point range or desired set point according to the load management protocol [9-11]. There are two main reasons for choosing HVAC as the variable load. First, heating and cooling is still considered to be one of the largest loads which accounts for about 48% of the energy use in a typical U.S. home, making it the largest energy expense for most of the residential homes [12]. Second and most importantly, HVAC systems offer us the simple yet great opportunity to use the thermal mass of the building by pre-heating or pre-cooling this mass and using its thermal storage potential for shifting electrical loads away from the utility peak period.

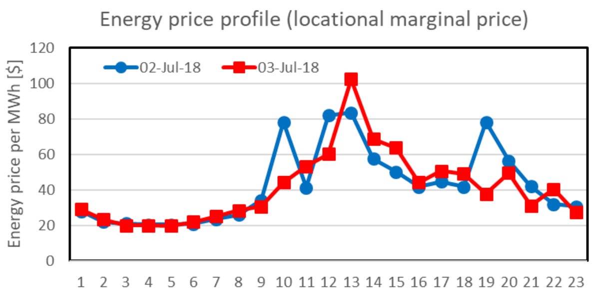
4. Research Methodology and Results

In this work, we have explored an extensive empirical analysis of thermal storage based virtual energy storage systems. To do so, we have been using the Bucknell Residential Microgrid System as our testbed. It is a residential home. The system has PV array and a natural gas generator as distributed resources and a main-grid connection. The grid is also equipped with smart thermostats and a smart electricity metering system that allows real-time load monitoring. At the same time, the grid has a raspberry-pi based central control unit that can be utilized to provide a web-based smart load management scheme in the residential home. It is important to note that the residential home considered in this work is well insulated.

We consider the microgrid system with two operating conditions depending on the load management: normal and experiment. We randomly picked 2 summer days to compare the results and find theoretical validation of our claim: July 2 and July 3, 2018. These two days are considered experiment day and normal operation day respectively. They are very similar in terms weather as shown in Figure 4(a). The energy price profile for these two days are shown in Figure 4(b). On July 2, 2018, the experiment day, the load management was done according to the day ahead local marginal price from PJM. According to that, the house was precooled for 3 hours at 68º F from 1 pm to 4 pm and then the variable load HVAC system was forced off for next 3 hours from 4 pm to 7 pm with only fan running, the indoor temperature was allowed to rise by 6º F overall.



(a)



(b)

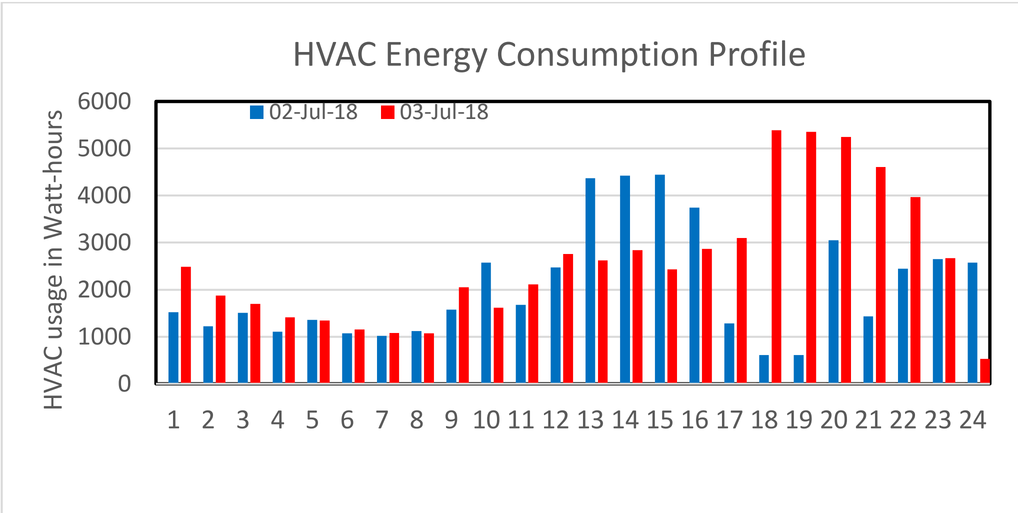


Fig 4: Two typical summer day's (a) temperature profile; (b) energy price profile (c) energy consumption by HVAC.

On July 3, 2018 the HVAC system ran at its own pace without any external interruption and control with the normal setting temperature 72 ºF. Figure 4(c) shows the comparison in HVAC system energy consumption between these two days. It also shows, how clearly the peak load can be shifted to the period of the day when PV generation is available. Not only that, by quantifying the energy usage, we find that the experiment day HVAC usage is 12.43 kWatt-hours less than the normal operation day.

On closer inspection: The Experiment day HVAC usage was 49.883 kWh
The Normal operation day HVAC usage was 62.314 kWh
Average energy price on normal day $39.25 / MWhr
Utility Cost saving = 48.79 cents daily = $14.64/ month

Also on average, electricity sources emit 1.222lbs CO2 per kWh. [13] So clearly it reduces the carbon footprint on the environment.

5. Conclusion

Virtual energy storage has proved itself both financially and environmentally beneficial to a grid with renewable resources like solar system. While we are utilizing the solar generation for meeting peak demand, we are saving the same amount of energy not being drawn from the main electrical grid reducing our cost for usage and carbon footprint on environment. It is also helping by reducing energy consumption during high price period creating scope for extra savings. The future prospect of this research work will be to create the optimal range of thermal mass and find out the critical design criteria required for a microgrid system than can provide such benefits and explore the long term benefits of virtual energy system over conventional energy storage systems.

6. References

[1] "Solar PV - Statistics & Facts", https://www.statista.com/topics/993/solar-pv/

[2] Jäger-Waldau, Arnulf. (2017). PV Status Report 2017. 10.2760/452611.

[3] IRENA (2018), Renewable Power Generation Costs in 2017, International Renewable Energy Agency, Abu Dhabi.

[4] "US Energy Storage Market Tops the 1 GWh Milestone in 2017", https://www.greentechmedia.com/articles/read/us-energy-storage-market-tops-the-gwh-milestone-in-2017/

[5] "Facts and Figures", http://energystorage.org/energy-storage/facts-figures

[6] C. W. Gellings, "The Concept of Demand-Side Management for Electric Utilities," Proceedings of the IEEE, vol. 73, no. 10, pp. 1468-1470, 1985.

[7] P. Diefenderfer and P. M. Jansson, "Rationalization of a residential microgrid on PJM," 2014 IEEE PES T&D Conference and Exposition, Chicago, IL, USA, 2014, pp. 1-5.

[8] P. Asare, C. Ononuju and P. M. Jansson, "Preliminary quantitative evaluation of residential virtual energy storage using power sensing," 2017 IEEE Sensors Applications Symposium (SAS), Glassboro, NJ, 2017, pp. 1-6.

[9] M. Avci, M. Erkoc and S. S. Asfour, "Residential HVAC load control strategy in real-time electricity pricing environment," 2012 IEEE Energytech, Cleveland, OH, 2012.

[10] D. T. Nguyen and L. B. Le, "Joint Optimization of Electric Vehicle and Home Energy Scheduling Considering User Comfort Preference," in IEEE Transactions on Smart Grid, vol. 5, no. 1, pp. 188-199, Jan. 2014.

[11] H. Karami, M. J. Sanjari, S. H. Hosseinian and G. B. Gharehpetian, "An Optimal Dispatch Algorithm for Managing Residential Distributed Energy Resources," in IEEE Transactions on Smart Grid, vol. 5, no. 5, pp. 2360-2367, Sept. 2014

[12] "Heating & Cooling", Department of Energy, ENERGY.GOV, https://www.energy.gov/public-services/homes/heating-cooling

[13] https://thelukewarmersway.wordpress.com/2016/03/27/concentrations-are-calculated-emissions-are-estimated/ ; accessed on 22 Aug