# Application of Used Electric Vehicle Batteries to Buffer Photovoltaic Output Transients

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***Abstract*— Methods to mitigate the effects of power transients associated with grid-tied concentrated photovoltaic systems due to fast-moving cloud coverage were assessed. The approach was to buffer intermittency of concentrated photovoltaic output power with used electric vehicle batteries. The main goals of using grid-tied photovoltaic in conjunction with the proper energy storage (340kWh) were 1) to smooth out the intermittent solar power and 2) to defer part of the peak load to a convenient time with a proper control strategy. Real data from the summer of 2011 were utilized to conduct this study. Hence, simulation results showed that not only the unit was capable of putting a constant amount of power (20 kW) onto the grid, but also was able to shift the less valuable off-peak electricity to the on-peak time, when the price of electricity cheaper.**

***Index Terms*— Concentrated Photovoltaic (CPV), Intermittency, Energy Storage Systems, EV, Load shifting.**

## I. Introduction

Variability affects the way photovoltaic (PV) systems are tied to the grid. During cloudy weather conditions, the PV power output changes suddenly by responding instantaneously to fluctuations in sunlight. Under certain weather conditions, PV systems can change output between 100% and 10% in a 30- to 90-sec time frame, many times per day [1]. Hence, it has been speculated that PV fields could have large and frequent ramp events that may create challenges for electric grid operators [2]. Cloud coverage and PV output variability are intimately related and dependent on the system size, shape, transparency, speed, and direction of cloud's movement [3].

In this work used electric-vehicle (EV) batteries that have reached end of automotive life are proposed instead of new batteries for 1) economic reasons because the current $/kWh is still high and 2) environmental reasons due to the disposal of some of their major components. Additional details are found in [3].

There are various ways to reduce peak load, for instance, using consumer-side management techniques by means of a direct control of their appliances or price control of load strategies [4]. Other alternatives include achieving load leveling and power quality through the utilization of energy storage system (ESS) [2]-[5]. The primary purpose of energy storage is to push away the limits of fixed demand trends of electricity by shifting the supply of PV power to a certain desired time schedule. Although sufficient energy storage is expensive, it virtually can help not only to shift any amount of power, but also to peak shave power demand, proportional to their size without any limit. Hence, the usefulness to photovoltaics and energy storage is strictly interrelated in two different ways [6]: 1) the absorption of surplus power and 2) the allowance of energy to be utilized at convenience, most of the time when it is not produced, or to suppress intermittencies. So, shifting one portion of the electrical load, as done by Denholm [7], from peak time to off-peak hours has great economic implications and will lessen the total electricity burden on society.

This paper focuses on two strategies: 1) smoothing the concentrated photovoltaic (CPV) power transients due to cloud coverage via a first energy storage system, ESS1, and 2) shifting less expensive power to the peak demand time. The CPV unit charges the ESS1. Then a second battery bank (ESS2) will charge directly from the utility at night when the price of electricity is the cheapest. The motivation for this strategy is more economical than technical. Hence, the direct implication is the gain in compensation from the difference in the price and the amount of load shifted [8].

This paper is organized as follows. Section II describes the CPV system showing its major characteristics. Section III explains thoroughly the procedures and control strategies adopted to advocate a large penetration of renewable on to the grid. Section IV emphasizes on the battery sizing to achieve a specific goal. Simulation results are discussed in Section V, followed by the conclusion in Section VI.

## II. Description of the CPV System Under Study

CPV technology differs from conventional flat-plate PV in various ways: Firstly, the former are highly efficient due to triple junction designs instead of single junction. Secondly, the mirrors and lenses they use are of great advantage compared to the traditional flat-plate technology. The semiconducting material price is related to quality. Thus, less material is used in chip manufacturing design. As a result, less semiconductor material associated with energy efficient optics is used to implement the chips of the CPVs. Figure 1 illustrates the optics behind a CPV for a unit cell.

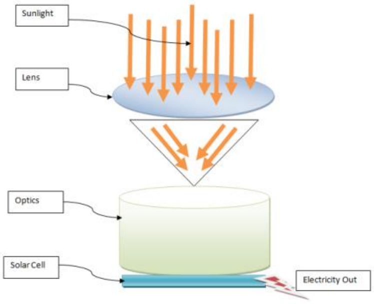


**Figure 1**- The optics of CPV.

### A. *The Characteristics of the CPV*

CPV technology utilizes dual-axis tracking systems and a single unit is comprised of seven Mega modules. Its efficiency is far greater than conventional panels, allowing it to generate over 40% more energy. The unit is easy to install and easy to disassemble, making it cost effective with respect to renewable energy standards. The overall efficiency delivered to the grid is in excess of 29%. This technology has proven to be cost-effective and environmentally friendly by producing clean energy and is capable of generating power on a large scale for use by electric utilities. Furthermore, this technology is characterized by a name plate capacity (AC) of 53kW ($\pm$ 5%) and an operating three phase voltage of 480VAC. It uses a double axis tracking system and its operating temperature range is -10$^{o}$C to +50$^{o}$C. Figure 2 shows the unit used in the study.

**Figure 2-** CPV 7700 unit, UNLV (CER).

It is important to note that the unit does not always output the exact amount of power that it is supposed to, because the optics may sometimes fail to respond properly to the incoming sunlight as can be seen in Fig. 3 (typical power generation on a cloudy day).

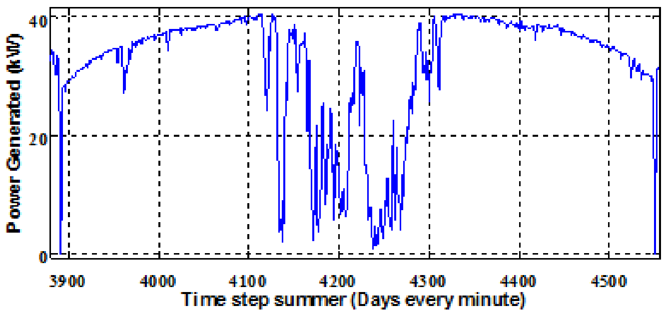


**Figure 3**- Typical power generation on a cloudy day.

## III. PROCEDURES AND CONTROL STRATEGIES

The main goal of this test is to come up with efficient ways to smooth out the fluctuations in the output power due to cloud coverage. The ESS buffer demonstrates a tremendous impact based on some preliminary assumptions. Hence, this section provides the necessary procedures, the assumptions, and the results that are the benchmark of our subsequent analysis. To advocate a large penetration of the renewable PV system onto the grid, different control strategies were investigated under Las Vegas' weather conditions for the summer 2011. The study started by collecting data from the CPV panel and NV Energy summer load. Corrections were performed prior to the analysis due to missing data. The gaps are bridged provided that the direct normal insolation (*DNI*) is greater than 50W by utilizing Eq. (1) for net power P, where *DNI* and *P* are both in W/m$^2$ [9].

$$P = 0.0045DNI - 0.99 \qquad (1)$$

Theoretical CPV grid-tied feasibility is attempted using Matlab codes. Since the codes read only full hours, the reference is set up at 1pm which is also the beginning of NV Energy's peak hours. More of the details on the strategies can be found in our accompanying work [3].

### A. *Variables and Assumptions*

Battery banks are proposed as buffers to smooth out PV output power before grid integration. Simply the power which will be put onto the grid was first treated as a variable starting from 15kW reference point. The battery was also treated as a variable parameter that sensibly equals the calculated values. After few trials, a final value corresponding to a certain level of ideal power was achieved.

On the one hand, in order to theoretically calculate the power and energy capacity of the battery banks and the number of battery modules required, some assumptions were made. Hence, the inverter's output is assumed to be 38kW and the discharge time to be equal to fractions of a second up to a maximum of 0.34h for ESS1 (aims to smooth the intermittencies) and 6 hours for ESS2 (aims to differ power). Also, the round trip loss is 12%; the inverter efficiency is 88% [10]. Finally, the battery voltage is 24V nominal. These assumptions led to an energy capacity of 851.50Ah or 20.436kWh [3]. The latter values were later fit into the codes in order to achieve uninterrupted power supply throughout the summer season (June, July, and August), but also to generate the graphs necessary for the analysis. The battery capacity was found using

$$P = \frac{E}{t} = \frac{20.436kWh}{0.34h} = 60.1kW \qquad (2)$$

On the other hand, the operation strategy required to shift part of the electrical load from peak time to off-peak time in order to cut down the electrical charge is as follows:

- ESS2 will specifically charge from the grid during night time when to power is cheap. The power conversion unit associated with it is bi-directional as can be seen from Fig. 4.

- ESS2 will then put on the grid the appropriate amount of power within the limits of its discharge constraints, i.e., from 1pm to 7pm.

Figure 4 portrays the functional diagram of the whole system. The two battery banks are placed in two different compartments and can supply power either in parallel or separately as intended.

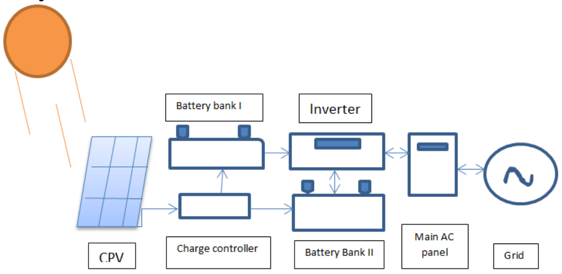


**Figure 4**- Grid-tied CPV with ESSs.

*1) Maximum power generated by the CPV*

Figure  illustrates the unit's power output for a portion of summer season.

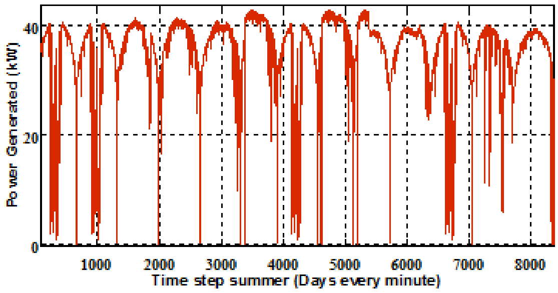


**Figure 5**- The CPV 7700 output pattern in kW, CER UNLV.

*2) The system's setup*

The operating time was divided into two parts. 1) 6am to 1pm is referred to as off-peak time. The strategy proposed is, ESS1 will store the less expensive electricity to target the peak time (Fig. 6). 2) The on-peak starts at 1pm and ends at 7pm. Here, the system is set up to contribute efficiently in shaving part of the peak load by putting onto the grid a constant amount of power and at the same time guarantees a UPS from the CPV.

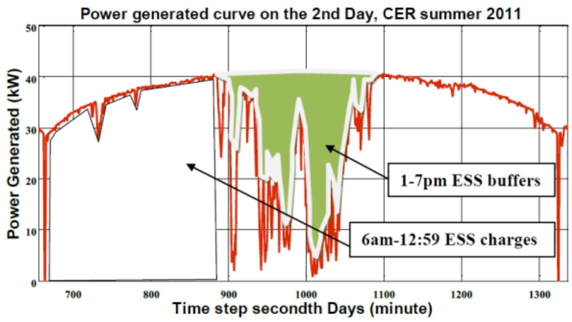


**Figure 6**- The ESS1 charges in the morning and buffers in the afternoon (Load shifting application).

The second part of this study deals with the daily and seasonal load leveling. This peak load curtailment is very crucial and enhances the economical operation of the electric power systems. Therefore, it is essential to notice that most of the time the electric load peaks at a particular time when the intensity of the sunlight, i.e., PV output is very low. Hence, these are the fundamental reasons why the second battery bank is proposed to not only store less expensive power, but also shift it at a time it is most needed. Demand shifting is meant to improve the economy and energy efficiency of electric power plants.

## IV. Battery Parameters and Functions

To better understand the techniques behind battery sizing scenarios and other parameter calculations that go along with CPV output smoothing and/or electrical load shifting, the reader is encouraged to refer to our accompanying work [3]. The findings are summarized in Table I, where ESS1 is rounded to the nearest whole number, 20kWh.

Table I. Battery capacities

| | Energy [kWh] | Functions |
|---|---|---|
| ESS1 | 20 | Power smoothening |
| ESS2 | 368 | Load shifting—off to on-peak. |
| ESS Total | 388 | Both functions |

## V. Simulation Results and Analysis

### A. Smoothing solar generation transients

We set Base power and  Battery capacity to 15kW and 30kW, respectively, in the simulations. After a few iterations, the system reached its limit and the program converged to the final constant power that the CPV with ESS1 can handle. The measured values are in perfect accordance with the simulated values. Any subsidiary transient due to clouds is solely an offset and the system is capable of achieving a constant 20kW of power. Therefore, we conclude that the study is economically and technically sound and viable. As a result, a battery bank of 60.10kW (or 20.436kWh) can achieve a constant power throughout the summer season which is known to be the worst case scenario for the entire year as illustrated in Figure 7.

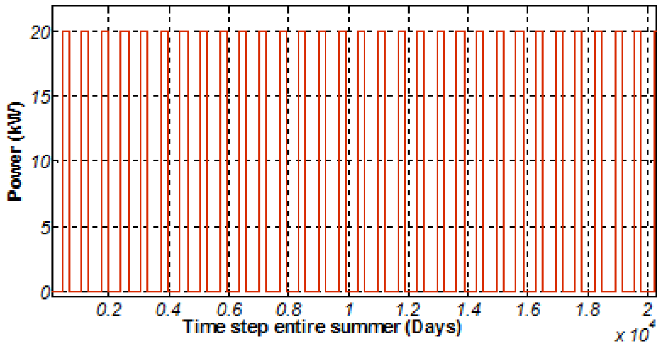


**Figure 7**- Constant 20kW produced based on 20.436kWh ESS1 for the whole summer.

### B. Load shifting

Figure 8 depicts the achievability of a constant amount of load (238kWh) to be shifted from on-peak to off-peak on a daily basis extended to the entire season. The power quality is therefore enhanced tremendously.

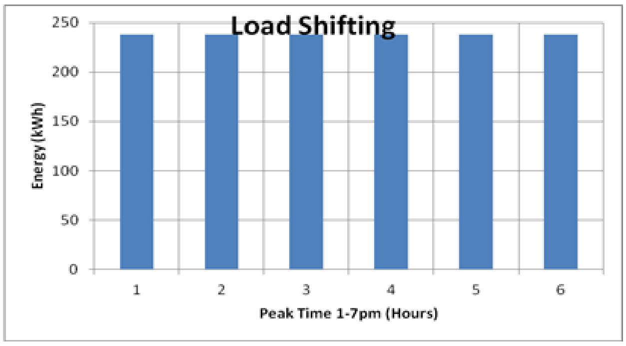


**Figure 8**- Constant 238 kWh Load shifted by the ESS2.

### *C. Analysis*

An improvement from our previous study [11] is the addition of ESS2 which added a dimension to the problem. Signs of great advantages were achievable if the unit were to be physically tied to the grid with the proper ESS (ESS1 and ESS2). For half of each day, solar power generation can be shifted to absorb an equivalent amount of load. This demonstrates the ability of the system to not only offset, but also quickly shave, severe summer peaks. It pumps onto the grid a double constant amount of power.

This study substantially showed how to mitigate solar power fluctuation due to cloud coverage by utilizing real CPV data and actual load data. Clearly, there is a link between the available CPV output and the time periods of the day when Nevada inhabitants need a reliable power supply. This paper demonstrates that the system can provide dependable summer peak capacity of $\geq$ 20kW from ESS1 on one hand and 238kW from ESS2 on the other throughout the season.

On the other hand, there is a direct correlation between PV grid integration and the amount of $CO_2$ reduced by cutting the run-time of peaker conventional plants that pollute the environment the most. It is especially noteworthy to point out that the utility industry contributed up to 34% of total $CO_2$ emissions in the US in 2010 [12].

Overall, the system can put onto the grid a constant 258kW/day for the entire summer during peak time regardless of harsh weather events based on the previous knowledge of local weather. Hence, for the CPV system of nominal 53kW installed at UNLV, furnishing a constant 258kW for the peak demand period is something acceptable at the expense of a higher ESS cost [3].

Additionally, since the average recorded power ever is less than 25kW for this unit because of weather events, the results of this study were realistic in terms of peak shaving capabilities. As a consequence of these findings, many of these units would be tied to the grid in the near future if the battery prices drop below their current values.

## VI. CONCLUSION

By means of control methods, reducing variability in voltage, frequency, and power factor angle caused by grid-tied solar power is studied. Repurposed automotive batteries that have reached end of automotive life are proposed to do the buffering job for economic purposes. Additionally, the intent is to not only prove the technical feasibility of a grid-tied CPV, but also methods that lead to their massive penetration onto the grid with a battery as buffer. Also, the study aims to foster a large scale renewable penetration on to the grid with the proper schemes. The results show that the proposed size of the partially degraded battery (388kWh) achieves a desired outcome of a constant 258kW of power. This can be put onto the grid when coupled to the unit for given weather conditions in Las Vegas during the specified period of time.

## REFERENCES


[1] R. McCann, R. Winkelman, and D. Moody, “A Battery Storage System for Distributed Demand Response in Rural Environments,” *IEEE Trans. Power …*, 2008.

[2] C. Hill, M. Such, and D. Chen, “Battery energy storage for enabling integration of distributed solar power generation,” *Smart Grid, IEEE …*, vol. 3, no. 2, pp. 850–857, 2012.

[3] Y. Moumouni and R. Jacob Baker, " CPV Battery Buffer Sizing and Economic Analysis,” submitted for publication in MWSCAS 2015.

[4] C. Venu, Y. Riffonneau, S. Bacha, and Y. Baghzouz, “Battery Storage System sizing in distribution feeders with distributed photovoltaic systems,” *2009 IEEE Bucharest PowerTech*, pp. 1–5, Jun. 2009.

[5] S. Schoenung and C. Burns, “Utility energy storage applications studies,” *Energy Conversion, IEEE …*, pp. 1–2, 1996.

[6] J. Marcos, O. Storkël, L. Marroyo, M. Garcia, and E. Lorenzo, “Storage requirements for PV power ramp-rate control,” *Sol. Energy*, vol. 99, pp. 28–35, Jan. 2014.

[7] P. Denholm and R. M. Margolis, “Evaluating the limits of solar photovoltaics (PV) in electric power systems utilizing energy storage and other enabling technologies,” *Energy Policy*, vol. 35, no. 9, pp. 4424–4433, Sep. 2007.

[8] C. W. Tan, T. C. Green, and C. a. Hernandez-Aramburo, “A stochastic method for battery sizing with uninterruptible-power and demand shift capabilities in PV (photovoltaic) systems,” *Energy*, vol. 35, no. 12, pp. 5082–5092, Dec. 2010.

[9] Aaron Sahm, private communication, Center for Energy Research, CER January 10th, 2012.

[10] J. VENTRE, *Photovoltaic systems engineering*, Second. Boca Raton London New York Washington, D.C: CRC Press, 2004.

[11] Y. Moumouni and R. F. Boehm, “utilization of Energy Storage to Buffer PV Output during Cloud transients,” 2014, Applied Mechanics and Materials, 705, 295.

[12] A. EPA, “Inventory of US greenhouse gas emissions and sinks: 1990-2009,” 2011.