2016-09-02

Energy Managment of Photovoltaic Charging Station (PV-CS) For Green University Campus Transportation

Ayda Esfandyari
Technological University Dublin, ayda.esfandyari@tudublin.ie

Brian Norton
Technological University Dublin, brian.norton@tudublin.ie

Michael Conlon
Technological University Dublin, michael.conlon@tudublin.ie

Sarah McCormack
TrinityCollege Dublin, mccorms1@tcd.ie

Recommended Citation

Esfandyari, A., Norton, B., Conlon, M. and McCormack, S. J. (2016) Energy Managment of Photovoltaic Charging Station (PV-CS) For Green University Campus Transportation. *Irish Transport Research Network* conference (ITRN), 2016, Dublin, Ireland

ENERGY MANAGMENT OF PHOTOVOLTAIC CHARGING STATION (PV-CS) FOR GREEN UNIVERSITY CAMPUS TRANSPORTATION

Ms Ayda Esfandyari[1]
PhD Candidate
Dublin Institute of Technology

Professor Brian Norton
President
Dublin Institute of Technology

Professor Michael Conlon
Head of School
Dublin Institute of Technology

Dr Sarah J. McCormack[1]
Assistant Professor
Trinity College Dublin

Abstract

Battery Electric Vehicles (BEVs) have been recognised as the ideal solution for lowering the CO_2 emissions in the transport sector and helping to achieve a sustainable future. When BEV technology is leveraged with a solar energy source such as a Photovoltaic Charging Station (PV-CS), the CO_2 saving potential is extended to both generation and consumption points. Due to the intermittent nature of our solar resource, once the PV-CS is combined with a storage unit, energy production is achieved without risking the disruption to power supply reliability and quality. Dublin Institute of Technology (DIT) has recognised the viability of this dual design solution, with its recent deployment of a 10.5 kWp PV-CS. The charging point has the potential to accommodate the existing charge of two campus Light weight Electric Vehicles (LEVs). Depending on the vehicles charge time, the demand can be accommodated through an individual or combination of the following options: direct solar, PV stored energy of BESS unit and the grid, while the surplus generation is used to charge the BESS or spilled into the grid. This paper presents the AC coupling configuration of grid tied (GT) and Battery Based (BB) inverters in the campus charging point. In order to prioritise the optimal energy flow of the PV-CS, an Energy Manager (EM) device along with Battery Energy Manager (BEM) has been incorporated. The EM controller is set with an objective to maximise self-consumption and further reduce the energy dependency on the grid. The preliminary results obtained from the online portal illustrates the relationship between the captured outputs of: PV generation, BESS charge / discharge, direct / total consumption, grid feed in and external grid supply, and further speculates the incorporated control strategy of EM and ancillary control components.

1 Introduction

Battery Electric Vehicles (BEVs) is an attractive option for substituting the conventional diesel and petrol sources, while delivering zero emission at the usage point [1]. The opportunity to cut CO_2 emission is further maximised when leveraging this technology with renewable solar energy source at the generation point [2]. Giving that BEVs are both energy consumers and storage devices, the battery element can be used as the energy storage buffer for feeding electricity back into the grid (V2G), thus helping to meet the spikes in the demand [3].The method of adopting Photovoltaic in the charging station (PV-CS) has been appraised in [4]. Accommodating the BEVs charge via PV-CS scheme has the potential to reduce the energy demand on the grid, as the electricity is locally generated in a green manner by means of solar panels. Due to intermitted nature of solar energy and the variability of PV production, smart charging can be done via load variation/curtailment and or integration of local storage as part of PV-CS design [5].

Dublin Institute of Technology (DIT) realises the value and application of BEVs vehicles for short distance commutes around its newly built campus of “Grangegorman” located in inner Dublin city. The campus vehicles are two CarryAll 13.76 kWh vehicles, referred to as Light weight Electric Vehicles (LEVs) [6]. Due to intermitted level of sunshine and variable nature of load demand, for reliable utilization of the solar generated electricity in Grangegorman the designated PV-CS design incorporated a Battery Energy Storage System (BESS) [7] .

Integration of a storage unit introduces additional system cost, as the appropriate sizing of this unit component is quite important. Previously the campus BESS capacity was evaluated based on various methods of: Peak Sunshine Hour (PSH), correlation between generation and load demand and analytical energy management optimization that was validated via TRNSYS modelling [6][7][8]. In the first approach, the days of autonomy that determine the autonomous functionality of the batteries were calculated according to Irish PSH of 2.83. The recommended battery capacities for both summer and winter loads were too bulky and infeasible. In the second approach, the DC outputs of the array were normalized, categorised into specified generation ranges and correlated with the load demand profile of the LEVs. The optimal capacity fell in the range of 6-8 kWh. The last method, adopted an energy management optimisation to justify the potential range of equivalent BESS size. The energy balancing approach adopted the Simple Payback Period (SPP) method in order to investigate the acquired positive gains (Gain-1 and Gain-2) by BESS unit. The key variables for tuning the BESS capacity were load profile and size of BESS (7 kWh, 14 kWh and 21 kWh). The recommended size of the BESS unit mainly depended on the load demand of the buggies and the energy tariffs. The optimal calculated capacity ranged between 7 to 14 kWh capacity ranges.

This paper discusses the commissioned PV-CS system in Grangegorman and provides an overview of the AC coupling configuration, i.e., AC common coupling via GT and BB inverters connection. It further considers the detail of combined PV, BESS and Inverter components while making a comparison with the equivalent designed choices. The control and ancillary monitoring and communication sensors such as Energy Home Manager (EM), Sunny Island (BEM), Sunny Remote Control(RC), SMA Radio Control Socket (CS), Energy Meter (EMET), Grid Meter (GM) are fully explained, while special attention paid to possible energy management flow signals during day and night, hence, PV- Load, PV- Battery and Battery-Load. The preliminary results of the online portal are discussed and lastly the potential for self-consumption and grid independency are concluded.

2 Deployed PV-CS in Grangegorman

2.1 AC Coupling

PV solar systems can be configured in Direct Current (DC) or Alternative Current (AC) coupled schemes [9] [10]. In the DC coupled configuration normally used in traditional off-grid system, BESS is charged by connecting the PV array to the appropriate charge controller. The charge controller has the capability to regulate the voltage and current of the battery. The system can further be accustomed with a Grid-Tied (GT) inverter to convert the PV generated electricity from DC to AC and accommodate both DC and AC types load [10].

The constructed PV-CS in this research was arranged in the AC coupled structure as shown in Figure 1. As displayed in the diagram, Battery-Based (BB) inverter has been included in addition to GT inverter as part of the system configuration. Moreover, the GT and BB inverter are coupled at a common AC point to share their energy to the load (LEV) [10]. In a normal mode of operation when PV power is available, the energy from the PV array flows through the GT inverter to the direct AC load panel (PV-Load), where any excess energy flowing through the load panel is used to charge the BB (PV-BESS) and or spilled to the grid. When the solar radiation is not available, there will be no PV power flowing through the GT and hence the loads. Therefore, the batteries will discharge to provide the required load demand (BESS-Load). This will continue until the solar radiation is retrieved or the BESS Depth of Discharge (DoD) is reached, i.e., under this circumstance grid would supply the load. When the sun returns, the system reverts to the power flow from the PV to charge the load, and once again any extra energy on the AC is converted to DC to charge the batteries.

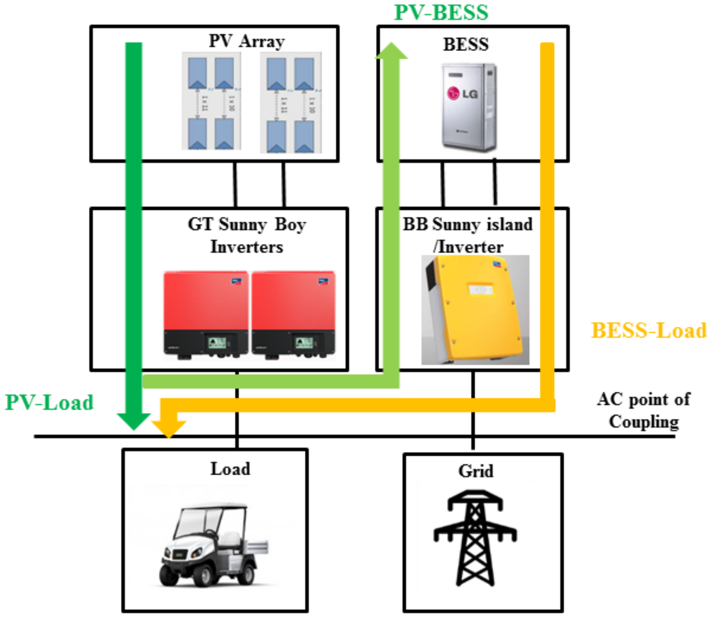

Figure 1 : AC common coupling of BESS based PV-CS via GT and BB inverters

2.2 System Components

DIT's expanding campus of Grangegorman is located in Dublin 7, i.e., this is illustrated in Figure 2 (a). During the design phase, Orchard house, i.e., Figure 2 (b)., was chosen as the potential location for deployment of campus PV-CS [6]. Nevertheless, due to protected nature of the building structure, the PV-CS location was changed and infrastructure ultimately deployed in North Annex building in Grangegorman, i.e. Figure 2 (c) shows the 3D roof plan of this building.

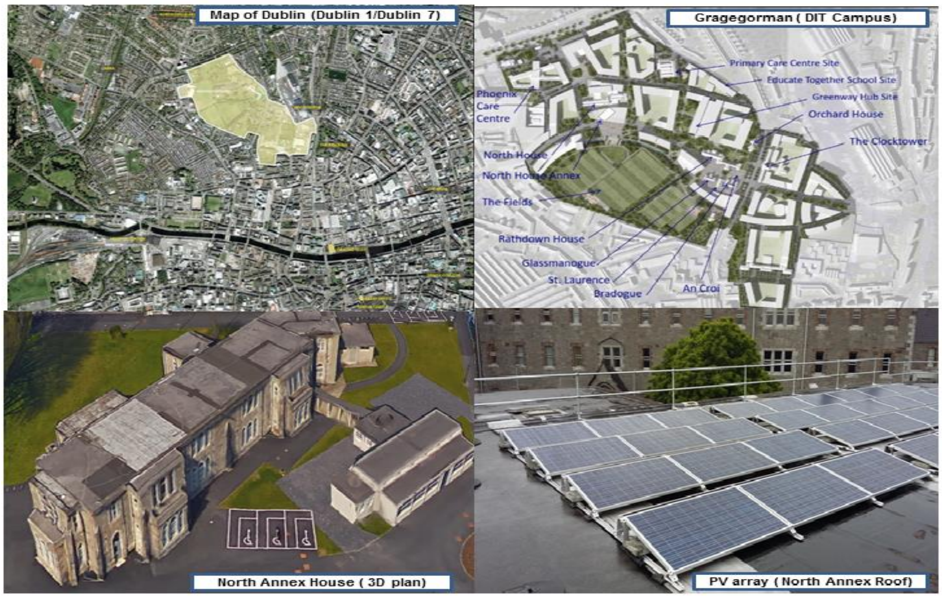

Figure 2 : System Logistics: (a): Maps of Dublin; (b): Maps of Grangegorman, (C): North Annex House, (d): PV Array roof top of North Annex

Since the main idea behind DIT's PV-CS prototype is to harvest green electricity and maximise grid independency, PV array of 10.5 kWp was recognised to have a satisfactory size [6]. As tabulated in Table 1 and shown in Figure 2 (d), the deployed PV module is composed of 42 panels and divided into 2 strings, i.e., 2x (10 series and 11 series). Each module is rated at 250 Watts at Standard Test Condition (STC). The technical details of this monocrystalline silicon based module, such as manufacturing specification [11], inclination angel, orientation and installation type is further provided in the table.

In addition, the two strings of PV are connected to two GT, i.e., SMA Sunny Boy, inverters. The MPP based inverters are sized to be in a compatible range with the PV string and thus, each GT allows maximum AC power rating of 5 kW. The specification of the GT is further provided in Table1 [12].

Table 1: PV, Inverter and BESS Specification

PV Generator Module	
PV Modules	42 of 250 Watts(4 strings of 2x10 and 2x11)
Manufacturer	Vikram Solar Pvt. Ltd
Inclination	10°
Orientation	Southeast (135 °)
Installation Type	Roof Parallel
PV Generator Surface	68.3 m^2
GT Inverter	
Inverter Type	2 x Sunny Boy 5000TL-21 (Transformerless)
Manufacturer	SMA Solar Technology AG
Configuration	MMP1 : 1x 11 | MPP2 : 1x10
BESS	
Manufacturer	SMA Solar Technology AG
BB Inverter	SMA Sunny Island 8.0-11 Set –LG Chem 5,0 kWh
Batteries	LG Chem – 1 x LG RESU 6.4 kWh + 1 unit extension 3.2 kWh
Nominal Capacity	189 Ah
Weight	60 kg
Dimension	664 mm x 406 mm x 165 mm

Finally, the assembled Lithium-ion BESS unit is manufactured by LG company. The BESS size is 9.6 kWh in total, i.e., which is composed of a unit of 6.4 kWh with a supplementary unit of 3.2 kWh [13]. As suggested by the authors in [8], the BESS capacity falls between the range of 7 kWh-14 kWh. Moreover, since the cutting edge Lithium-ion LG battery is more affordable and even more compact when compared to the new Tesla Powerwall [14], it was identified as a reasonable substitute. The BB inverter with its Battery Energy Manger (BEM) functionality is a Sunny Island SMA product [15]. Since this item is directly linked to the control and monitoring segments of PV-CS, the full performance review of this component along with the rest of the ancillary control devices is given in the next section.

3 Control and Ancillary sensor components

As explained in [16], control and monitoring of the PV and Balance of Sysem (BoS) is imperative. Moreover, BESS unit has been integrated to promote self-consumption, where the excess energy from the PV generation is accummulated. This buffered PV energy can be used when solar radiation is not avaliblible to optimise self-consumption and supply for the load. Thus, supervisory controller can monitor the measurement signals, decide on the optimal energy saving flow of PV-CS, and further amplify the share of solar generated power supply for load serving. Due to the aformentioned, the campus PV-CS encompasses an energy manager controller which can priotise the operation and reservior flows, i.e, PV-Load, PV-BESS, BESS-Load.

The controller and sensor components schematic is illustrated in Figure 3. As it is signified in the AC configured PV-CS diagram, inclusion of controller and ancillary service components, i.e., alongside PV, BESS, load, BESS, GT and BTT inverters, is indispensable.

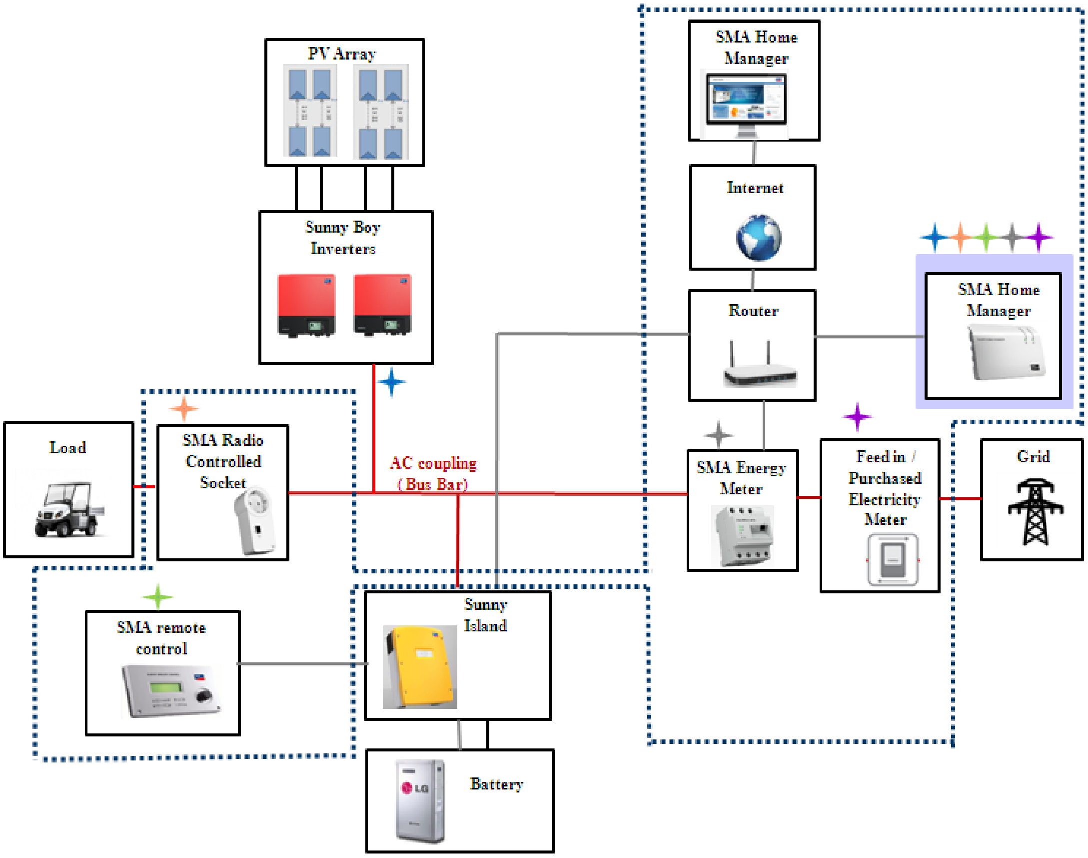

Figure 3 : AC coupled PV-CS components (Control and ancillary monitoring sensors)

The control sensors in the dashed lined area allow system flexibility, where each device has a particular role to facilitate energy prioritising and balancing. In order to understand the overall energy control of the system, understanding the functionality of the following components is vital : Sunny Island (BEM), Sunny Remote Control(RC), SMA Radio Control Socket (CS), Energy Meter (EMET), Grid Meter (GM), Energy home Manager (EM) and Sunny portal.

As stated in section 2, Sunny Island inverter which also has the BEM functionality would allow reliable control of BESS energy reservoir [15]. In other words, this BB inverter controls the electrical energy balancing in BESS for increased self-consumption. With Sunny Island systems, PV energy is continuously obtainable when it is required – even after sunset and on cloudy days. This device supplies LEVs by discharging BESS or alternatively charges the storage unit with the energy provided by PV sources (GT inverter), i.e., based on the State of Charge (SoC) and adjusted DoD of BESS. Sunny Island can further be configured to control the system from a central location using the RC display [17]. However, BEM automatic (charge and discharge) is communicated via Bluetooth to EM, i.e., as shown by the green star in Figure 3.

Load existence can be sensed via CS device which also communicates with EM via Bluetooth signals [18]. As illustrated by the orange star, this communication is especially important for cost optimisation and or load shedding, where the control decision is made by EM. Moreover, EMET and GM take phase-exact and balanced electrical measured values as a grid feed-in and purchased electricity meter and communicates these values along with PV generation data via speed wire [19]. These signals are labelled by blue, grey and purple stars.

The hub for intelligence and energy management control of PV-CS is incroprated in EM device. Sunny home manager recieves all the measurement data from the aformentioned devices, i.e. PV generation, grid feed-in, purchased electricity, load profile, battery charge and discharge. It further prioritises and optimises the overall energy flow management. This is done via intelligent load control and optimised energy management, which leads to maximised self-consumption. The priority control actions are formulated as following: whenever a load is switched on while the solar radiation is available, the PV generated energy is consumed directly (PV-Load) and any surplus is used to charge the BESS (PV-Battery) and or feed back to the grid. On other hand, when the PV generation is considerably lower than energy demand, to allow self-consumption significant portion is accommodated via BESS (BESS-Load), where the grid is used as the back-up reservoir. All the attained data in EM can further be visualised via internet connection in the sunny portal server. Sunny portal would be able to display the status of the energy flows, live graphics as well as all the numerical energy flow values. Section 4 discuss some of these preliminary obtained data from the operation of PV-CS, and further exhibits the breakdown of the energy flow signals.

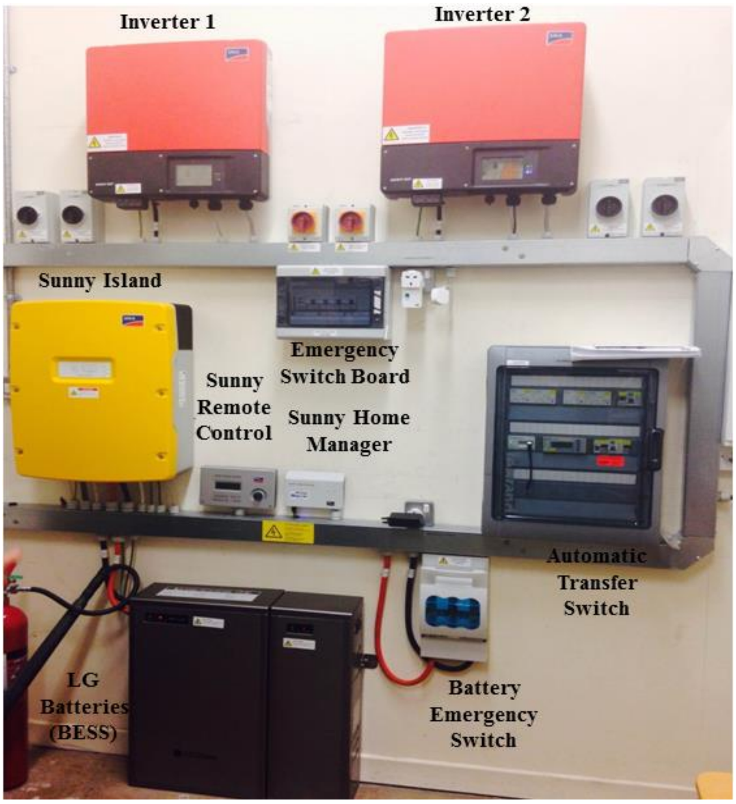

Figure 4 : BoS and Sensor Layout (Control Room in North Annex)

Figure 4 summarises all the discussed components and reveals the layout of the control room in North Annex Grangegorman.

4 System Operation Results

To increase the possibility of self-consumption and self-sufficiency, power and energy control at the AC coupled PV-CS was set with the following objective: before the PV system feeds into the utility grid, the electrical energy should be consumed directly or stored intermediately in BESS unit. Moreover, before the load draws energy from the utility grid, the energy should be provided by the PV system or by discharging the battery.

Figure 5 presents the obtained data from the online portal. The data was captured at 15-minute intervals on a daily basis for a month during July - August. The energy balancing signals are organised as follows: Daily consumption is the sum of energy consumed by the load directly in addition to the amount of energy discharged via the BESS and the injections from the grid. Internal supply is the balance of the direct consumption as well as BESS discharging, i.e., as already mentioned, direct consumption refers to the amount of load served directly via the PV. Finally, self-consumption refers to the amount of PV generation consumed via direct load serving and BESS charging. Since the day 21 had the highest level of PV generation of 59.45 kWh for green harvesting, Figure 6 illustrates the hourly breakdown of energy signals for this particular day.

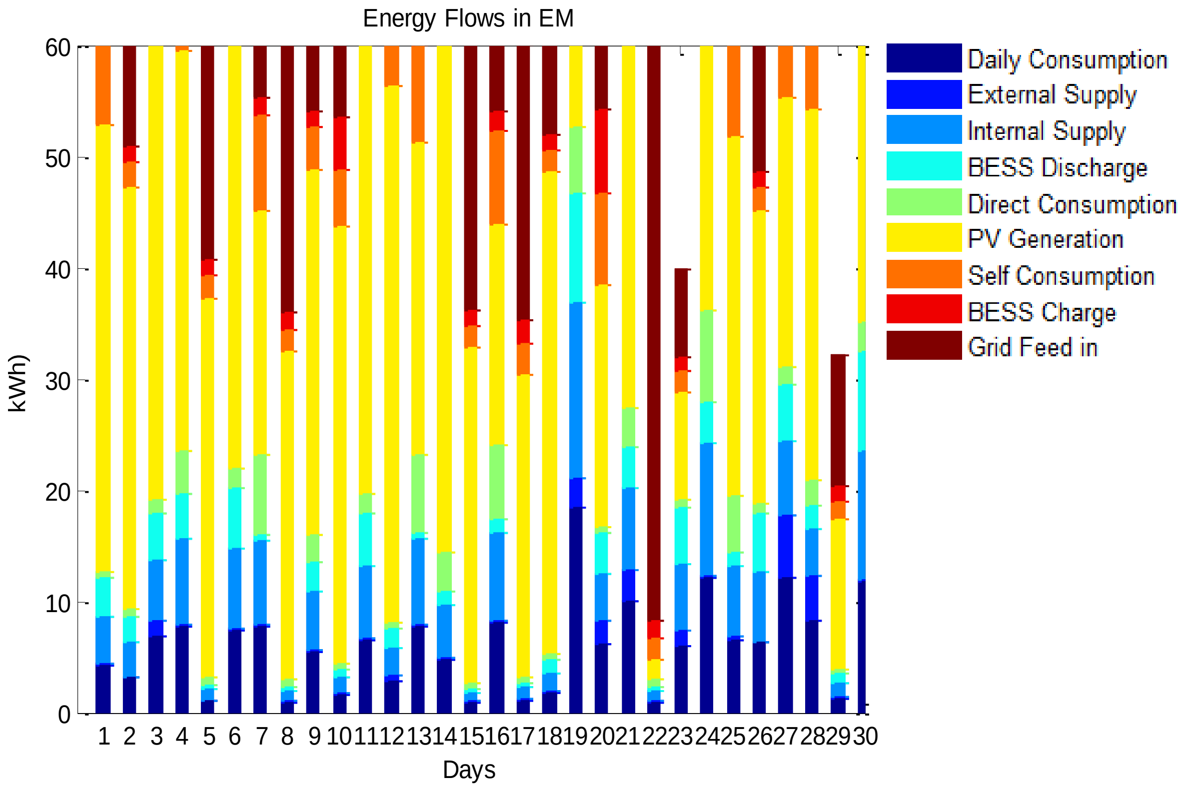

Figure 5: Energy Flow signals obtained from EM controller

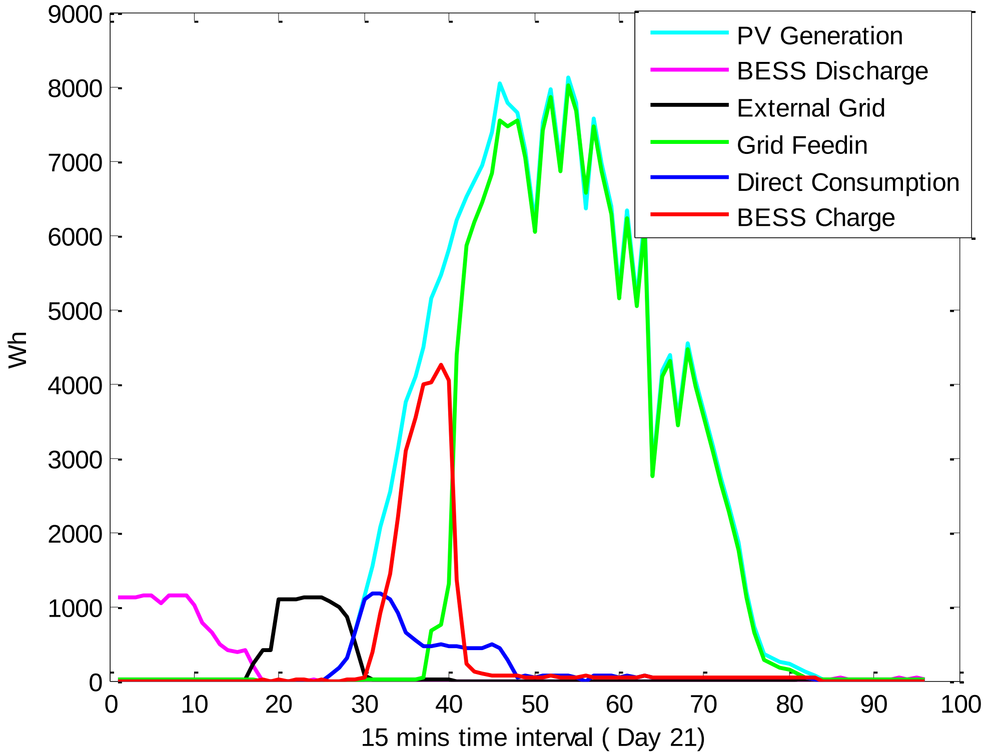

Figure 6: Energy Flow signals obtained from EM controller

As it is evident from the graph, during the hours of no sunshine, BESS unit charged the load demand by discharging its intermitted stored energy (purple line). Moreover, when solar radiation became available at 6:15 AM, it began accommodating the load directly (blue line) as well as restoring the charge of BESS (red line). Nevertheless, it is indisputable that the current level of consumption was much lower than the PV generation. In other words, although the system was self-sufficient, due to the low level of demand th#e major portion of generation was fed into the grid (green line). As the PV-CS is recently installed and data acquisition is ongoing, further investigations into optimisation and amplification of PV-CS self-consumption is required.

Conclusion

The main aim of this research was set to investigate the performance of BESS based PV-CS. The objective of EM was set to store surplus PV energy on-site, thus the additional generated energy would be accessible at later time to cover the demand of LEVs. This paper looked into the preliminary result of AC coupled PV-CS operation. The obtained result from EM controller component allowed assessment of the control prototype. Daily and monthly observations illustrated the breakdown of energy yields. To embrace the full potential of PV-CS green generation, it would be beneficial to incorporate additional auxiliary campus loads as part of the system demand. This could potentially lead to increase in system self-consumption and reduction of energy procurement from the grid.

Acknowledgment

The authors would like to acknowledge Dublin Institute of Technology, Fiosraigh Scholarship, Grangegorman Development Agency, Trinity College Dublin and all the estate management team: Mr Paul McDunphy and Mr Terry Maher.

References

[1] W. Smith, “Can EV electric vehicles address Ireland’s CO2 emissions from transport?,” *Energy*, vol. 35, no. 12, pp. 4514–4521, 2010.

[2] SEAI, “A Guide to Electric Vehicles,” 2012.

[3] W. Kempton and J. Tomić, “Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy,” *J. Power Sources*, vol. 144, no. 1, pp. 280–294, 2005.

[4] A. Rauf, Z. Salam, M. Junaidi, B. Abdul, K. Pui, and R. H. Ashique, “Electric vehicles charging using photovoltaic : Status and technological review,” *Renew. Sustain. Energy Rev.*, vol. 54, pp. 34–47, 2016.

[5] G. R. Chandra Mouli, P. Bauer, and M. Zeman, “System design for a solar powered electric vehicle charging station for workplaces,” *Appl. Energy*, vol. 168, pp. 434–443, 2016.

[6] A. Esfandyari, B. Norton, M. Conlon, and S. J. Mccormack, “Essentials for on-Campus Photovoltaic Charging Station(PV-CS): Grangegorman,” no. August, 2015.

[7] A. Esfandyari, B. Norton, M. Conlon, and S. J. Mccormack, “The Battery Energy Storage System (BESS) Design Option for On-Campus Photovoltaic Charging Station (PV-CS),” no. November, pp. 8–12, 2015.

[8] A. Esfandyari, A. Swierc, B. Norton, M. Conlon, and S. McCormack, “No Title No Title,” in *Modelling and Energy Managment Optimisation of Battery Energy Storage System (BESS) Based Photovoltaic Charging Station (PV-CS) for University Campus*, 2016.

[9] J. Weniger, T. Tjaden, J. Bergner, and V. Quaschning, “28th European Photovoltaic Solar Energy Conference and Exhibition,” in *32 European Photovoltaic Solar Energy Conference and Exhibition (PV-SEC)*, 2016, pp. 1085–1089.

[10] I. Ranaweera and O. M. Midtgård, “Optimization of operational cost for a grid-supporting PV system with battery storage,” *Renew. Energy*, vol. 88, pp. 262–272, 2016.

[11] “Active CSR | Vikram Solar.” [Online]. Available: http://www.vikramsolar.com/active-csr/.

[12] “SUNNY BOY 3000TL / 3600TL / 4000TL / 5000TL with Reactive Power Control.” [Online]. Available: http://www.sma.de/en/products/solarinverters/sunny-boy-3000tl-3600tl-4000tl-5000tl-with-reactive-power-control.html.

[13] “Product | ESS Battery | LG Chem.” [Online]. Available: http://www.lgchem.com/global/ess/ess/product-detail-PDEC0001.

[14] Tesla, “Tesla Powerwall,” 2015. [Online]. Available: http://www.teslamotors.com/powerwall. [Accessed: 02-Aug-2015].

[15] “SUNNY ISLAND 6.0H / 8.0H.” [Online]. Available: http://www.sma.de/en/products/battery-inverters/sunny-island-60h-80h.html.

[16] A. Esfandyari, K. O’Fareell, B. Norton, and S. J. McCormack, “Electric Bike Photovoltaic Charging Station (PV _ CS):Experimental Design for fault Investigations,” in *Irish Transport Research Netwoerk(ITRN)*, 2014.

[17] “SUNNY REMOTE CONTROL.” [Online]. Available: http://www.sma.de/en/products/battery-inverters/sunny-remote-control.html.

[18] "SUNNY HOME MANAGER." [Online]. Available: http://www.sma.de/en/products/monitoring-control/sunny-home-manager.html.

[19] "SMA ENERGY METER." [Online]. Available: http://www.sma.de/en/products/monitoring-control/sma-energy-meter.html.