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Performance and cost analysis of building scale micro-grid operation

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Abstract

The energy targets of the Sustainable Development Goals (SDGs) call for both a reduction of total energy use and an increase in the share of renewables as part of the total consumed energy. With the emergence of Renewable Energy Systems (RES) on a local scale there is still little research on the efficiency of actual micro-grids on building scale, let alone on how their functioning relates to reaching the energy targets of the SDGs. Here it is shown how an expected degree of decrease in renewable energy generation from solar panels, combined with a failure to anticipate intensifying building energy needs, can impede reaching the SDGs' energy targets on the local level. When examining a building scale micro-grid, not only had solar panel performance decreased by twice the expected average, but building energy use had doubled by 156-203%, and thereby the share of renewable energy of total energy use has decreased by 29-47%, depending on the season. This indicates that in order to reach the SDG energy targets, it is important that newly designed building, as well as community Energy Management Systems, do not merely account for current energy users, but accommodate increasing RES concurrent to increasing energy demand.

Keywords: BEMS; RES; micro-grid; performance analysis; cost analysis; PV; lead-acid battery; SDGs

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1. Introduction

Goal 7 of the Sustainable Development Goals (SDGs), affordable and clean energy, calls for energy transition in the form of both a substantial increase in renewable energy as a share of total energy use, and a doubling of the global rate of improvement in energy efficiency, to be reached by 2030 [1]. Methods to help reach the energy targets of the SDGs include decreasing total energy consumption and the localized generation of renewable energy (Fig.1).

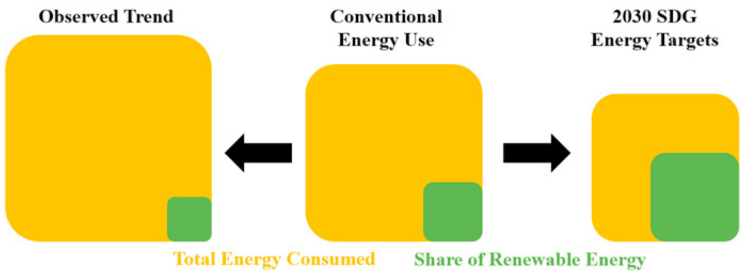

Fig. 1. Current and future energy use as envisioned by the SDGs (based on [2]).

For individual households there are now ample options to both decrease total energy consumption and increase the share of renewable energy used. Scaling up to larger, especially high-rise buildings, achieving the SDG energy targets becomes more difficult. While organizations owning larger sized buildings may have larger funds available to invest in Renewable Energy Systems (RES) and find additional motivation in promoting the image of being sustainable, the physical and geographical characteristics of many buildings, in combination with high energy consumption, leave comparatively little opportunity for localized RES reaching the SDG energy targets. This can be aggravated by design limitations that complicate maintenance as well as RES not growing in proportion to building energy use, which leads to a decreased share of renewable energy from the total energy use: the opposite trends of the energy targets of the SDGs. This issue may be solved through future larger (regional) scale integrated operations by community energy management systems that regulate energy transfers between storage batteries, high demand functions from building energy management systems, and hybrid RES with surplus energy production [3].

The NanoGREEN/WPI-MANA building of the National Institute for Materials Science (NIMS) is the first commercial building in Japan to be installed with a “Micro-Grid System”. This is an RES consisting of four arrays of solar panels (photovoltaic (PV) electricity generation) (Fig. 2, Table 1) and a lead-acid battery, enabling energy-saving during peak hours of electricity consumption and costs, as well as a backup energy supply during emergencies. It is incorporated into the building Energy Management System (EMS). Since installation in 2012 and start of operation in 2013, the solar panels have not undergone any maintenance, and the efficiency of the system is not known. The objective is therefore to determine to what degree the solar panels of the micro-grid are cost effective, given their expected decline in performance ratio. At the same time, the building’s total remaining energy use is examined.

Table 1. Overview of micro-grid PV array characteristics

Array #	Location	Crystalline Silicon Type	Capacity [kW]	Panels (#)	Area [m^2]
1	Roof, east and west sides	Mono-Si	50.73	380	332.78
2	Roof, center north and south sides	Multi-Si	24.74	399	251.44
3	Roof, center north and south sides	Mono-Si	11.33	60	107.81
4	Wall, east side	Multi-Si	3.78	18	29.56

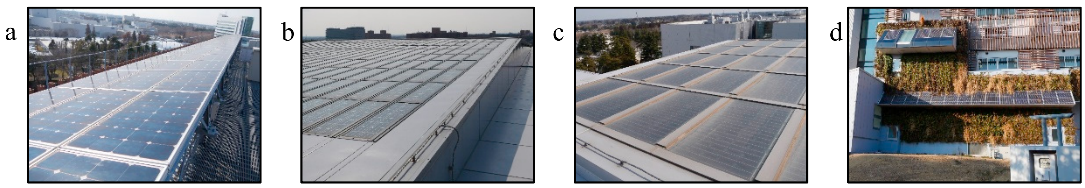

Fig. 2. Micro-grid PV Arrays (a) array 1; (b) array 2; (c) array 3; (d) array 4.

Despite the increase in studies regarding micro-grids and smart grids applying renewable energy systems [4], few studies report micro-grid performance and cost analysis as opposed to hypothetical optimization. Furthermore, while household sizes often increase, or more electricity consuming products are installed over the years, in commercial and research sized facilities these effects are often enlarged. As a novel viewpoint, this study compares the development of the originally installed PV capacity and performance with building energy use.

2. Methods

On 26 and 27/02/2018 the four solar panel arrays were inspected for visible defects, soiling, etc. and the findings documented with photo camera and infrared camera (FLIR ONE Pro) where possible. Not all panels were accessible due to proximity of installed heavy machinery on the rooftop (Fig. 3c). Taking infrared (IR) pictures of the top surface of the panels led to cloud reflections, therefore, pictures were taken from the rear surface instead. Taking IR pictures of array 2 was not possible due to rooftop integration (Fig. 2b).

Regarding data availability and analysis, a 5-year hourly data set of the micro-grid was available for analysis (solar irradiation [W/m^2], solar power generation [kWh], battery charge/discharge [kWh], and electricity from the utility company to cover the remaining building energy consumption [kWh]). Missing or erroneous data were excluded. The total usable data formed 42,882 hours or 97.64% of the total set. A second data set concerned electricity contract prices varying by hour, season, and year [5]. This consists of annually increasing electricity prices for the periods: holiday/Sunday/night time (22:00-08:00); summer peak time (13:00-16:00, Jul-Sep, non-holiday etc.); summer day time (08:00-22:00, Jul-Sep, non-peak time, non-holiday etc.); and non-summer day time (08:00-22:00, non-holiday etc.). Note that fuel regulatory costs (adjustment charges), basic connection and spare line fees, and other costs related to the entire research site were not considered. A more accurate data set from the micro-grid was available for 1-year (03/2016-02/2017), which was measured and recorded at slightly earlier time intervals. Compared seasonally, these values proved to be within 3.9% difference volumetric wise, upon which continuation of use of the 5-year data set was deemed justified.

As data were available in excel file format, the files were combined using VBA programming and manually checked for consistency/validity. PV efficiency was compared monthly to the first year of operation relative to solar irradiation (Financial Year 2013, commencing in April). The hourly data was linked to the electricity price of the respective moments in time through an if/then formula. The final results were compared per season and per year.

3. Results

Solar panels in array 1 suffer from shade by design errors, with as main cause the mandatory placement of a lightning conduction wire on the south side of the building (Fig. 2a). IR photos showed some overheating cells (Fig. 3a) among the 250 inspected panels (32 cells/panel, Fig. 3b). Other shadows were caused by the building itself and a closely placed antenna (Fig. 3c), which was also found to attract birds and thereby dirt. Arrays 2 and 3 are affected by dirt accumulation (Fig. 3d). Array 4 suffers from overgrowing plants, and shade from a nearby building (Fig. 2d). During measurements of Fig. 3a-c, the ambient temperature was between 5.8-9.4 °C.

When analyzing the results per year and per season, battery charging has always been higher than battery discharging. It has also nearly always cost more than it has saved cost-wise, with four exceptions. Financially this is not a great burden or profit as the total seasonal costs-savings run between -21,153 and 14,002 JPY (USD -195 – 129 as per April 2018 conversion rates [6]). Averaging the monthly solar panel efficiency, the decrease over 5 years was 10.12%, amounting to 2.02% annually.

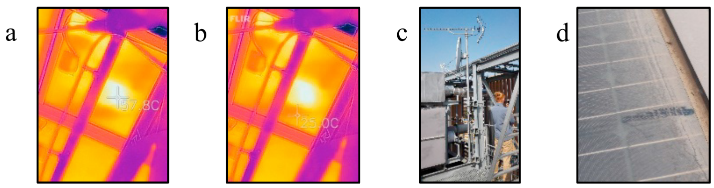

Fig. 3. Visual inspection (a) overheating cell 57.8 °C; (b) normal cell 25.0 °C; (c) antenna adjacent to panels (array 1); (d) dirt (array 3).

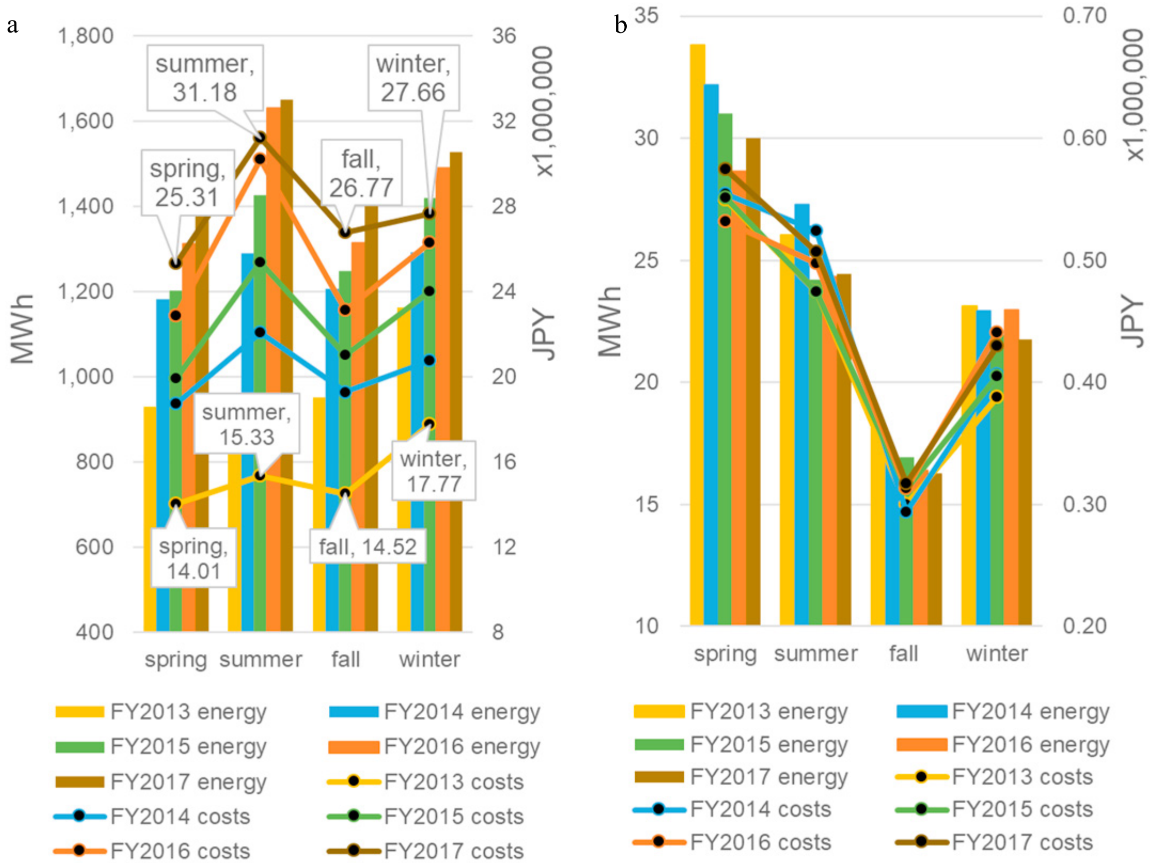

Fig. 4. (a) net building energy use [MWh] and costs [JPY]; (b) PV energy generation [MWh] and saved costs [JPY].

As for cost effectiveness, over the past five years electricity prices have increased from 12.10 JPY/kWh (night/holiday time)/19.85 JPY/kWh (summer peak time) to 15.18 JPY/kWh / 22.79 JPY/kWh. The remaining building energy use has close to doubled in most seasons (Fig. 4a), whereas the installed PV capacity has remained the same and its performance ratio has decreased (Fig. 4b). When evaluating the FY2013 net building energy costs (set at 100%), the corresponding price trends show the opposite directions of what is ideally desired when considering the SDGs involving decreasing energy use and increasing the % of renewable energy sources (Fig. 5), as both energy costs (and use) are increasing and the share of costs saved by PV (and generation) is decreasing.

4. Discussion and conclusions

The battery is designed to operate with two potentially conflicting goals: reducing energy use from the main grid and thereby reducing costs during the peak hours of summer, and functioning as an emergency power backup. In case the battery has become depleted during the day time when reducing energy from the main grid, the battery is recharged in the late hours of summer daytime prices. This phenomenon occurs on most days during summer, and is the main cause of high costs of battery charging. As there are no known studies to value the power quality and stability functions of integrated HRES [7], the value of steady emergency backup power was not part of this cost analysis. Despite the doubling of the building energy use, on a daily basis the peak cut (during summer) helps save several tens of kW from the total energy use. Contract details mention that an excess use of power beyond a set amount would be charged to 150% of the normal price, implying that peak cut helps save surcharge costs as well.

Compared to the average PV degradation for mono/multi crystalline Si PV of <1% annually [8], the annual average decrease of solar panel performance of 2.02% is significantly larger. As pointed out by [8], panels with high degradation rates are usually removed or replaced and thereby not reported as often as panels with low degradation rates. As 90% efficiency for the first 10 years of operation is guaranteed by the warranty of the solar panels, it is unrealistic the current performance of 89.88% can be maintained to nearly fulfill this guarantee. Part of the reduction in electricity generation by the solar panels can be lessened since it is not due to irreversible degradation, but rather due to neglected maintenance and overgrowth by plants. Although the electricity generation reduction caused by shading from the lighting conduction wire is minor, this partial shading represents a strong risk of early PV module failure due to the formation of hot spots, for which the overheating cells are a first indication.

Building energy use has increased by >100%, as the building still had many unoccupied rooms at the start of the operation in FY2013. Since FY2018 the building has become close to fully occupied. It is therefore likely the current building energy use will no longer increase significantly. The solar power generation will however continue to decrease. Though the observed trends are in opposition of the ideal SDG targets and may be lessened by maintenance, the effects cannot be reversed without compensating for the large increase of building energy use. The installation of additional solar panels in proportion to this increase can help overcome this trend. Their location may be on the side of the building, the rooftops of neighboring buildings, or above car parking lots. As of 2017, no method exists for assessing the economic and environmental impacts of smart grids [9]. To reach the SDG energy targets, future economic and environment impact assessments of newly designed building and community EMS should anticipate and allow for increasing RES concurrent to increasing energy demand.

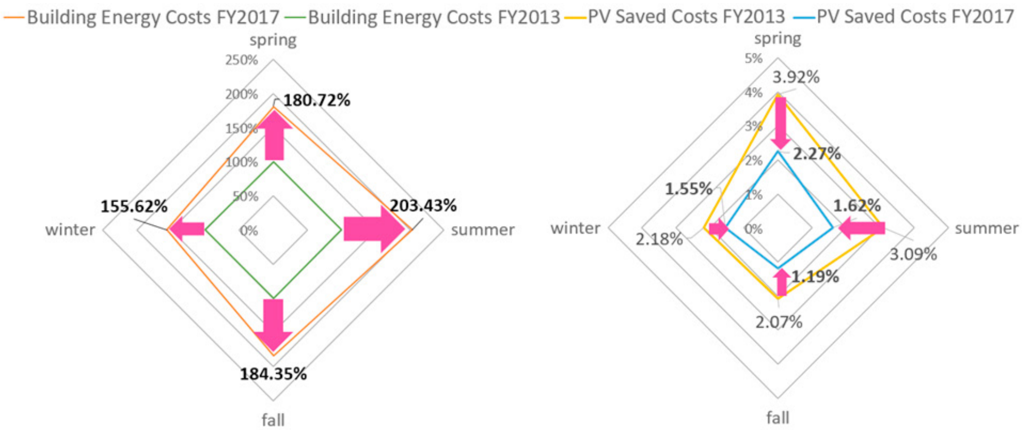

Fig. 5. Net building energy costs and PV saved costs in FY2013 & 2018.

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References

[1] UNDP. Goal 7 targets. 2019. http://www.undp.org/content/undp/en/home/sustainable-development-goals/
[2] Maes B. Utilities under transformation. Elia Group International; 2018.
[3] Toshiba Corporation. Development of Community Energy Management System. 2018. https://www.toshiba.co.jp/rdc/rd/fields/12_e04_e.htm
[4] Cardenas J, Gemoets L, Ablanedo R, Jose H, Sarfi R. A literature survey on smart grid distribution: an analytical approach. J Clean Prod 2014; 65: 202-216.
[5] Tokyo Electric Power Energy Partner. High pressure seasonal power by time zone. http://www.tepco.co.jp/ep/corporate/plan_h/plan09.html
[6] XE Currency Converter. 2018. https://www.xe.com/
[7] Fathima AH, Palanisamy K. Optimization in microgrids with hybrid energy systems – a review. Renew Sust Energ Rev 2015; 45(C): 431-446.
[8] Jordan, DC, Kurtz SR. Photovoltaic Degradation Rates - An Analytical Review. NREL; NREL/JA-5200-51664, 2012.
[9] Moretti M et al. A systematic review of environmental and economic impacts of smart grids. Renew Sust Energ Rev 2017; 68(2): 888-898.