ORIGINAL PAPER

ASSESSMENT OF A DATA CENTER MICROGRID WITH STORAGE AND PHOTOVOLTAIC GENERATION

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Manuscript received: 30.09.2019. Accepted paper: 04.11.2019.

Published online: 30.12.2019.

Abstract. *On-premises Data Centers have constant high energy demands, they represent an olways-on load at buildings energy balance level. By separating such a load in behind a microgrid system with storage and photovoltaic generation, important CO2 reductions could be achieved. This paper presents the results of such an implementation analyzed from a technical and economical point of view. The pilot installation is analized based on a 3-year data set, measurements consisting in: consumption, PV production, imported energy and storage operation. The pilot achieved for 2017 a 59.66% PV energy coverage from its total usage, thus a financial economy of estimated 3300 Euro from the energy bills. Based on the simulation results the Return of Investment is at the end of the operational lifetime of the installation considering no state incentives nor energy export sold back to the grid. A total of 22.4 T/year CO2 emissions are avoided.*

Keywords: *Data Center, IT infrastructure; Off-Grid photovoltaic; Self consumption PV; Energy Self-Sufficiency; Energy Management; Return of Investment; Economic analysis.*

1. INTRODUCTION

Based on the European Union (EU) Building Stock Observatory: 35% of the buildings are over 50 years old and 75% of the building stock is energy inefficient. They consume more than 40% of the total energy and they are responsible for 36% of the CO2 emissions. Energy efficiency is at the cornerstone of the European energy policy and one of the main targets of the EU 2020 Strategy for smart, sustainable and inclusive growth adopted by the European Council in June 2010. [1]

In Romania, Education and Public Administration buildings represent 50% of the total non-residential consumption. [2] Under the current Energy Performance of Buildings Directive (2010/31/EU) - All new buildings must be nearly zero-energy buildings (nZEB) by 31 December 2020 (public buildings by 31 December 2018).

In office buildings the on-premises Data Centers and the IT infrastructure are one of the main power consumers. Their 24 hours a day continuous operation and cooling needs makes them the second largest consumer after Heating Ventilation and Air Conditioning (HVAC). [3] Trends in IT tend to externalize these services or migrate them into third-party

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clouds, nowadays hybrid structures are the de facto standard. New data privacy General Data Protection Regulation (GDPR) regulations favor this hybrid cloud (on premises + in cloud) approach. [4] The ICSTM IT infrastructure and Data Center is a hybrid cloud arhitecture and a converged network topology, local storage being used with resiliency in mind.

Global computing power demand is growing 20% a year, consuming approximately 3-5% of the world's electricity in 2015. Following a 2016 study, Andrae [5] concluded that without staged increases in energy efficiency, the IT infrastructures could use 20% of world's electricity and emit up to 5.5% of the world's carbon emissions by 2025.

Solar radiation is one of the best alternatives for covering high energy demands in self-sufficient enclosed systems. [6] Achieving higher levels of energy efficiency in buildings by incorporating active (PV modules) construction elements represents a solution that could be used in retrofitting and in new architectural concepts. [7] Distributed energy generation (at regional level) contributes to a larger CO2 reduction impact over the environment. [8,9] Large scale grid storage or distributed PV systems with integrated storage are key elements in the distribution network balance. [10]

Storage of electricity from sun over night presents technical problems for which there are no economical industrial solutions at present time. [11] Main technologies used nowadays are lead acid batteries, flooded lead acid batteries OPzS or the more expensive lithium technology / LiFePO. Due to Lithium extraction price decrease, they become the main standard. [12-15]

Sizing a microgrid with storage PV system [16] for Data Center needs is a technical challenge which we will describe in this paper. The pilot system developed, operated well for the past 3 years and we will further present its results. Important economies were achieved at the level of buildings net energy balance.

This paper presents RDI results from the Institute of Multidisciplinary Research for Science and Technology (ICSTM) of Valahia University from Targoviste. Its building is specifically built to suit all requirements of research laboratories and the technical requirements for nZEB. This pilot site or "living laboratory" is also used for the study of Building Integrated Photovoltaics (BIPV), distributed networks and Building Automation and Control Systems (BACS). The microgrid, used in this study, powers the entire IT infrastructure (including the Data Center and its cooling) of the institute using PV modules installed on the south facade of the building and a storage area in the basement. (Figure 1)

Figure 1. ICSTM BIPV (sun-shading, curtainwall and large array tracker) microgrid power source.

2. MATERIALS AND METHODS

The IT infrastructure that drives the information backbone of ICSTM is constructed on a converged network with the following Data Center Tier level 2 (according to Uptime Institute: Tier 2 – Redundant, Tier 3 - Concurrently Maintainable, Tier 4 - Fault Tolerant).

IT resilience is the ability to seamlessly adapt to change while protecting one's activity and collaborators from disruptions. This is achieved at the ICSTM DC level by using Microsoft hybrid cloud technologies and Citrix Xen workload mobility. Continuous data protection (replication, journal-based recovery, long-term retention) are enabled by using HP 3PAR and OneStore.

Figure 2. ICSTM Data Center (front: primary; back: secondary + distribution; right side: collocation).

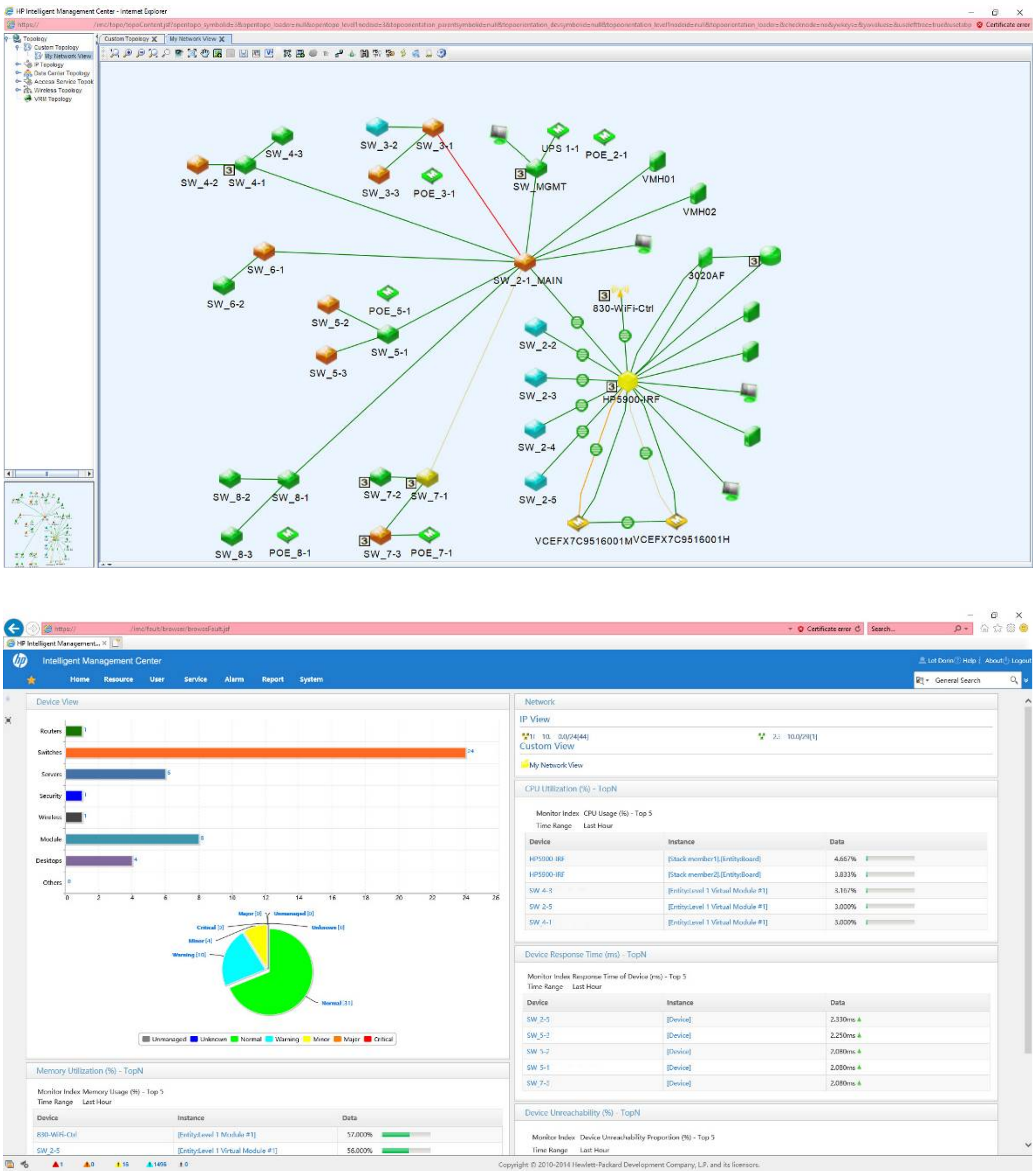
The DC is situated in a specially designed room endowed with antistatic walls and flooring, sound-insulation; redundant Inverter type air conditioning and an autonomous fire suppression system (Clean agent is waterless and does no harm to electronic components. Data center can remain operational during a discharge). (Figure 2 - top red fire suppression)

In Figure 3 the primary rack hosts:

- WAN interconnect (HP MSR3024 AC Router; Next Generation Firewall HP S3020F; 2x switch TOR HP 5900AF-48XG-4QSFP+; wireless controller HP 830),
- Processing (16U blade servers Enclosure HP C7000, with 2 HP Blade System Proliant BL460Gen9 and 2 HP Blade System Proliant WS460Gen9),
- Storage (Fast Storage array HP 3Par and one NAS server)

The secondary rack hosts 4 more servers used for internal systems (BACS, Licensing, Access control, a.o); third rack hosts distribution switches for part of the network and the fourth rack hosts 4 collocated servers and a NAT storage unit. All these 8 servers are not energy efficient.

The distribution network is CAT 6A 10GBASE-T with 8 regional racks with an average of 3 managed switches. Power over Ethernet PoE injectors in each rack, are serving Voice Over IP phones and WiFi Access Points. The SW/HW management is done using centralized platforms (HP Intelligent Management Center IMC and HP OneView). The network topology and the Energy Management System EMS are integrated for ease of management. (Figure 3)



a) b)

Figure 3. ICSTM Network Operation Center (NOC): a) Live network diagram, b) HP IMC.

This IT infrastructure (DC and NOC plus distribution) except end points is entirely powered by a **Microgrid PV System**. Green IT in this concept means Zero energy usage for all services. This is a carefully weighted solution for 24 hours a day, 365 per year, power consumer. The microgrid system also assures energy security for the entire IT infrastructure.

The generation part of the system consists in sun shading Building Integrated Photovoltaic BIPV semitransparent modules. These solar modules were custom designed to fit the chromatic of the buildings facade and to allow enough natural light for use in the south facing laboratories as well as for use on the main hallway.

The distributed PV system totals 43kWp peak power installed and is comprised from the following installations:

- 30kWp Microgrid powering the entire IT infrastructure and data centre of the institute. From BIPV sun shading custom semitransparent PV modules at 60 degrees and curtain wall

90 degrees commercial installed PV modules. Driven by inverter-chargers and a 48V 190kWh VRLA gel battery bank. With a 12 hours autonomy in case of a black out.

- 4.5kWp Emergency (UPS configuration) hybrid PV-Wind with Self-Consumption and surplus power delivery. From 60 degrees fixed inclination semitransparent PV modules installed as sunshades and one MagLev with Darrieus-Savonius rotor wind turbine driven by inverter-chargers with a 48V 32kWh VRLA gel battery bank. Providing 20 hours backup time in case of a black out. Connected inside the microgrid.
- 3.7kWp Self-Consumption and surplus power delivery On-grid PV for LED Street lighting. From BIPV sun shading custom semitransparent PV modules at 60 degrees, driven by inverter-chargers with a 48V 21kWh VRLA gel battery bank. Connected inside the microgrid.
- 4.5kWp On-Grid Large Array solar tracker with commercial PV modules installed.

Figure 4. Microgrid power distribution room.

The microgrid is piloted by a group of 6 hybrid inverters Victron Multiplus 5kW connected 3p4w master/slave per phase. (Figure 4) The PV modules are charging the battery banks using 10 Victron Blue Power MPPT regulators with 4 points charge curves. The battery banks are comprised of Victron VRLA Gel Deep Cycle 220Ah batteries. All devices are interconnected by individual bus lines with a central controller (Victron ColorGX).

The system controller also acts as a performance monitoring data logger. It long term stores Digital Acquisition DAQ data to cloud servers over secured Internet connection. The logged data respects IEC 61724 requirements. [17] Environmental monitoring is done at Baseline Surface Radiation Network BSRN standards with calculations of uncertainties and solar spectral correction. [18]

3. RESULTS AND DISCUSSION

Consumption analysis

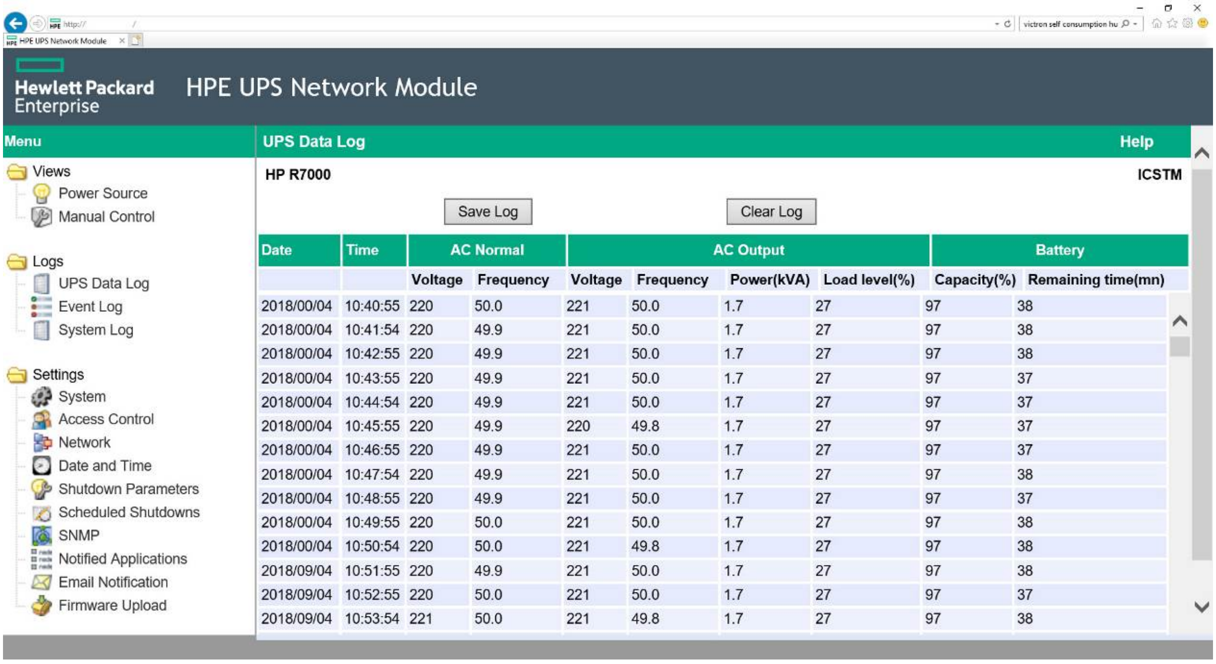
The main loads considered to be integrated into the pilot microgrid development were:

- The Institute's Data Center (processing servers, graphical workstations, storage servers, primary wan interconnect comprised of router, firewall and top of rack switches; the distribution network infrastructure cabled and WiFi) inventory: 4 DC rack's plus 8 distribution net racks, 7 UPS's and 6 distinct electrical circuits;
- The ICSTM buildings 3 elevators for emergency back-up;
- 4 sewage waters pumps from the basement;

- Power security for a critical consumer, the Scanning Electron Beam Microscope (SEM);
- Perimeter street lighting.

Total available storage is of 190kWh. To ensure Tier 2 level for the DC energy management scenario special care was taken to sort loads on specific distributed PV systems. Each individual system was configured with an EMS scenario.

The primary DC rack is EMS enabled. Granular politics of energy efficiency were implemented, and special care was taken over the redundancy of the power source. Thus, 2 UPS are used, one of them in N+1 configuration. The blade server's chassis has its own integrated power and ventilation mechanisms based on physical zones.



Date	Time	AC Normal		AC Output				Battery	
		Voltage	Frequency	Voltage	Frequency	Power(kVA)	Load level(%)	Capacity(%)	Remaining time(mn)
2018/00/04	10:40:55	220	50.0	221	50.0	1.7	27	97	38
2018/00/04	10:41:54	220	49.9	221	50.0	1.7	27	97	38
2018/00/04	10:42:55	220	49.9	221	50.0	1.7	27	97	38
2018/00/04	10:43:55	220	49.9	221	50.0	1.7	27	97	37
2018/00/04	10:44:54	220	49.9	221	50.0	1.7	27	97	37
2018/00/04	10:45:55	220	49.9	220	49.8	1.7	27	97	37
2018/00/04	10:46:55	220	49.9	221	50.0	1.7	27	97	37
2018/00/04	10:47:54	220	49.9	221	50.0	1.7	27	97	38
2018/00/04	10:48:55	220	49.9	221	50.0	1.7	27	97	37
2018/00/04	10:49:55	220	50.0	221	50.0	1.7	27	97	38
2018/00/04	10:50:54	220	50.0	221	49.8	1.7	27	97	38
2018/09/04	10:51:55	220	49.9	221	50.0	1.7	27	97	38
2018/09/04	10:52:55	220	50.0	221	50.0	1.7	27	97	37
2018/09/04	10:53:54	221	50.0	221	49.8	1.7	27	97	38

Figure 5. DC Primary rack main UPS logs.

From Figure 5 we can observe average 1.8kWh consumption over 2 hours. At highest peak loads the primary rack consumed 4.1kWh when intensive GPU computing tasks were running. Power capping ensures Virtual servers' migration between the different physical hosts cluster configured. The secondary UPS serves exclusively the networking equipment and works in tandem with the main one.

The blade chassis is software licensed for environmental and power monitoring as well as for ventilation management. Redundancy is achieved both at power and at connection level (8 redundant power sources 80 Gold efficiency and 10 redundant fans, all plug-and-play). There are 2 independent electric circuits connecting the main UPS on 2 separate phases of the microgrid system.

From Figure 6 we can observe average 700Wh power consumption of the blade servers. This value is achieved during idle operation, no CAD/CAE workstation loaded in the virtual environment. Note: first cluster servers are using low power processors (CPU) and low voltage RAM, the second cluster uses high power CPU and GPU units.

At DC level we also must consider the power needs of the 2 redundant AC units. To estimate this value, we must consider the building envelope (walls and floors radiating heat) and the processing needs served. Considering the best thermal insulation is provided, the influence of outside temperature over the operating hours of the AC units is minimal, thus it remains only the daytime usage dissipated heat of the servers to be considered.

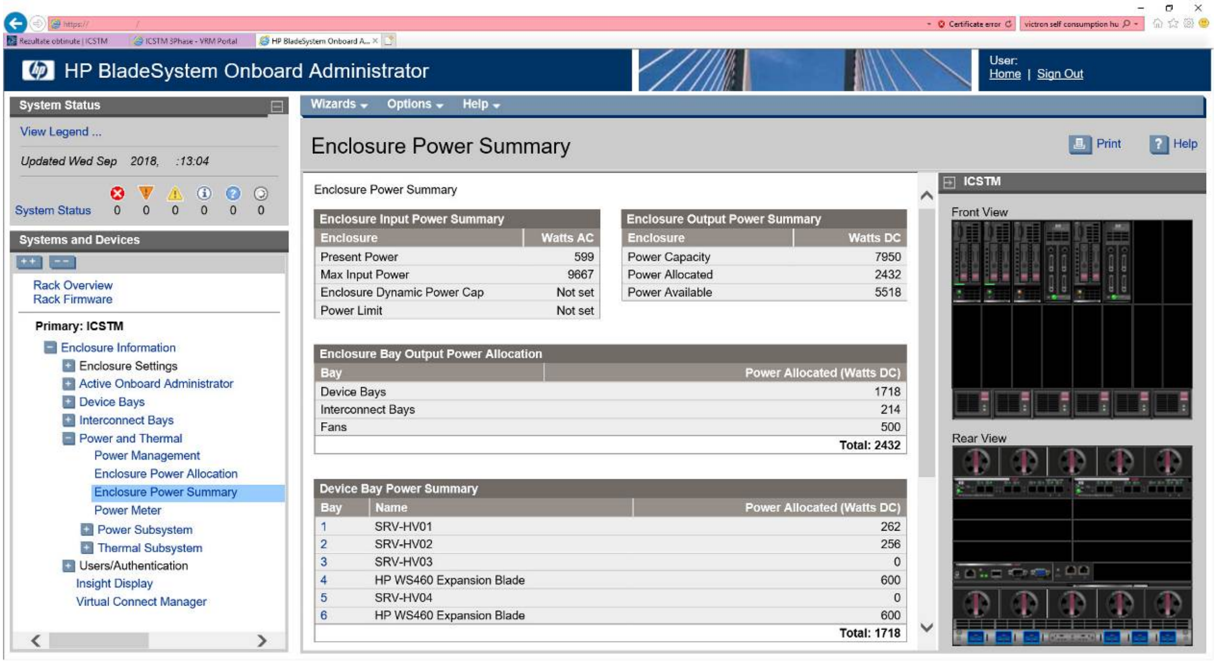


Figure 6. Blade chassis power monitoring.

Production analysis

Performance data analyzed from the long-term cloud storage [Note: all data is available open access at reference 19] reveals that the largest consumption of 5,8MW was in January 2018. (Figure 7) At that date the PV production was of only about 700kWh because of wintertime inability of snow cleaning of the PV modules. Although, the module's inclination is stiff, and behind them the air cushion should melt the snow, this process happens slowly for 2 or more days.

One would consider that the consumption from an IT infrastructure should be more of a constant. The explanation is that the presented data is from a distributed system, 3 other installations (2 configured in self-consumption and one On-Grid) provide PV power at daytime thus helping the main system recover battery charge faster.

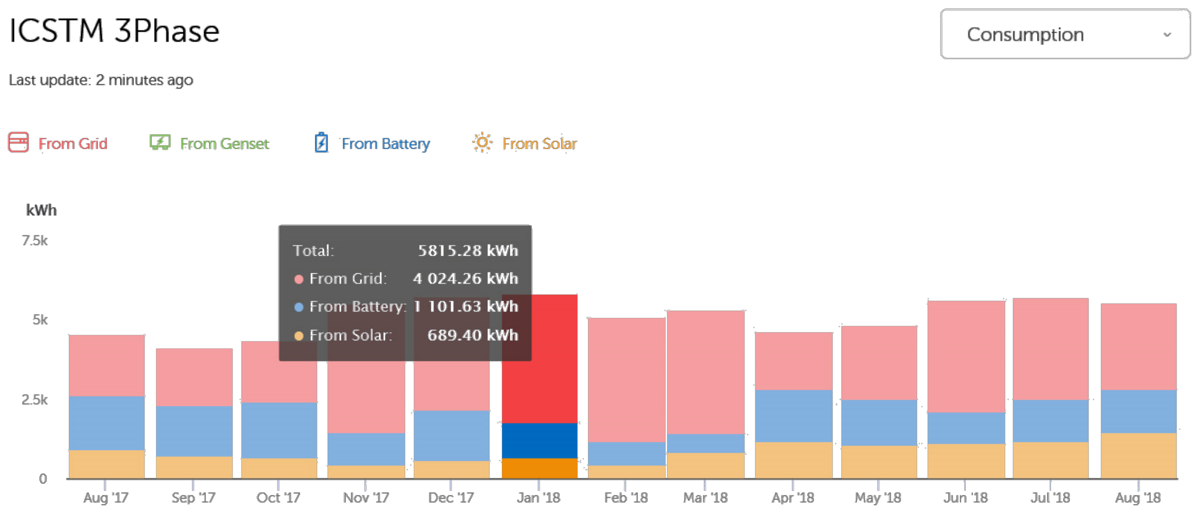
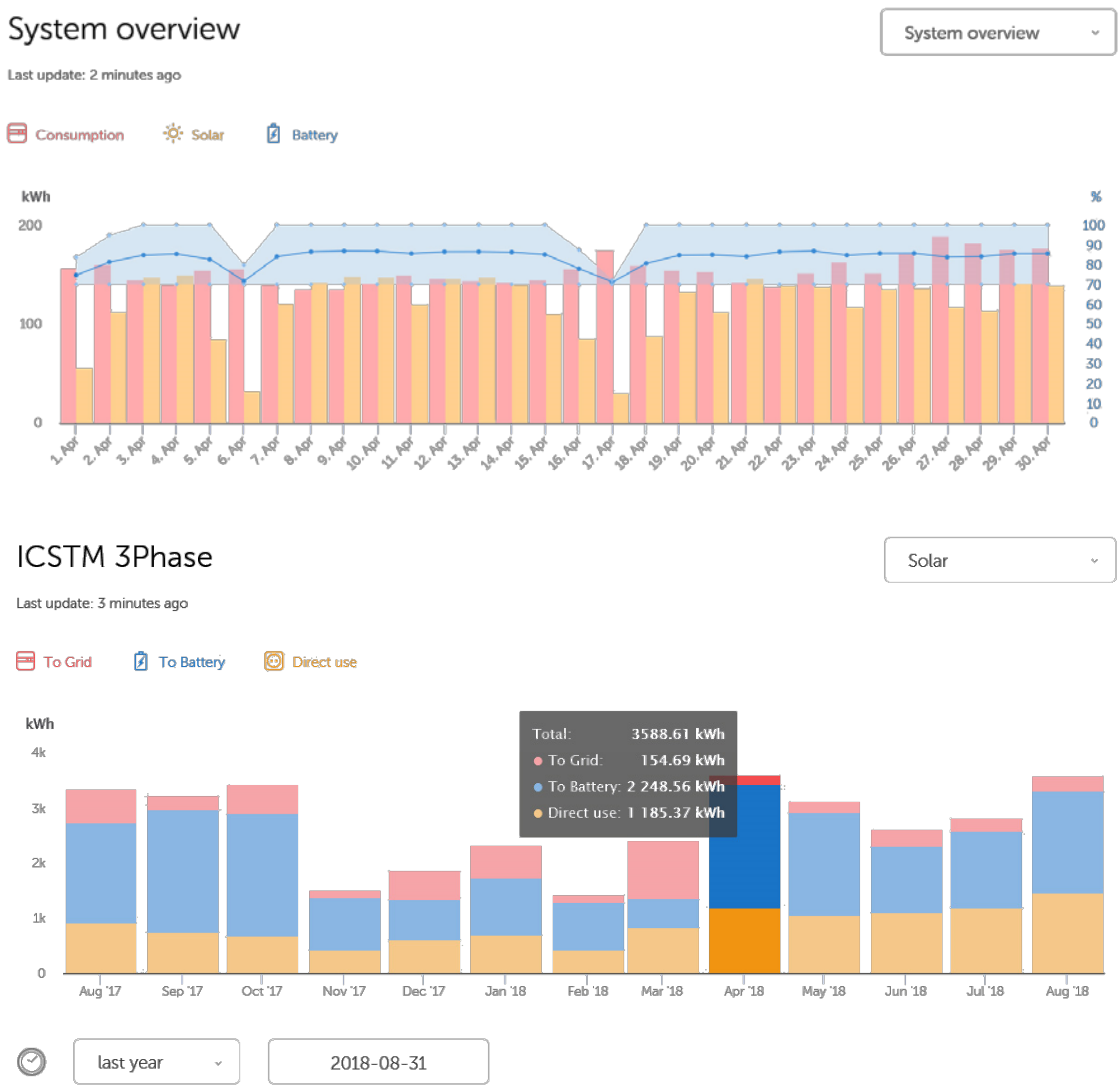


Figure 7. Microgrid consumption over a year interval [30].

The microgrid infrastructure has a total power output of 60kW, 20kW on each phase; half drown from batteries and the other half from the national grid. The microgrid storage can provide 12 hours of autonomy in case of black-out and its configured in a self consumption scenario to use 30% Discharge Rate (DCR). This value is automatically augmented in case of non favorable days (cloudy ones). The DCR is very important in batteries lifetime and help protect full discharges which would increase the number of battery cycles. Proper ventilation and climatisation of the microgrid power infrastructure room, which also contains the battery banks, is kept at 25 degrees for battery life conservation and proper efficient operation of the regulators and the inverters. In this scenario the life expectancy of the battery bank is 5 years.

Performance data analyzed from the long-term cloud storage reveals that in 2018 the most favorable month was April with 3.6MWh production (Figure 8b). The graph shows the influence of sunny days over winter times (Figure 8a). The gaps in battery charge from days 1, 6 and 17 are due to 3 prior cloudy days, the system can’t cope with more then 2 cloudy days because it does not have enough PV power installed. The yellow “Direct use” value from Figure 8a) refers to direct loads power usage over daytime. The operating energy consumed by the system “own consumption” is not represented on the graphs. But the system even in no grid import mode still consumes a small amount of energy for proper grid phase sync.



a)

b)

Figure 8. ICSTM microgrid production and consumption a) for April 2018 b) for 2018.

Best day and the one that proves that the system is close of achieving self-sufficiency is April 9, 2018 (Figure 9). The graph shows more energy production then consumption. In this scenario the system is configured to export the surplus energy.

Figure 9. April 9, 2018 microgrid energy balance.

4. CONCLUSIONS

Considering present needs of the ICSTM IT resources we don't foresee short term additional HW upgrades. Based on current configuration the hybrid cloud could extend in third-party facilities, keeping local resources only for critical or private data.

In perfect weather conditions the system reaches its self-consumption designed values (Figure 9). But overall, only ~60% of the systems yearly needs are covered.

The Performance Ratio (PR) of the system is average due to modules 60-degree angle of installation. This compromise is done in favor of not overheating the south facing laboratories. The BIPV installation as sunshades of the PV modules has a positive impact in summertime when cooling needs are reduced for the direct sun facing labs.

The microgrid system was operated on the DCR side by manualy chosing the rate based on next 3 days cloud coverage forecasts. This operating mode can change with and automatic alghorithm based on production forecasting, this in theory would provide better system stability and performance.

Only by combining additional PV production with the microgrid or by eliminating the electrical cooling needs using another renewable system, total self-sufficiency can be achieved. ICSTM has a solar thermal installation coupled with an adbsorbtion chiller of 26kW, this system can be modified and used for the Data Center cooling needs.

From the long term performance data analysis we can observe that the pilot achieved for 2017 a 59.66% PV energy coverage, thus a financial economy of estimated 3,300 Euro (According to HG 994/2013 - 3 cert * OPCOM price = PZU 35.00 €/cert (EEG 2017) – PV).

Future developments can include more strict power conditioning of infrastructure assets based on data traffic analisys and endpoint presence status, these could lead to nighttime idle or even power off scenarios extending to distribution devices.

Presently for redundancy reasons the cooling is done in parallel by 2 units, these could be automated to a stand-by operation scenario for one of them. Both units can be converted to such a scenario if main load could be switched to a different system aka fan-coild with cold water from the adsorbtion chillers.

Acknowledgments: *This work was supported by the project "E-LAND Integrated multivector management system for Energy isLANDs", funded by European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No. 824388. Authors want to thanks to Eng. Lucian Popescu (SC Prowatt SRL) for all the know-how and support regarding Victron products used in the construction of the microgid and guidance during system development and upgrades and to Eng. Titi Munteanu (SC Mabec SRL) for all the technical support during the PV plant installation.*

REFERENCES

[1] *Energy efficiency in public buildings*. Available online: http://www.enrima-project.eu/energy-efficiency/ energy-efficiency-in-public-buildings (accessed on 08.08.2019)
[2] *Strategia pentru mobilizarea investitiilor în renovarea fondului de cladiri rezidentiale si comerciale, atât publice cât si private, existente la nivel national*. Available online: http://www.mdrap.ro (accessed on 20.08.2019)
[3] McKenna, R., Merkel, E., Fichtner, W., *Appl. Energ.*, **189**, 800, 2017.
[4] Ahmed, A.I., *International Journal of Advanced Computer Science and Applications,* **9**, 304, 2018.
[5] Anders, S.G.A., Total Consumer Power Consumption Forecast, *Proceedings of the Nordic Digital Business Summit*, 2017.
[6] Salvo, F., Ciuna, M., Ruggiero, M., Marchianò, S., *Buildings*, **7**, 54, 2017.
[7] Chantal, R.W., *The Journal of Chemical Physics*, **193**, 811, 2018.
[8] Lu, M., Lin, A., Sun, J., *Sustainability,* **10**, 1051, 2018.
[9] Faria, P., Spínola, J., Vale, Z., *Appl. Sci*., **8**, 1283, 2018.
[10] Oprea, S.V., Bara, A., Uta, A.I., Pirjan, A., Carutasu, G., *Sustainability,* **10**, 2264, 2018.
[11] Silva, G.D.E., Hendrick, P., *Appl. Energ.*, **195**, 786, 2017.
[12] Zhang, Y., Campana, P.E., Lundblad, A., Yan, J.Y., *Appl. Energ.*, **201**, 397, 2017.
[13] Schimpe, M., Naumann, M., Truong, N., Hesse, H.C., Santhanagopalan, S., Saxon, A., Jossen, A., *Appl. Energ.*, 210, 211, 2017.
[14] Bertsch, V., Geldermann, J., Luhn, T., *Appl. Energ.*, **204**, 1, 2017.
[15] Zhang, Y., Lundblad, A., Campana, P.E., Benavente, F., Yan, J.Y., *Energy Conversion and Management,* **133**, 249, 2017.
[16] Liu, H., Li, D., Liu, Y., Dong, M., Liu X., Zhang H., *Appl. Sci*., **8**, 1453, 2018.
[17] Let, D., Cimpoca, G.V., Stancu, A., Fluieraru, C., Bacinschi, Z., *Acta Phys Pol A*, **121**, 65, 2012.
[18] Stancu, A., *Journal of Science and Arts,* **11**, 300, 2009.
[19] http://916.icstm.ro/content/rezultate-obtinute (accessed on 27.08.2019).