

Microgrid design considerations for a smart-energy university campus

Citation for published version (APA):

Morales Gonzalez, R. M. D. G., Goch, van, T. A. J., Aslam, M. F., Blanch, A., & Ribeiro, P. F. (2014). Microgrid design considerations for a smart-energy university campus. In *Proceedings of the 2014 5th IEEE PES International Conference on Innovative Smart Grid Technologies (ISGT Europe), 12-15 October 2014, Istanbul, Turkey* (pp. 1-6). Institute of Electrical and Electronics Engineers.
<https://doi.org/10.1109/ISGTEurope.2014.7028743>

DOI:

[10.1109/ISGTEurope.2014.7028743](https://doi.org/10.1109/ISGTEurope.2014.7028743)

Document status and date:

Published: 01/01/2014

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Microgrid Design Considerations for a Smart-Energy University Campus

R. Morales González^{*†}, *Student Member, IEEE*, T.A.J. van Goch^{*},
M.F. Aslam^{*}, A. Blanch^{*}, and P.F. Ribeiro^{†‡}, *Fellow, IEEE*

^{*}Dept. of Building Physics and Services, Eindhoven University of Technology, 5600MB Eindhoven, the Netherlands

[†]Dept. of Electrical Energy Systems, Eindhoven University of Technology, 5600MB Eindhoven, the Netherlands

[‡]Center of Excellence in Smart Grids, Federal University of Itajubá, 37500-903 Itajubá-MG, Brazil

Email: r.m.d.g.morales.gonzalez@tue.nl; p.f.ribeiro@tue.nl

Abstract—The goal of this paper is to propose a design approach to transform the current distribution network of the Eindhoven University of Technology campus into a smart grid. First, the needs and interests of different stakeholders are translated into a local definition of the smart grid concept. This definition is the starting point for outlining the values and services that the smart grid should provide, and the goals it needs to fulfill. Future campus loads, distributed generators, and mobile storage capabilities are modeled and simulated in order to assess their impact on the distribution grid and determine hosting capacity. Recommendations are given on the infrastructure needed for enabling the transition to smart grids, not only for the university as a concrete case study, but rather as a blueprint for future smart grid pilots.

Keywords—Distributed power generation, energy storage, power system management, smart grids, user-centered design.

I. INTRODUCTION

Growing electricity demands, market liberalization, and concerns over CO₂ emissions require changes be made to the way traditional power systems are structured and operated, without compromising the reliability, stability and efficiency of the existing system [1]. Over the last decade, the term Smart Grid has been extensively used during discussions concerning the future of electricity networks. Interpretation of the concept, and thus the roadmaps towards modernization of the grid, depend greatly on local policy and needs [2].

A number of universities are implementing Smart Grid demonstration projects in their own distribution networks with the purpose of improving grid performance by accommodating renewable energy sources (RES) and storage options [3], [4]; improving grid reliability and efficiency [5], [6]; raising awareness of students, faculty and staff to improve energy efficiency on campus [7], [8]; and facilitating research and education [9].

The campus of the Eindhoven University of Technology (TU/e), constructed in the 1960s and situated in the center of Eindhoven, the Netherlands, is currently undergoing major refurbishments and expansions to enable research and education in three strategic areas: energy, mobility, and health. The university's vision and strategy towards the future is focused on creating a Living Lab on campus —i.e., using the premises as a real-life test bed—with the purpose of promoting research, education, and collaboration with Industry, as well as strengthening the TU/e image. In addition, the university has

set for itself ambitious targets to significantly reduce its overall energy consumption and producing up to 50% of the campus' energy demands from on-site RES by 2030.

This paper explores the opportunities for a smart grid as a means to achieve the university's sustainability targets and realize the Living Lab concept. The goals of this paper are to: 1) provide a smart grid design methodology; 2) analyze the existing distribution network and its potential to evolve into a smart grid; and 3) provide recommendations for smart grid development. It is important to note that, although the focus is on the TU/e as a concrete case, these ideas can be generalized and replicated for the design of other smart grid projects.

This paper is organized as follows: the design methodology is described in Section II. The definition, values and goals of the TU/e smart grid are discussed in Section III. The local electricity distribution network, its future energy demands, and possibilities for distributed generation (DG) and storage are investigated in Section IV. Results are presented in Section V. Recommendations on the infrastructure needed to enable the transition to smart grids are given in Section VI. Finally, conclusions and future work are given in Section VII.

II. DESIGN METHODOLOGY

Designing “smart” electricity systems involves adding Information and Communications Technology (ICT) infrastructure to merge and control the physical and communications layers of the existing power grid [10]. The complexity of this task spans through several problem dimensions, involving technologies, stakeholders, and end-users. A good design should consider spatial, environmental, legal and social impacts in addition to technical issues. Although there is no universally accepted methodology for smart grid design, various approaches have been developed [11], [12]. In these, a good understanding of the different stakeholders is key to deliver the values and functionalities that are required of the smart grid. Fig. 1 illustrates the design approach adopted.

First, the project stakeholders' needs are analyzed to get insight into the expectations and requirements of a smart grid implementation at the university. The result of this analysis, together with the project constraints, leads to the definition of the smart grid design goals and a preliminary concept. Next, the concept is tested by modeling and simulating the effect of the expected shares of DG and (mobile) storage possibilities, and load control strategies for smart grid management.

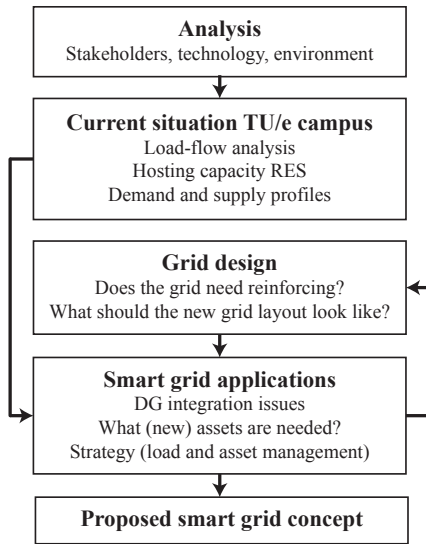


Fig. 1. Smart grid design approach for the TU/e campus

The simulation results give insight into the changes that the existing electricity infrastructure requires in order to be smart-grid ready, and the technologies needed to facilitate those changes. Based on the analysis of the results, a smart grid concept is proposed such that the expectations of stakeholders are met, technological capabilities are addressed, and environmental/social conditions are respected.

III. DEFINING A SMART GRID FOR THE TU/E

The values that the smart grid should offer are based on the stakeholders' buying motives, informed by Maslow's hierarchy of needs [13]. The stakeholder analysis defines the TU/e smart grid requirements in the following statement:

The TU/e smart grid should be an energy infrastructure capable of integrating a high penetration of renewable energy generated on-site, as well as energy-related innovations and research activities. It should also enable the interaction between buildings and users in order to strengthen community values, education, and research, while being efficient and effective in terms of energy use and costs.

From this definition, the following goals are extracted:

1) *Plug-and-play functionality*: The smart grid should be capable of connecting new loads and integrating future energy and mobility innovations with minimal needs of redesigning its basic ICT architecture or reinforcing electrical infrastructure. Similarly, in order to foster education and research by testing in a live environment, new algorithms should be easily integrated.

2) *User-friendliness and interactivity*: In order to create energy awareness and encourage participation in energy efficiency initiatives, user interfaces should provide students, faculty and staff with a concise, understandable flow of information.

3) *Accommodating a high share of RES*: In accordance with the university's sustainability targets, the electricity grid should accommodate growing electrical demands and an increasing share of renewable, distributed energy generation without reinforcing the existing grid.

IV. CURRENT STATE OF THE ELECTRICITY DISTRIBUTION GRID

A. Energy demands

In 2010, the university's electrical energy consumption was 52GWh, and the natural gas consumption was approximately 79GWh [14]. Increasing the renewable energy generation on campus will be accomplished mainly by expanding the capacity of the already-existing aquifer thermal energy storage (ATES) system from 20 MW_t to 30 MW_t. The ATES system provides direct high-temperature cooling for conditioning laboratories and office buildings, as well as low-temperature heating in combination with heat pumps during the winter.

Additionally, a 10.5 MW_p solar PV system (70,000 m²) will be installed on available roof spaces at an optimal orientation and tilt angle, amounting to a yield of approximately 10.1 GWh/y of electricity. Smaller contributions to satisfying the thermal and electricity demands will be provided by TU/e in-house innovations such as: biogas-powered collective micro CHP units (total installed capacity of 105 kW_e), two roof-integrated wind turbine prototypes (20 kW) [15], and mobility innovations [16]. Although the focus of this paper is to see the impact of renewable energy on the electricity microgrid, it is important to note that having an extensive thermal storage facility could be a valuable source of flexibility.

B. Grid robustness and hosting capacity

The electricity distribution network of the University campus is a privately-owned microgrid interconnected with the municipal medium-voltage (MV) distribution network via a central energy station located on campus. All assets are managed and maintained by the university's Real Estate department. The MV network will undergo significant expansions, upgrades, and demolitions. In this new configuration, the microgrid will consist of forty-four MV busses arranged in a meshed configuration of 9 radially-operated rings. These rings will feed ninety MV/LV transformer stations located at the different building sites. Each of these substations have a different capacity depending on the size and function of each building (e.g., laboratories, offices, residential buildings, and lecture halls).

Given that the network has a limited connection capacity of 12 MVA, it is important to assess the impact of the future loads and hosting capacity of the microgrid. By hosting capacity, it is meant the maximum possible amount of distributed energy generators that can be connected at the LV-side of the network of each building on campus, while maintaining adequate voltage and current levels and without having to reinforce the grid [17].

In order to evaluate the robustness of the microgrid assets and look for any possible weak points, the grid was modeled in Gaia®, a low-voltage (LV) network design software. Load-flow simulations were performed in Gaia® with the objective of determining whether the increased electrical loads resulting from the network expansion can be supported by the existing infrastructure without major reinforcements. A second load-flow analysis was carried out to test whether the proposed onsite distributed generation sources (PV, roof-integrated wind power, and micro CHP units) and mobile storage in the form

of charging stations for electric vehicles (EV) surpasses the microgrid's hosting capacity.

V. RESULTS

This section presents the results of the simulations showing the effect of RES and electricity storage on the loads and the distribution grid. The grid analysis and results presented reflect an initial attempt to model the electric system regarding load profile / capacity and voltage control. Further and more comprehensive studies related to the overall performance of the microgrid connected to the considerations made in the previous sections will be conducted when more definitive plans and functionalities are defined by the university.

A. Effect of renewable energy sources on load duration

The university's electricity demand profiles were analyzed to gain insight into the potential value of peak-shifting mechanisms and balancing electricity demand with local RES. The analysis was performed on a campus-wide scale.

The load duration curve of the university campus is shown in Fig. 2 as a solid line. From this graph it is possible to see that peak demand totals approximately 10.1 MW, and there is a considerable base load of approximately 5 MW. The base load is responsible for approximately 85% of the yearly electricity consumption and 50% of the the peak demand. It is mainly used to power and condition the numerous laboratory facilities.

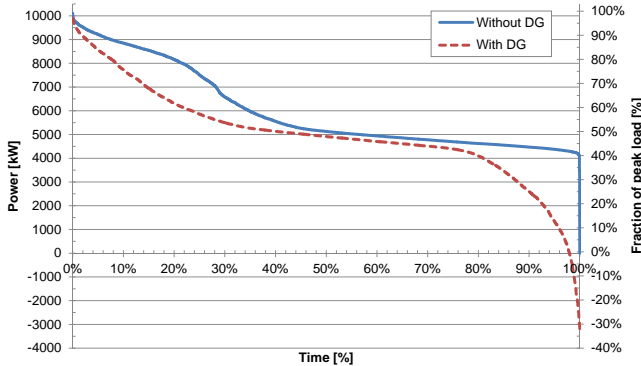


Fig. 2. Load duration curves of the university campus

The dotted curve in Fig. 2 shows the effect of renewable power generation on the load duration profile. Despite the large base load, there will be an overproduction of renewable electricity during 220 hours in the year. This surplus, totalling 240 MWh, would have to be curtailed, stored, or exported to the regional grid. It can also be seen from the figure that RES contributes to a reduction of the peak load by 2%, and a reduction of the base load by 6%.

The observed effect of RES in the university microgrid is without using any power management strategies. Power management strategies could be used to accommodate an increasing share of renewable DGs in the future, perform local congestion management to flatten peak loads and eliminate any potential need to reinforce the grid. Investing in additional controls to carry out these mechanisms could defer investments in power system infrastructure, such as cables, transformers, or even adding a new 10 kV distribution station.

B. Hosting capacity

The graphs on Fig. 3 and Fig. 4 show the node voltage and branch current bands of the microgrid in the present situation. It can be seen that there is considerable voltage drop in the nodes, although it is still within the $\pm 10\%$ allowance when the taps on the primary side of the transformers are adjusted accordingly. It can also be seen that the most heavily-loaded transformers are at almost 80% of their capacity.

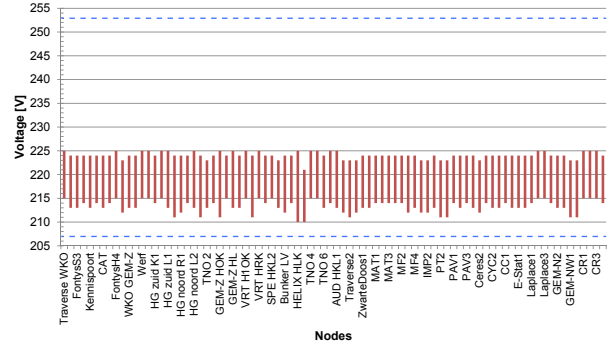


Fig. 3. Node voltages without RES

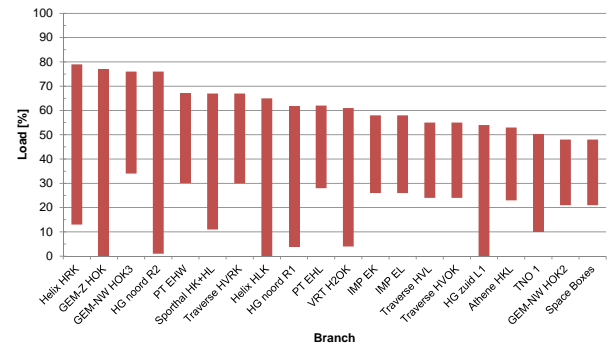


Fig. 4. Top 20 branch currents without RES

The effects of RES and mobile storage on the voltage levels of the microgrid are shown on Fig. 5. It can be seen that the voltage rise occasioned by the addition of PV and other DG brings the node voltages closer to 230 V compared to the case where there are no RES. RES are also beneficial for alleviating transformer loads, as can be seen in Fig. 6. Because of the high base loads of most of the buildings on campus, energy produced on-site can be utilized within the building at the time it is being produced. Therefore, the measurement of the power flows at the transformer will be lower, as it is the net result of the total demand minus the total generation [18].

The worst-case summer and winter load and generation profiles of a typical office building are shown in Fig. 7. The roof of the office building is fitted with a 20kW roof-integrated wind turbine, and a 243kWp PV system that covers 60% of the roof area. From Fig. 7, it can be seen that the share of renewables with respect to the rest of the building loads in the office building is negligible in terms of the added burden to the substation equipment. Given that the limited roof space availability and high base load conditions are also replicated in the other office buildings on campus, no significant reinforcements need to be made in order to accommodate for RES.

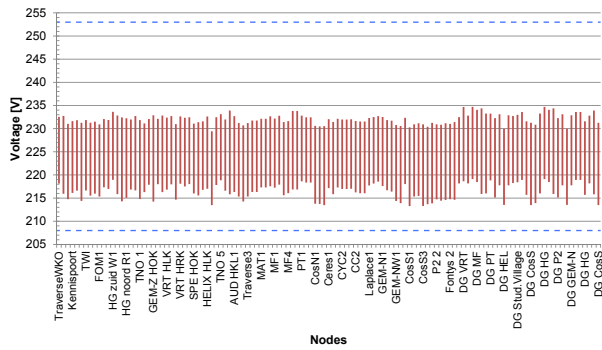


Fig. 5. Node voltages with RES and mobile storage

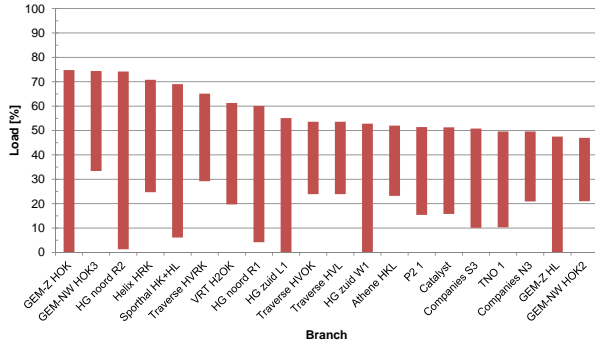


Fig. 6. Top 20 branch currents with RES and mobile storage

Fig. 8 shows the load and generation profiles of the living quarters of 300 students. This building will be equipped with communal micro-CHP units with a total installed capacity of 35 kW_e and a 190 kW_p PV system. Fig. 8 shows that the peak load at the secondary side of the transformer servicing this building is reduced by 15 kW in a worst-case winter scenario by consuming locally-produced electricity and using a micro CHP strategy similar to the one described in [19]. In a winter scenario, where the micro-CHPs are at maximum heat production, up to 540 kWh could be saved in one day.

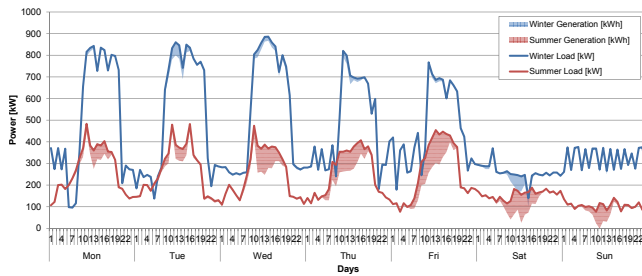


Fig. 7. Office building weekly load and generation profiles.

C. The value of flexibility

The value of adding an electrical storage system to manage the DG production surplus is investigated in this section. The goals of studying a storage management strategy is twofold: 1) to evaluate the economic feasibility of using the system for peak shaving; and 2) to propose a demand response (DR) strategy for the buildings on campus in order to assess the flexibility of heating and cooling loads by the strategic use of thermal storage for variable electricity tariff schemes.

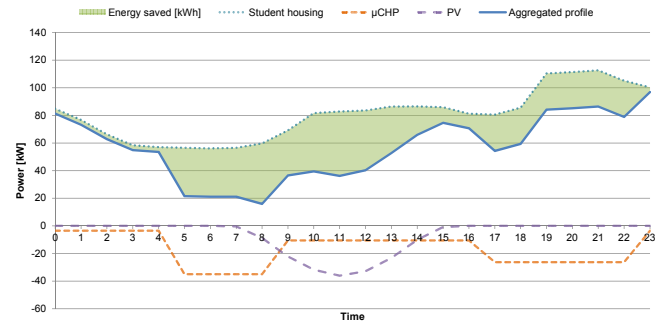


Fig. 8. Student Housing Tower daily load and generation profiles.

One of the requirements to provide smart grid services, such as congestion management and future participation in the existing or emerging energy markets, is flexibility in energy generation and demand. Flexibility can be enabled by postponing or expediting building loads using storage systems and thermal buffering (building inertia). Peak shifting, in which the consumption profile is smoothed by moving loads to different time periods, can reduce peak load, maximize asset life, and facilitate the increased penetration of on-site renewable energy generation. This can be achieved with electricity storage or demand response (DR) strategies. The following paragraphs discuss two options for electricity storage: fixed battery banks and mobile storage from EVs.

1) *Fixed battery banks:* A battery storage system is considered for a typical office building on the university campus. This building consumes 2.3 GWh/y, and has a peak load of 850 kW. It has the same load and generation profiles as those depicted in Fig. 7.

To assess the value of peak shaving, an on- and off-peak pricing is considered (0.13 €/kWh and 0.09 €/kWh respectively, including taxes and utility costs). A data-driven model is used, based on the actual load in 2010 and spot-market data of the same year. It is assumed that a perfect prediction of price and load is possible over a horizon of one day. Using the prediction, the charging strategy is derived. The system is controlled in such a way that an optimal set-point for the electrical load is pursued either by increasing the load when energy is cheap, or by reducing the load by using the battery banks when energy is expensive. This set-point is based on the predicted consumption profile for the upcoming days, which can be obtained with the techniques discussed in [20].

Battery costs are assumed to be €500/kWh for Li-Ion batteries. A lifetime of 15 years is considered. In order to ensure battery life, the state of charge (SOC) is limited between 0.8 and 0.2. Every hour, 0.8% of the energy leaks from the battery and storage efficiency is 82%. Input parameters of the model are battery energy (kWh), power capacity (kW) and prediction horizons on the load and the price. Performance indicators are profit and variance in the power demand signal. Optimizations were performed based on a generic algorithm in MATLAB to find trends in the storage system design parameters. Results of the simulation are presented in Fig. 9.

From the simulations, it is concluded that using strategic battery management is only economically feasible with limited battery sizes, and only when there are renewable energy

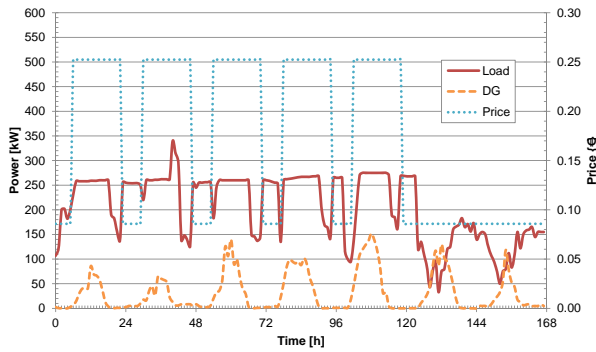


Fig. 9. Peak shaving with strategic storage

sources available on-site. Larger battery sizes lead to more peak shifting (-32% variance for the optimal cost result). In the worst-case scenario, where it is assumed that peak prices double in 15 years, the maximum possible profit is €140,000 (with an IRR 3,1%). Coupling the building to the electricity market leads to lower costs, since the storage system can help in trading more effectively. At present time, battery banks as a storage solution are not advisable given the low value of the investment and high risks. Furthermore, from a sustainability point of view, available battery technologies as well as environmental and health impacts should be considered. However, as energy prices increase and battery technologies become more affordable, this type of storage might become feasible.

2) *Mobile storage*: Electricity storage can also come in the form of electric vehicles parked on campus. The aggregated charging and discharging load profiles of an EV fleet of 22 cars were modeled in MATLAB as a function of time. The times at which charging and discharging cycles begin were modeled as normal probability distribution functions, with $\mu = 8.5$, representing charge start time in hours, and the standard deviation, $\sigma = 30$ minutes. It is assumed that the vehicles will start discharging as soon as employees arrive to the workplace. The load per car is 3.3 kW and its battery capacity is 24 kWh. It is assumed that the SOC of the battery will not go below 50% and that the maximum state of charge will be 80%. The charging circuit efficiency is assumed to be 87%.

The building energy management system detects the presence of an EV at the charging dock and sends a signal to the charging dock in order to discharge the battery down to 50% and deliver that power into the building. The EVs battery capacity reaches the minimum SOC at a point in the day when PV production is higher than electricity consumption in the building. At this point, the energy management system sends another signal to the charging dock in order to replenish the battery by using the energy produced by the PV that is not being consumed in the building directly.

Fig. 10 shows the simulation results of using EVs as storage devices. In the simulation, up to 400 kWh of flexibility can be gained from this charging and discharging strategy, with a maximum aggregated power output of 120 kW.

VI. RECOMMENDATIONS FOR ENABLING THE SMART GRID TRANSITION

The installation of smart meters and an accompanying communications network is necessary for the successful tran-

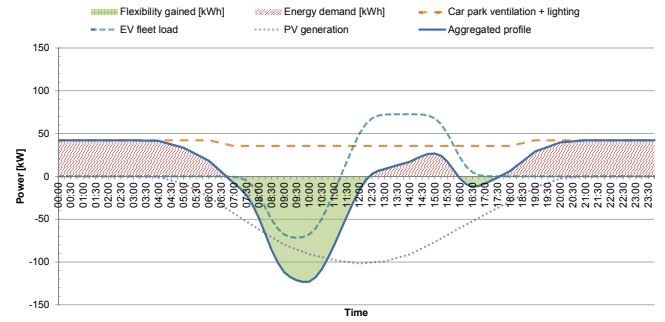


Fig. 10. Flexibility gained from mobile storage

sition into a smart grid. Traditional electricity meters have a limited spatial and temporal resolution, and are only capable of measuring net power flows. Therefore, it makes it difficult to pinpoint how much energy a particular load consumes and when, or what kind of growth patterns a load is experiencing. Finer resolution can facilitate management and control of the smart grid by providing near- or real-time data about electricity generation and consumption. Information about electricity use can also be made accessible to end-users to promote energy awareness or enable energy-saving competitions.

Apart from the deployment of measuring devices to collect, measure and analyze energy usage, the foundations for a campus-wide advanced metering infrastructure (AMI) require the enabling of two-way communication between the metering devices and control systems actuating the loads and generators. As the smart grid evolves, a robust ICT layer could enable the integration of new, additional advanced applications, thus helping to make the smart grid future-proof. For instance, the infrastructure could facilitate a more optimal operation of the distribution network based on distributed generation (DG) monitoring and management programs or demand response (DR) mechanisms that respond to market-based signals.

Two-way communication between generation sources and network operators is critical for enabling RES integration. This means that renewable sources should be equipped with monitoring, control and communication equipment such that network operators can perform real-time control to optimize asset utilization, system reliability, security, maintenance and troubleshooting. An appropriately designed wireless communications architecture is a key component of successful RES integration.

The smart grid should also provide network operators the tools necessary to ensure optimal grid operation. This means that network operators have access to data concerning voltage quality, grid stability, congestion and equipment health. The combination of sensing and measurement equipment, analytical tools and advanced control can be used to gather and convert data into actionable intelligence and support distributed intelligent agents in making decisions.

The incorporation of demand response (DR) mechanisms in the smart grid can help to exploit the flexibility of local generation and demand without the need for extensive storage systems. Using a DR strategy, end-users could respond to price signals (from the electricity markets) or triggers (from the microgrid or the regional network operator) to make short-term changes to electricity demand. Examples of such changes

are shifting heating/cooling loads, dimming artificial light, and controlling power flow to laptop chargers.

VII. CONCLUSIONS AND FUTURE WORK

This paper showed that smart grids do not only involve techniques and assets, but in particular people (stakeholders and end-users) who interact with each other. With the design methodology proposed, it is possible to offer the value of community engagement. Showcasing in-house innovations is one method of supporting this value while enhancing the university's image. The smart grid facilitates the integration of such innovations. Furthermore, the smart grid can strengthen the interaction between buildings and users and thus influences the relations between them. The data collected from the AMI can be used for visualization, research and education. A major requirement to facilitate these values is turning data into information and processing it into knowledge. This requires measurement, control, analysis, and education.

This paper also analyzed the potential of the existing microgrid infrastructure of a university campus to determine whether the ambitions of producing energy using local RES is possible without having to reinforce it. Results show that given the large base loads of the buildings, the effect of RES is actually beneficial for power system assets, even in an uncontrolled generation scheme. Investments in "smart" ICT technologies are recommended in order to utilize energy more efficiently and reduce operation costs. The effect of RES in the microgrid could be enhanced by coupling DGs, loads, and storage devices to a bidirectional control system that responds to the pricing or energy efficiency signals of a building energy management system.

Future work includes investigating a DR strategy based on [21] for the buildings on the university campus. The primary objective is to assess the flexibility of heating/cooling loads by the strategic use of thermal storage for different electricity tariffs (fixed, peak/off-peak). Building and automation system models, electricity tariffs, usage profiles, weather profiles and thermal comfort requirements will be used to formulate a constrained control problem solved by the application of model predictive control (MPC). The second objective is to extend the problem formulation and control method to include fixed and mobile electrical storage from batteries, laptops and EVs. Such a DR strategy can bring together the expertise of numerous research groups at the university, which can help make the university smart grid a special in-house innovation.

ACKNOWLEDGMENT

This work was supported in part by EIT KIC InnoEnergy, BAM Techniek, Cofely-GDF SUEZ, NXP Semiconductors, and Philips Lighting, under the Smart Energy Buildings and Cities (SEB&C) postgraduate program of the 3TU.School for Technological Design, Stan Ackermans Institute.

REFERENCES

- [1] J. A. Momoh, *Smart Grid: Fundamentals of design and analysis*. Piscataway: Wiley-IEEE Press, 2012.
- [2] M. G. Simoes, R. Roche, E. Kyriakides, A. Miraoui, B. Blunier, K. McBee, S. Suryanarayanan, P. Nguyen, and P. Ribeiro, "Smart-Grid technologies and progress in Europe and the USA," in *Proc. 2011 IEEE Energy Conversion Congress and Exposition*. Phoenix: IEEE, Sep. 2011, pp. 383–390.

- [3] S. Bracco, F. Delfino, F. Pampararo, M. Robba, and M. Rossi, "Economic and Environmental Performances Quantification of the University of Genoa Smart Polygeneration Microgrid," in *Proc. 2012 IEEE International Energy Conference and Exhibition (ENERGYCON)*. Florence: IEEE, Sep. 2012, pp. 593–598.
- [4] B. Roseth, "University of Washington launches research phase of smart grid project," Seattle, Oct. 2012. [Online]. Available: <http://www.washington.edu/news/2012/10/24/university-of-washington-launches-research-phase-of-smart-grid-project/>
- [5] The USC Energy Institute, "Energy Systems and Infrastructure: Smart Grid." [Online]. Available: http://energy.usc.edu/research/energy_systems/smart_grid.html
- [6] A. J. Flueck and C. P. Nguyen, "Integrating Renewable and Distributed Resources - IIT Perfect Power Smart Grid Prototype," in *Proc. 2010 IEEE Power and Energy Society General Meeting*, no. July. Minneapolis: IEEE, 2010, pp. 1–4.
- [7] R. Tatro, S. Vadhva, P. Kaur, N. Shahpatel, J. Dixon, and K. Alzanoun, "Building to Grid (B2G) at the California Smart Grid Center," in *Proc. 2010 IEEE International Conference on Information Reuse & Integration*. Las Vegas: IEEE, Aug. 2010, pp. 382–387.
- [8] Cornell University, "Smart Grid Technology improves the Cornell energy grid with integrated information technologies." [Online]. Available: <http://www.sustainablecampus.cornell.edu/initiatives/smart-grid-technology>
- [9] Lappeenranta University of Technology, "Green campus: Smart Grid." [Online]. Available: <http://www.lut.fi/web/en/green-campus/introduction/smart-grid>
- [10] European Commission, *EUR 22040 — European Technology Platform SmartGrids*. Luxembourg: Office for Official Publications of the European Communities, 2006.
- [11] P. F. Ribeiro, H. Polinder, and M. J. Verkerk, "Planning and Designing Smart Grids: Philosophical Considerations," *IEEE Technology and Society Magazine*, vol. 31, no. 3, pp. 34–43, 2012.
- [12] CEN/CENELEC/ETSI Smart Grid Coordination Group, "Smart Grid Reference Architecture," Brussels, Tech. Rep. November, 2012.
- [13] A. Maslow, "A Theory of Human Motivation," *Psychological Review*, vol. 50, no. 4, pp. 370–396, Jul. 1943.
- [14] M. Meulen, "Energiejaarverslag 2010," Eindhoven University of Technology, Eindhoven, Tech. Rep., 2011.
- [15] Ibis Power BV, "IRWES: Integrated Roof Wind Energy System," 2012. [Online]. Available: <http://www.irwes.com>
- [16] Eindhoven University of Technology, "Solar-powered family car covers 875 km in Australia on a single charge," 2013. [Online]. Available: <http://www.tue.nl/en/research/strategic-area-smart-mobility/news/solar-powered-family-car-covers-875-km-in-australia-on-a-single-charge/>
- [17] M. Bollen and F. Hassan, *Integration of Distributed Generation in the Power System*, M. E. El-Hawary, Ed. Piscataway: Wiley-IEEE Press, 2011.
- [18] M. Berende, A. De Ruitter, and J. Morren, "Changes in forecasting of HV/MV-transformer loading due to distributed generation," in *Electricity Distribution (CIRED 2013), 22nd International Conference and Exhibition on*, no. 0018. Stockholm: CIRED, 2013, pp. 10–13.
- [19] A. D. Hawkes and M. A. Leach, "Cost-effective operating strategy for residential micro-combined heat and power," *Energy*, vol. 32, no. 5, pp. 711–723, May 2007.
- [20] P. R. J. Campbell and K. Adamson, "Methodologies for Load Forecasting," in *Intelligent Systems, 2006 3rd International IEEE Conference on*, no. September. London: IEEE, 2006, pp. 800–806.
- [21] F. Oldewurtel, A. Ulbig, M. Morari, and G. Andersson, "Building Control and Storage Management with Dynamic Tariffs for Shaping Demand Response," in *Proc. 2011 IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe)*. Manchester: IEEE, 2011, pp. 1–8.