Microgrid Case Study : Durban International Convention Centre

Mike Barker, Member SAIEE IEEE
BuildingPhysics, mike@BuildingPhysics.co.za

***Abstract*— Smart grids allow commercial buildings that generate and store power to become active smart loads. As an example, the economic viability of incorporating a microgrid at the Durban International Convention Centre is considered. A combination of electrical and thermal energy storage work alongside traditional diesel gensets and new PV to provide a high level of resiliency while still reducing the cost of energy.**

Keywords—Microgrids, Smart loads, Smart grids, Power system economics

I. Introduction

Liberalisation of electricity markets forced by distributed energy resources (DER) and the resulting smart load will have an impact on how future buildings are energised. This in turn will have wide ranging consequences for building systems design and operation. Best practice requires that the intelligence be pushed out to the grid edge, meaning out to the commercial buildings and their Building Energy Management Systems. The implementation of these smart control systems will become the responsibility of the Building Services Engineer.

This paper will briefly introduce the interaction between the building and the smart grid and then focus on a techno-economic case study of a proposed microgrid for a highly serviced building, the Durban International Convention Centre. The setting is the year 2022 when energy storage and electric vehicles (EVs) are expected to be both viable and commonplace. Apart from providing uninterrupted power, microgrids need to be designed to optimise the profitability of the energy supply for the life of the building.

II. The Smart Grids and Microgrids in Commercial Buildings

The future national grid, a Smart Grid, will supply smart loads such as buildings and campuses that will have their own localised energy generation and storage. The Smart Grid is one of the most ambitious advances that many countries are undertaking and buildings, as smart loads, are one of the critical components. Buildings will exchange active and reactive power and relevant data as required by the building's energy management system (acting autonomously) and do so in the best interests of the building owner, and in accordance with grid codes.

There must be an understanding of this mutualistic relationship with the national grid, and so there are a slew of new standards that seek to set out rules that new distributed generators must adhere to in order to connect to the grid. Relations between the grid and the microgrid in the building are not trivial and will occupy Building Services Engineers for decades to come, especially since buildings will not only be their own "power stations", but will also become the "petrol stations" for electrical vehicles.

The intelligence at the grid edge will be in the form of a microgrid controller, and will supervise and mange not only the technical issues, but the economic requirements too.

In parallel to the legislative frameworks, technical standards are being developed by the IEC, US DoE, IEEE and the like. International standards take years to complete hence the suggested approach is to adopt beast practice guidelines in the meanwhile. Existing standards only require automatic and rapid disconnection of all DER during grid disturbances, and so limit the fault ride through ability which has limited value currently to the grid itself.

Table I – Technical Standards and expected release dates

Technical Standards	Organisation	Status
EN 50438:2013, Requirements for the Connection of Micro-generators in Parallel with Public Distribution Networks	CENELEC	2013
IEC/TS 62898-1 Guidelines for General Planning and Design of Microgrids	IEC	> 2017
IEC/TS 62898-2 Technical requirements for Operation and Control of Microgrids	IEC	> 2017
IEEE 1547.4 - Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems	IEC	2011
IEEE 2030.X – Series of Microgrid Standards	IEEE	2015 - 2018

Developing countries with grid deficiencies need microgrids as much as 1st world countries. For example the State of New York is financing microgrid deployment with the intention of reducing the outages experienced when hurricanes like Sandy made landfall in 2012. A US microgrid vendor that tracks outages worldwide notes "An upward trend of extended outages due to aged equipment, loss of experienced utility workers, and an alarming increase

Work described in this paper was based on DER-CAM from Lawrence Berkeley National Laboratory, California. A DER-CAM model is available for inspection in the interests of open transparent modelling. http://openmod-initiative.org/

in severe weather-related events is interrupting electric services"

Despite ongoing pronouncements in the popular media, buildings with microgrids are not about going off the grid or grid defection. The Electric Power Research Institute notes that, "Distributed energy resources and the grid are not competitors but complements" [1].

The answer to sustainable and reliable energy is not necessarily only the grid. Having an element of self-generation allows building owners to control their destiny, both in terms of the cost of energy and the availability. Having an element of battery storage takes care of a building's uninterrupted power supply (UPS) loads, improves the stability of intermittent renewable generation resources, and in years to come when the battery price is right, will provide long-term storage over days instead of hours.

Agile MicroGrid controllers will be able to go shopping for the best deals in a competitive energy market, and to take advantage of very low spot prices. Such an advanced grid where electricity will be traded freely will be known as a smart grid.

III. CASE STUDY – COMMERCIAL BUILDINGS

It's instructive to use a building like the International Convention Centre in Durban (South Africa) as an example of how to evaluate the potential advantages of a microgrid from an economic point of view. The technical requirements of a microgrid such as stability, black starts, and automatic islanding were not considered – in this case the interest was less about resiliency and more about grid-tied economic performance.

The 33 000 m² Centre was opened by Nelson Mandela in 1997 and is one of the most flexible in the world. For example its HACCP certified kitchens can serve 6000 plated meals in 15 minutes. It has hosted high profile events like the Commonwealth Heads of Government Meeting and the was a media centre for FIFA 2010 Events.

Best practice microgrid design guidelines are in their infancy, but a novel approach developed by the Lawrence Berkeley National Laboratory (USA) is freely available [2]. The Distributed Energy Resources Customer Adoption Model (DER-CAM) is a cloud-based optimisation tool. Its aim is to minimise the total annual costs or CO2 emissions when providing energy services to a given building, and includes electricity and natural gas purchases, plus amortized capital and maintenance costs for any microgrid equipment investment. (Figure 1.)

DER-CAM seeks to address the following :-

- Which is the cost-optimal configuration of distributed generation technologies that can be installed ?
- What is the appropriate level of installed capacity of these technologies that minimises cost ?
- How should the installed capacity be operated so as to minimize the energy bill ?

IV. THE DER-CAM MODEL

The Centre has 4 off 1 MW diesel gensets and 180 kW of traditional UPS. A dual 11kV redundant supply has meant the gensets have hardly been used and power outages are infrequent. While the gensets would be of used during grid blackouts, this DER-CAM case study focused on the most profitable grid tied solution based on renewable technologies such as PV and electrical and thermal storage – in other words the expected scenario for 99% of the year. DER-CAM also allows for an extensive range of Combined Heat and Power (CHP) plants (diesels, gas turbines, fuel cells) but this was overridden since domestic hot water requirements were a small percentage of the total load.

Assumptions were made that reflected the expected condition in 2020. This included the increased efficiency of equipment, and the substantially lower cost of renewables and electrical storage. Goldman Sachs for example is predicting a 60% decrease in the cost of electrical storage by 2020.

The electricity tariff has ToU charges for both energy and power. The Tariff is weighed toward demand (power) instead of energy. Peak charges in the afternoon are best representative of a future with a high level of renewables and EVs on the grid and are based on scenarios predicted for California. (Figure 2.) No feed-in-tariffs or net metering is considered – see the Addendum I about self-consumption.

The building has no heating, only cooling throughout the year, and the existing ice storage system was resized as required by DER-CAM. Typical Load profiles were specified for 3 circumstances – event breakdown days, typical event days, and high load event days. Weather files included insolation. (Figure 3.)

The building and it's 1000 bay parking garage are the natural home of the Electric Vehicle. DER-CAM ability to model the Vehicle-to-Building (V2B) interactions are unique and are discussed in some detail.

V. OUTCOMES AND PREDICTED SAVINGS

The modelled results show a 12% total annual saving compared to a grid-connected baseline over a 20 year period. The operation of the microgrid on a typical event day shows load shifting, and the building as presenting a well behaved load to the grid which has further value. (Figure 4.)

Initial modelling efforts explored the possibility of operating off the grid, with the grid as a backup. DER-CAM results revealed was that even with future PV energy efficiencies of 30% and even with the lowest predicted battery costs there would never be enough roof area at the site to power the building, especially once the participation of the anticipated electric vehicles were introduced.

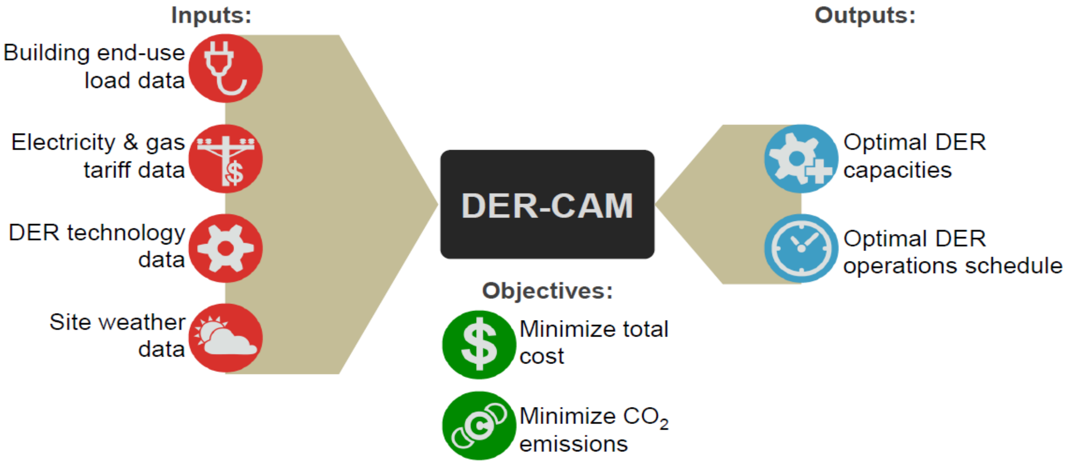

Figure 1. DER-CAM outputs include Investment Decisions and Control Strategies

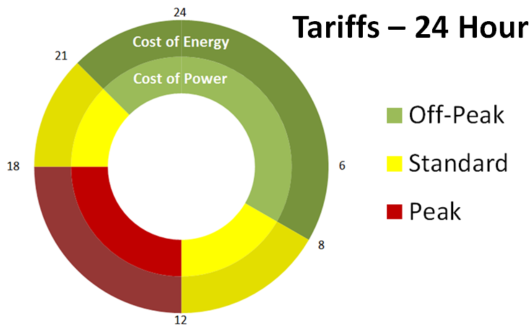

Figure 2. Example of Electrical tariffs included ToU power and energy. Peak charges in the afternoon are best representative of a future with a high level of renewables and EVs on the grid and are based on scenarios predicted for California.

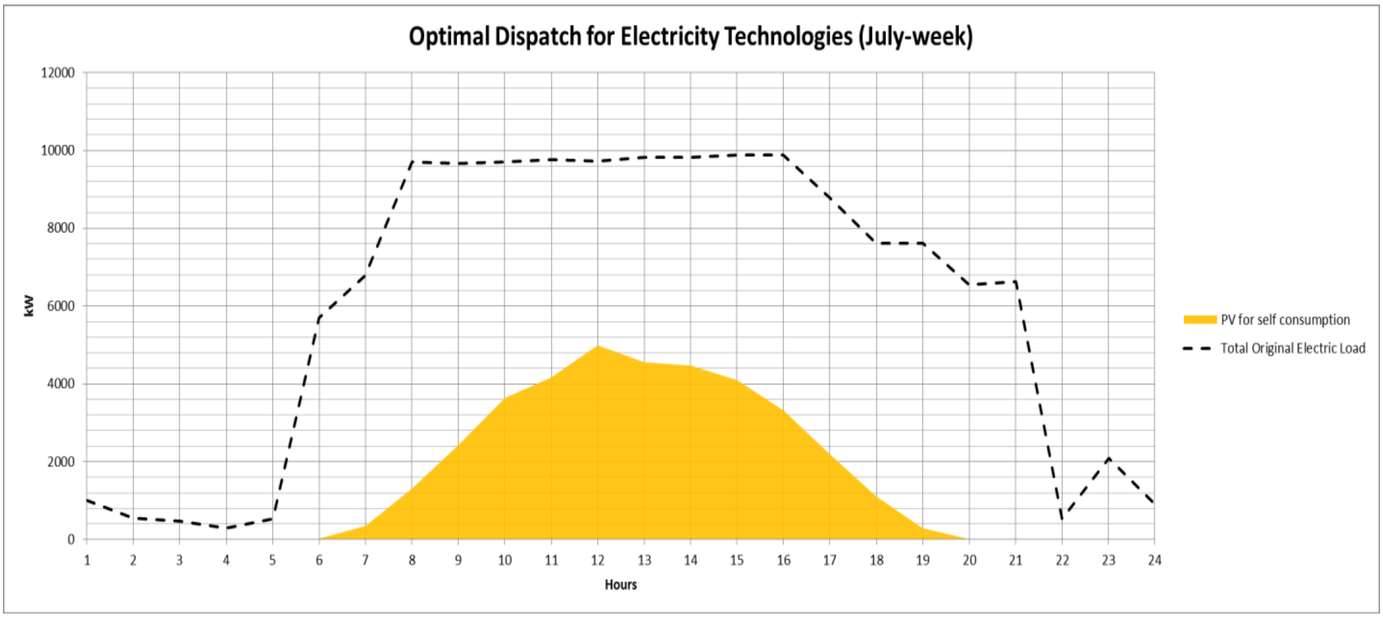

Figure 3. Building load profile for a typical event day, and idealised PV output.

EVs are an attractive source of electrical energy storage – their inclusion can be seen as intermittently available mobile storage devices with the advantage that their capital cost is not part of the building expenditure.

Only one benefit-sharing mechanism was modelled. Vehicle-to-Building (V2B) economics focused on trading the value of the undercover parking with that of the energy exchange interactions. A V2B Management System will identify vehicles that will be in the building until at least the early evening, not an unusual occurrence for delegates at a conference. These are the vehicles that will be topped up as they arrive in anticipation of later usage. Furthermore it is expected that the EV owner would get free parking in exchange for the effort of connecting to the building.

No Vehicle will have its battery drained beyond the SoC that it arrived with. In addition, no Vehicle will have its battery drained beyond a set value ($\text{Min-SoC}_{\text{Disconnect}}$) ensuring no EV owner is ever left stranded. EVs that may arrive with deplete batteries can buy energy but this is a separate business case and was not considered in the modelling.

An issue that is bound to be raised is reluctance of EV owners to share their battery because of their fear of battery capacity and power fade. Recent research suggests however that exchanging energy with the building in a particular way could actually reduce battery life fade [4]. The paper suggests that "This effective degradation reversing $\Delta\text{SoC}_{\text{Drive}}$ and $\Delta\text{SoC}_{\text{V2B}}$ range arises through the optimal balancing of storage and cycling degradation"

It was assumed that a maximum of 20% of 1000 parking bays would be have EV charging stations and would participate. Modelling the coming and going of EV owners is complex, so a stochastic approximation is used of a scenario with 188 EVs that would be parked in the basement for most of the day and early evening. (Figure 4.)

The DER-CAM process selected the following investments as optimum :-

PV Installation = 6.1 MW

Ice Storage Installation = 34 000 kWhr

Electrical Building Battery Storage = 12 000 kWhr

EV Aggregate Storage = 11 400 kWhr

The Building Battery was forced to operate with a minimum discharge level of 50% in order that it could act as a UPS supply. The ice storage system played a major role in load shifting the cooling load into the night, with the two electrical storage systems (Building Battery and V2G EV Batteries) supplying power once the PV contribution reduced at the end of the day. Battery storage will also allow for PV smoothing although this was not modelled.

VI. CONCLUSIONS

This Case Study is a simplistic first pass at understanding the benefits of a microgrid for a commercial building with thermal and electrical storage. The advantage of the DER-CAM Model is that a range of energy tariffs can be tested, and a range of equipment price points can also be explored.

The modelled results in this case show a 12% total annual saving compared to a grid-connected baseline over a 20 year period. The operation of the microgrid on a typical event day shows load shifting, and that the building had a well behaved load which has further value to the grid. (Figure 5.)

No value has been assigned to the increased level of resilience, but this capability is much prized for mission critical services at a Convention Centre.

The technical execution and economic benefits of Vehicle-to-Building interactions are complex and not understood at this point. This is the focus on wide ranging research around the world. This Case Study was able to demonstrate that B2G capacity can play a significant part in supplementing a building's existing storage capacity, and in the bigger picture assist the building to act as a grid-friendly load.

A MIT study suggests that Grid Defection is most likely societally inefficient [7]. The Author therefore suggests that truly sustainable buildings need to be good grid citizens and seek beneficial co-existence on the grid rather than elitist isolation. This brings to mind the South African Government's mantra "I am not self-sufficient alone. We are self-sufficient in community"

ACKNOWLEDGMENT

The author gratefully acknowledges assistance from Dr Michael Stadler and Goncalo Ferreira Cardoso, both of the Grid Integration Group, Lawrence Berkeley National Laboratory, California.

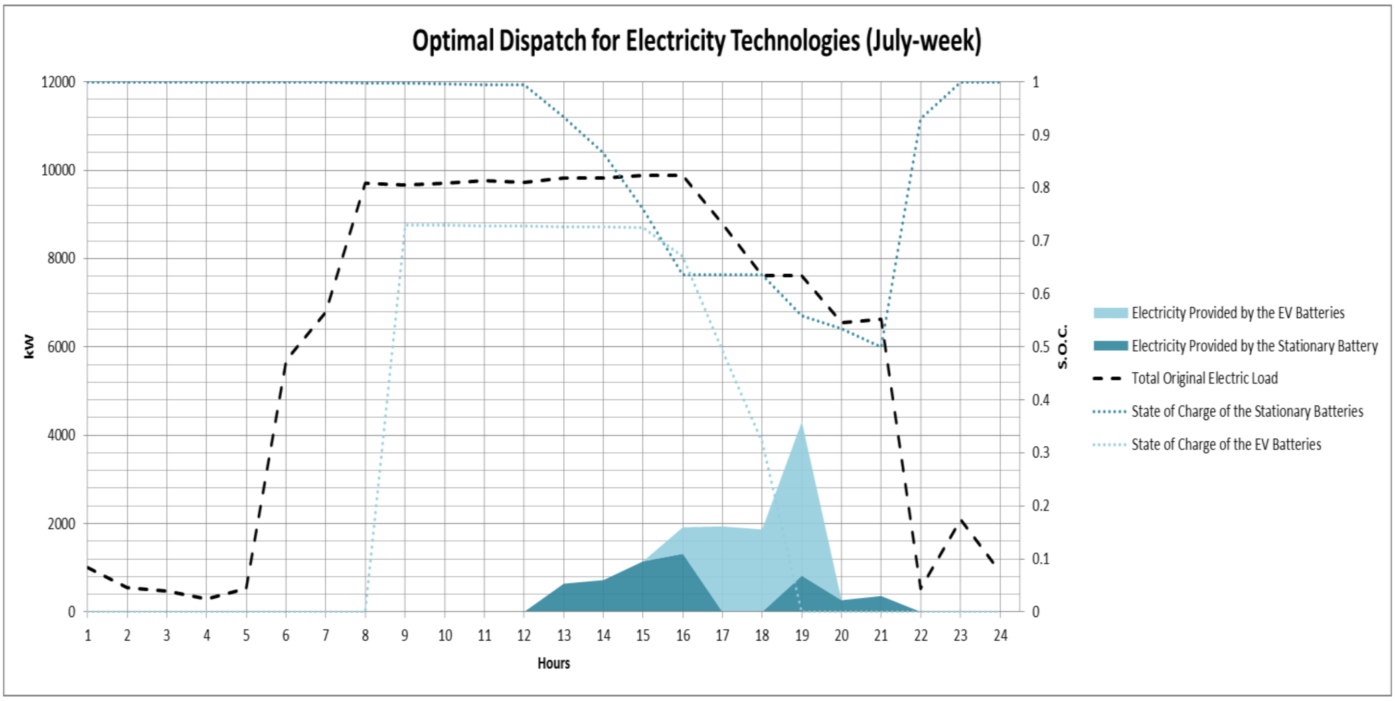

Figure 4. Contribution and State of Charge of the storage resources.
(SoC of EV battery reflects only extra over energy from V2G charging / discharging, and is not the true SoC)

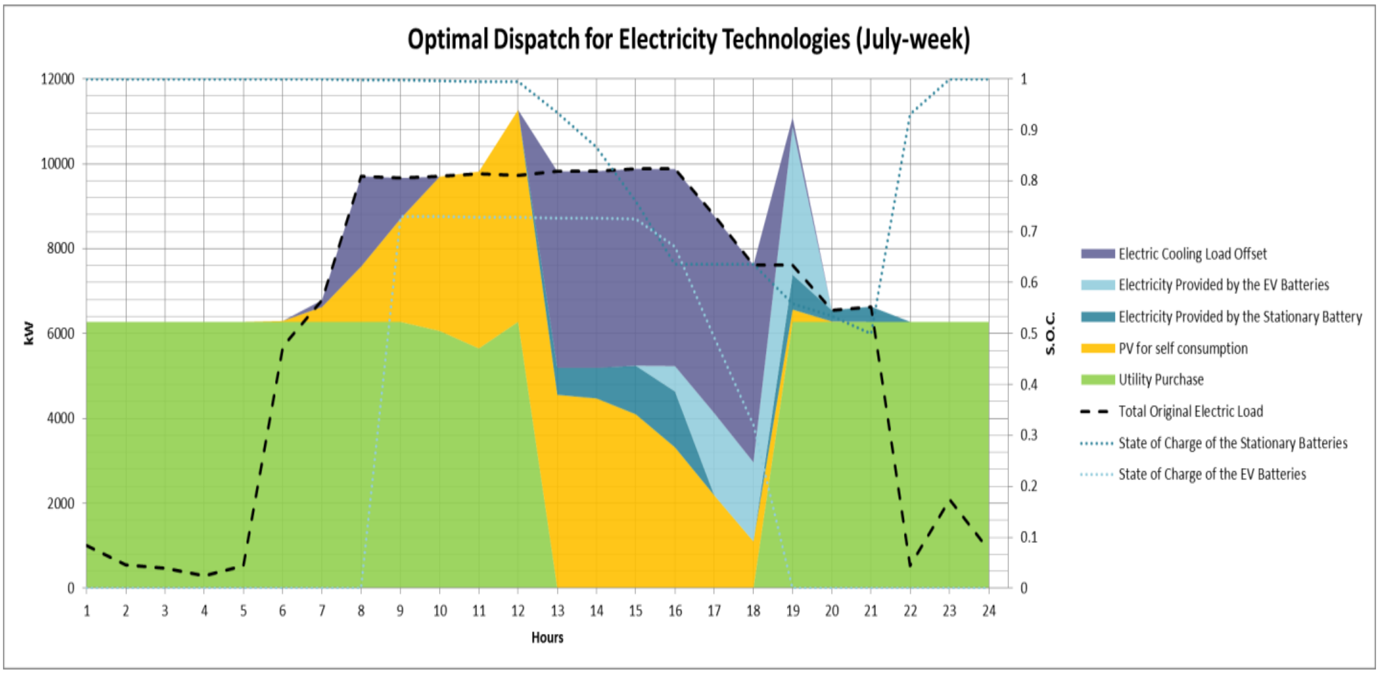

Figure 5. Optimal dispatch of resources for a typical event day. Note- no power is need be drawn from the grid during peak hours. Diesel gensets were not run at all due to high costs.

References

Papers:

[1] Stadler, M., 2012. Application of the Software as a Service Model to the Control of Complex Building Systems. ECEEE 2011 Summer Study, Belambra Presqu'ile de Giens, France, 6? 11 June 2011.

[2] DeForest, N., Mendes, G., Stadler, M., Feng, W., Lai, J. and Marnay, C., 2014. Optimal deployment of thermal energy storage under diverse economic and climate conditions. Applied energy, 119, pp.488-496.

[3] Stadler, M., Cardoso, G., Bozchalui, M.C., Sharma, R., Marnay, C. and Siddiqui, A., 2012. Microgrid modeling using the stochastic distributed energy resources customer adoption model der-cam (No. LBNL-5937E). Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA (US).

[4] Uddin, K., Jackson, T., Widanage, W.D., Chouchelamane, G., Jennings, P.A. and Marco, J., 2017. On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by a flexible integrated vehicle and smart-grid system. Energy.

Technical Reports:

[5] EPRI. The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources. EPRI Feb 2014, Product Id: 3002002733

[6] DER-CAM User Manual. DER-CAM Version 4.4.1.4. Lawrence Berkeley National Laboratory (LBNL) - Version 27 April 2016

[7] MIT Energy Initiative (MITEI) 2016. UTILITY OF THE FUTURE

Standards:

[8] WG C6.22 Microgrids Evolution Roadmap CIGRE 2014

[9] EN 50438:2013, Requirements for the Connection of Micro-generators in Parallel with Public Low-voltage Distribution Networks CENELEC 2013

[10] IEC/TS 62898-1 Guidelines for General Planning and Design of Microgrids IEC 2017

[11] IEC/TS 62898-2 Technical requirements for Operation and Control of Microgrids IEC 2017

[12] IEEE 1547.4 - Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems IEC 2011

[13] IEEE 2030.X - Series of Microgrid Standards IEEE 2015, 2018

Addendum I

Tomatoes and the lure of net-metering and feed-in-tariffs

Communicating the technical issues behind NM and FiT to Building Owners is difficult enough without well-meaning inference by politicians and advice from salesmen. Owners need to understand that FiT and NM can disappear at the stroke of a policy maker's pen and that they are probably better advised to focus on self-consumption as a long term strategy, hence this letter :-

Dear Building Owner,

You may have heard that you can profit by selling PV energy back to the National Grid or your local municipality.

Before you get too excited, please remember the tomato story.

> You grow tomatoes in your backyard. Depending on the season, the rain, and the birds you will at times have more tomatoes than you need. Why not trade them with your friendly supermarket ? After all, he sells tomatoes all the time, and you often buy them there when your crop falters.
>
> So you offer to trade your surplus in exchange for an equal amount of tomatoes to be collected the following month. The Supermarket Manager will refuse. He will point out that he buys his packaged tomatoes via a supply chain that guarantees both quality and supply, and that he certainly is not interested in any exchange on a one-to-one price basis. He buys his tomatoes at a wholesale price far below the retail price for one, and he does not have the staff or the knowledge to accept and process your unknown and untested tomatoes either.
>
> Why don't you, he suggests, bottle the spare tomatoes and use them at a later date. And, if you need more tomatoes at a moment's notice, his supermarket always has in stock.

The very same approach holds for electricity.

> In an ideal world, the magical grid will have infinite capacity and be run by a benevolent charity willing to take your meagre amounts of self-generated energy at a moment's notice and with fabulous reward (Feed-in-tariffs) - or at the very least in equal exchange for electricity whenever you needed it in the next 12 months (Net Metering)
>
> In the real world a neighbourhood full of buildings festooned with PV that produce excess energy in the middle of the day may find the grid unwilling to pay the retail rate for that energy. More so, in the real world, the ill–timed contribution from such buildings could be turned away, and any self-generated excess will have absolutely no tradable value.

You would be far better off if you could store that energy (literally) for a rainy day ? Time to start thinking large scale energy storage ! The real advantage of battery power is not only the financial benefit – the need to be independent and the ability to control one's future will drive the industry.

A few decades ago a top quality building had marble tiles and a piano in the foyer – then it was high speed internet access. Now it will be a microgrid with its own energy generation and energy storage resources. Prospective tenants will ask of the landlord "are batteries included ?"