Domestic energy storage, energy storage for mini- and micro-grids and the role of storage behind the PV rooftop investor's meter

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From next year, municipal distributors will only be able to purchase Eskom energy for resale on a time of use basis. Each year a greater proportion of peaky residential load and self-dispatched renewable energy is being connected to their grids. The effect is a deteriorating load factor, leading to a higher cost of supply. DSM tools are needed to contain these costs and energy storage fits the bill as both a flexible load and a generation resource. Where it is located is almost irrelevant, provided the distributor can control the charge and discharge cycles.

Residential energy storage: as-is assessment

Energy storage in plain sight

Today, residences are full of devices that depend on some kind of energy storage arrangement; typically, batteries of varying chemistries. In most cases the storage is built into the device to make it portable. Management of these devices is now routine, even the youngest are familiar with the technology and extend their device usage using 'power banks'. The most obvious such device is the cell phone, but includes devices such as laptops, tablets, cameras and portable game consoles.

There, but not so obvious

Small scale stationary battery storage is also surprisingly widespread; millions of households have burglar alarm systems, electric fencing systems and electric gate motors that contain batteries, typically a 7,5 Ah sealed lead acid battery that is only called into service in the event the grid fails.

Spawned by load shedding

In response to the shock of load shedding, (2008 to 2014) many of the middle to upper income households made investments either in petrol generators or UPS appliances to power essential lighting and electronic appliances through load shedding events. Unfortunately, these devices are now largely stranded assets, gathering dust.

Another consequence of load shedding has been the uptake of bottled gas for cooking purposes. The LPG gas regulations allow a 9 kg gas bottle to be used indoors provided a ground level air vent is installed. If an assumption is made household that switched to gas has one full spare 9 kg bottle on hand, seeing as the energy content of 1 kg of LPG is 46,4 MJ, a full 9 kg bottle effectively stores a massive 116 kWh of energy. Normal cooking consumes between 1,8 kWh, and 5 kWh per day, so conservatively it can be claimed that, a gas bottle is good for a daily energy storage value of 2 kWh.

Hidden from view or just not recognised

The above mentioned are the more obvious instances of energy storage within a household. Often overlooked, electric geysers are also energy storage devices by virtue of the fact that they are designed to store thermal energy in the form of hot water.

An unusual property of water is its rather high specific heat capacity. At 4,2 kJ/kg/°C means that a fully charged 150-liter geyser set to 60° centigrade is capable of storing approximately 7 kWh worth of energy. It can easily do this both mornings and evenings if necessary. This storage mechanism works without fault every day and is fit for purpose provided sufficient hot water is made to meet the household's needs at each cycle, either mornings, evenings or both.

This is one of the cheapest forms of energy storage available and has no constraints on the number of cycles it can perform. Using geyser control systems such as "ripple control", many municipalities have used this storage characteristic to reduce the evening peak loading by delaying the time the geyser's heating element may be energized to re-heat the water. If done responsibly, the household will not even notice the switching and the financial benefit of doing this is an annual reduction in the cost of Eskom energy to service geyser load of R 1 776 per geyser controlled.

The load profile challenge

A large proportion of municipal electrical load is residential, characterized by a morning and evening peak profile driven by human habit. The peak periods are priced higher in Eskom's Local Authority Megaflex tariff which is designed to apply time differentiated pricing signals, aimed at reducing peak period consumption. A substantial amount of municipal distributors do still purchase from Eskom on flat tariffs, however, from 2018 onwards all Eskom energy purchased for re-sale will only be available on the new, Megaflex equivalent, Muniflex tariff.

The choice of renewable energy around Johannesburg is rooftop PV, the generation profile of which may contribute in part towards reducing the morning peak period consumption of Eskom power, but will make absolutely no contribution to reducing the troublesome evening peak period consumption between 17h30 to 19h30.

Aside from imposing centralized control of geyser load, there is very little a distributor can do to get residential customers to voluntarily manage their consumption during peak periods. Purchasing power on a time of use tariff and re-selling through flat tariffs is a risky business – a cold winter season in Johannesburg for example can reduce the annual surplus generated from electricity sales by hundreds of millions of Rand. The way to mitigate this risk is to re-sell also on a time of use basis, in order to pass on the pricing signal (risk), to change customer behavior or at least recover the input cost of the peak energy delivered.

In hindsight, Regulation R773 promulgated by the then DME in July 2008, requires that “any end user or customer with a monthly consumption of 1000 kWh and above must have a smart metering system and be on a time of use tariff no later than 1 January 2012”, if complied with, would have reduced this risk to the municipal electricity distribution industry. This however remains an outstanding matter for most of the industry. The implementation of residential TOU tariffs is key to justifying the end user’s business case for energy alternatives and coordinated use of energy storage systems in the household.

Table 1 gives an idea of the potential amount of peak period energy consumption that could be avoided by a household by taking advantage of the energy storage characteristics of the appliances listed.

Table 1 - Residential energy storage system assessment - daily usage assumed.

Batteries	Quantity	Capacity A hr	Operating voltage	Useable capacity	Capacity kWh	Total Capacity kWh
Cellphone	4	1,5	3,7	85,00%	0,0047175	0,02
Laptop	2	4,5	14,8	85,00%	0,05661	0,11
Burglar alarm	1	7,5	12	35,00%	0,0315	0,03
Electric Gate	1	10,5	12	35,00%	0,0441	0,04
2 kVA UPS Unit	1	100	24	35,00%	0,84	0,84
					Sub-total	1,05
Gas Bottle	Quantity	Capacity kg	Energy cont. MJ/kg	Useable capacity	Capacity kWh	Useful capacity
Indoor gas cooker	1	9	49	100,00%	122,5	2
					Cooking energy averages 2 kWh per day	
Storage Water Heater	Quantity	Capacity liter	Energy kont. kJ/L	Useable capacity	Capacity kWh	Total capacity kWh
Geyser set to 60 deg Centigrade	1	150	206,4	80,00%	6,88	10,32
					Partially used morning and evening	
					Total daily storage potential, kWh	**13,37**

Urban densification

High income area subdivision

Immediately prior to the 2008 global economic slowdown, the demand for new service connections in City Power's area of supply exceeded 340 MVA. Over 50% of this demand could not be serviced without serious deep infrastructure upgrade, particularly if the new capacity was required within the long established "leafy suburbs". In these areas, houses on one acre stands were being demolished and replaced with up to six "cluster houses", creating a demand for power that the existing networks simply could not deliver.

This resulted in perhaps the first "micro grids" appearing behind the meter, as developers began to use battery storage with first generation grid-tied inverters to unlock their developments. All the system had to do was supplement the grid supply over a relatively short evening peak period, the concept being made achievable through the application of energy efficiency technologies and where possible, using alternatives such as gas for thermal energy requirements. Provided the land owners agreed to sign a servitude of constraint on their title deeds, approval for such development was granted and they went ahead.

Low income area sub-letting

The phenomenon of the "backyard shack" is a very similar issue, however in this case it is the distributor that will need to consider the installation of an element of storage, installed down at the so-called "grid edge" – the end of the distribution network. As was the case of the high income area developments, the point at which the grid needs supplementary energy to be injected is beyond the final distribution transformer, typically at the junction box to which groups of houses are connected. Unfortunately, such a distributed application of storage will be costlier than a single utility scale installation at the bulk supply substation, and may be a lot more difficult to secure.

Perhaps a more workable option is to develop small, one to two kWh "feed through" units that are located within the houses and are capable of being collectively controlled as a mini-grid, using mature power line carrier communications communicating through the grid itself. The storage part of this concept functionally serves the same purpose that the many thousands of 1 to 2 kVA inverters put into service during load shedding era performed – to ride through a relatively short period of power constraint.

The load profile in the low income residential areas is particularly peaky, characterised by dominant early morning and evening peaks. Technically, these are troublesome from an outage causation point of view, which appropriately coordinated storage could alleviate. However, there is also a subtler financial issue attached to this load profile. The National Electricity Pricing Policy requires that distributors keep the cost of electricity as low as possible to the low income sector and permits this be done by creating a cross-subsidy from their commercial and industrial customer base.

The issue here is that as the cost of Eskom power continues to increase, so does the cost of providing the cross-subsidy. This results in runaway commercial and industrial tariffs and the risk of business migrating out of the area of supply. To add an insult to injury, because the load profile of the sector being subsidized is so biased towards peak periods, the subsidy is required to provide the most expensive energy available.

This adds yet another use case to the "value stack" that energy storage brings to the grid. In addition to solving the backyard shack overload issue, such localised storage will enable a portion of the subsidized energy requirement to be sourced from cheap, off-peak power available overnight.

Scaling up to suburb scale

The population of Johannesburg reportedly grows by more than 100 000 people each year. There are consequently over 180 informal settlements within the metro's boundaries, some of which are going through a 'blocking' or 'regularizing' process to formalize them. South of Johannesburg, two such settlements are Lawley and Thembelihle, areas previously underdeveloped and only with limited "peri-urban" Eskom supplies installed.

These settlements have somewhat rapidly come into existence. The City recognises its municipal mandate to provide services to these communities, perhaps the most socially uplifting of these being energy services. In the case of Lawley in particular, the existing Eskom supply available is in the order of 1 MVA while the number of regularized houses is around 2000. To increase the capacity of the Eskom supply requires deep network upgrades that are only planned for the five to ten-year horizon. So – 1 MVA for 2000 houses – a distribution planner's nightmare, with only 0,5 kVA available for each house, at a stretch perhaps 1 kVA after diversity is taken into account. This is significantly lower than the 2,5 kVA used for rural electrification and the 4,5 kVA that is today's norm for urban townships.

A new energy mix policy was developed by City Power to try to address the problem. The solution proposed that the limited electrical grid power would be provided for high value utilities such as public lighting and each home's lighting, small appliances including cellphones and entertainment devices, small kettles and refrigeration needs. Bottled gas distribution and free issue gas stoves would be provided to meet each household's thermal needs – energy for cooking and water heating.

The areas are reticulated as per the 4,5 kVA norm, and to augment the limited grid supply, a pylon supporting a 3 kVA solar panel and a 2 kWh battery and inverter system has been installed per cluster of twelve houses. As part of a pilot project to test the concept, 80 such pylons were installed this year and the project is being monitored, while the gas component has not yet been implemented.

Benefits of residential TOU

From the discussion so far, it is quite clear that it is in everyone's interest to shift as much consumption during peak pricing tariff periods to off peak periods. The effect is to reduce the overall cost of the same amount of energy supplied to the system, while network overload outages are also reduced proportionately. In order to create the environment for customers to realize a financial benefit as a reward for such consumption shifts, distributors urgently need to roll out residential time of use tariffs.

The tariff is designed in such a way that if a customer is converted and does nothing to change their load profile, the cost increases marginally as a penalty. If however, after conversion, the customer is able to shift out a reasonable portion of peak load, the price of the balance of non-peak consumption also reduces, bringing down the total cost for the customer and distributor alike.

Where this can be done by simply timing the use of appliances such as washing machines, dishwashers and geysers – the "heavyweights", significant cost savings can be realised. This is also where an element of storage such as those many thousands of UPS systems purchased during the load shedding days, charged off-peak and discharged during peak could earn a return every single day of the year and still be available to provide basic services in the event of a network outage.

To attach a value to each kWh shifted out of peak, the difference in peak and off-peak pricing will equal the savings realizable as shown in Table 2. Summer and winter price differences also need to be considered when calculating the annualized figure, and in the case of an energy storage system used daily, the round-trip losses will need to be taken into account as well.

Table 2 : Value of arbitrage per kWh shifted.

On City Power residential TOU tariff	Cents per kWh
Winter peak rate	308,65
Winter off peak rate	89,22
Value of winter evening energy arbitrage	219,43
Summer peak rate	134,16
Summer off peak rate	83,49
Value of summer evening energy arbitrage	50,67
Efficiency of charge and discharge cycle	75%
Average value (over a year) of evening arbitrage	71,63

PV and storage behind the meter

City Power has a NERSA approved small scale embedded generation tariff for both commercial and residential customers. The option only applies to post-paid tariffs that have a defined monthly network charge component, separate from energy charges. In the case of commercial customers, the compensation paid for each surplus kWh put onto the grid is 37 cents. In the case of residential customers, they are firstly required to convert to the residential time of use tariff, and they will be compensated at 42 cents per kWh.

Presently, the cost of storage is still too high for mainstream residential customers to justify going completely off-grid with a PV plus storage system. The risk of grid defection is however real and will become more significant to the distribution industry as time passes and the cost of storage reduces.

It does however make sense right now, if installing a residential PV system, to consider installing a hybrid system with just enough energy storage to carry the household over the two-hour evening peak period. The system should be programmed to maximize the customer's self- consumption by storing as much of the surplus PV energy as possible rather than allowing it to leak back onto the grid. This is the concept behind the Tesla Power Wall – it can provide just six kWh of storage, enough to use cheap PV power (or off-peak utility power) to avoid peak energy costs, and still be available for standby duty service in the event of a grid failure.

Town house complexes are also seeing the opportunity in converting to a TOU tariff and applying community scale versions of these new technologies behind the meter. The certainty that the promulgation of the new licensing exemption regulations brings to the industry, will no doubt promote the uptake of these new options.

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