Smart Communities - Embedded Residential Microgrids

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***Abstract*—the transition of consumers to prosumers will lead to green energy and energy efficient systems such as rooftop photovoltaic (PV) and energy storage becoming more prominent within the residential sector. The country has an average of more than 2,500 hours of sunshine per year and is ranked top in the world for solar power investments. Combine these irradiation figures with the decreasing cost of photovoltaic technologies, and the result is a very different customer profile from that of yester year. As this energy landscape is changing, so to must the utilities follow suit, by adapting and adjusting traditional business models to embrace this disruptive technology and make it work to its favour. A Smart Embedded Residential Microgrid Pilot is introduced to demonstrate how a power utility might reap benefit from the future customer or "prosumer" and look into possible future business models.**

I. INTRODUCTION

South Africa (SA) has an average of more than 2500 hours of sunshine per year and average direct solar radiation levels range between 4.5 and 6.5 kWh/m^2/day [1] and 2015 it was ranked the seventh in the world for photo voltaic solar power investments and third for concentrated solar power [2]. Residential rooftop solar PV systems have been gaining market share within South Africa since 2011 [3], and the market growth numbers are still increasing at a significant rate [4]. Many factors contribute to this increase, such as the decreasing cost of PV panels (grid parity), continuity of supply and the greener (environmentally friendlier) thinking from our electricity customers. Figure 1 and 2 illustrates the declining trend of PV prices (2010-2015) in international markets and Africa's respectively.

It is critical that we (as the utility) understand the role of power utilities within this market, and the impact it will have on future business and whether a utility should proceed in this sector or not. There is also the question of safety on the networks and how the rules of grid-tied systems will be applied and monitored to safeguard the network from illegal connections (grid injection), and grid tied inverter systems that fail to island itself from the grid. The SA utilities business model has remained fundamentally unaltered over the last century, whereby mainly the utility is responsible for generating power and selling it to the customer. Up to the last few years, customers were mainly simply energy consumers, with one way power flow from generation to load, where the demand was fairly predictable and manageable.

Today, the utilities model is undergoing a paradigm shift. With the introduction of smart and renewable energy technologies, consumers can now make more informed choices about energy usage and become energy both consumers and producers themselves – known as "prosumers" -resulting in a two way directional flow of power on the existing grid infrastructure. The evolution of the prosumer goes even further by incorporating information and communications technology (ICT) and automation, coupled to energy storage systems with the aim of a completely reliable source of electricity.

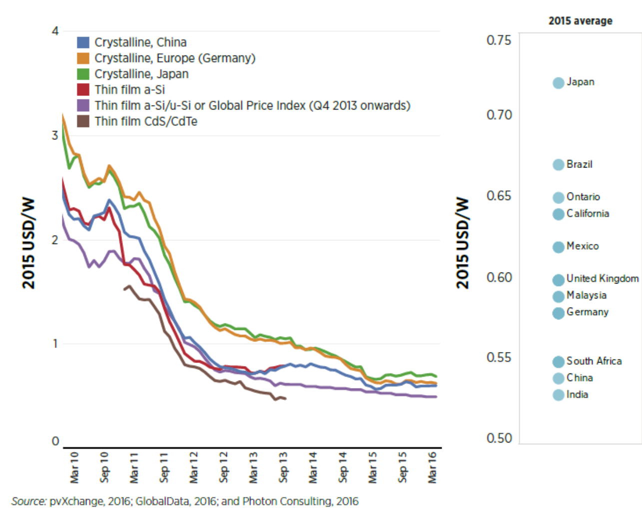

Figure 1: Quarterly PV Module Prices by Technology Sold in Europe 2010-2016 [3]

As this energy landscape is changing, so to must the utilities follow suit, by adapting and adjusting traditional business models to embrace this disruptive technology and make it work to its favour. It has become clear that the rise of the prosumer will challenge the utilities model as we know it, and there are many opportunities for customers and utilities to work together in this new era of two-way energy management.

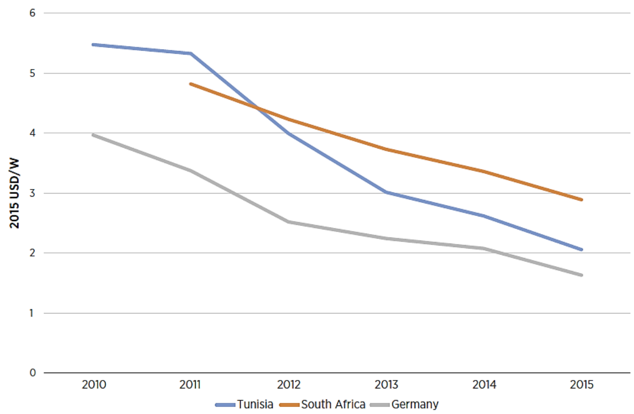

Figure 2 - Installed Photovoltaic System Prices in Africa (2010-2015) [3]

The decreasing cost of photovoltaic technologies has resulted in the installed price of solar energy declining significantly in recent years. This trend in Figure 1 and 2 indicates that the coming years will likely see utility-scale solar become cost competitive with conventional forms of electricity generation. As conventional produced energy costs continue to rise, there is a strong drive for even whole city districts to become "prosumers" who consume, produce and control their own energy use. The eThekwini Aerotropolis project is an example of this evolution. Smart energy management is an important key in the optimal efficient operation of any energy management system and consumers now have the knowledge and tools to take control of their energy needs, which will most likely make their sole dependencies on the utility grow less.

Power utilities have been introducing smart grid programs to encourage commercial and industrial consumers to use energy management best practices, especially during peak times when there are risks of grid blackouts.

The utility of the future should invest in on-site energy generation. Renewable embedded generation within a local microgrid can not only offset the cost of buying energy from the central grid, but it can also reduce the carbon footprint of the consumer and boost their image as a "green" corporate citizen. The gain of this renewable market share aligns the SA power utility favorably with commitments towards the SA Integrated Renewable Plan (IRP), carbon credits and green statuses.

Programs driven by the Utility for large power users (LPU) and small power users (SPU) presently encourage energy customers to adjust their consumption in response to pricing signals, penalties (notified maximum demand) or curtailment requests. When one couples demand energy responses (DERs) to the consumer's energy consumption loads and on-site generation capabilities, it is even more critical to manage these DERs to balance the grid.

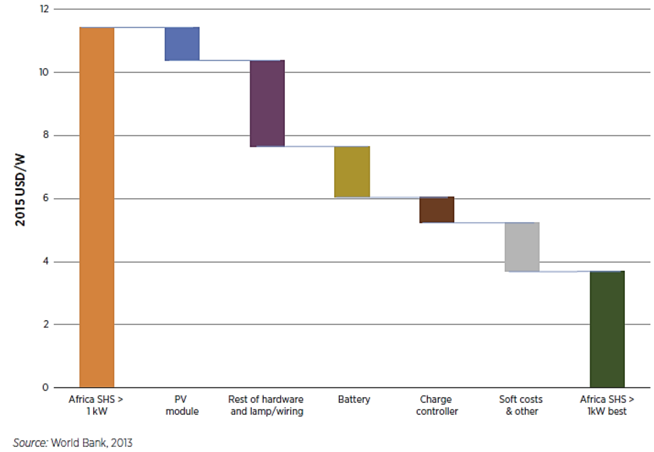

Figure 3: Average declining cost potential of (>1kW) solar home system components (such as the battery and charge controller) [3]

Within the residential sector, many customers are taking more direct control of the cost, reliability, and "green" mix of their energy supply. The SA load shedding situation of 2008 influenced self-generation and continuity of supply requirements in many different sectors across the country. The number of residential roof-top PV and battery storage systems installations increased significantly. Even though the price for this technology seemed high, the "convenience factor" took precedence over financial viability in certain cases. However the present low PV prices have given rise to more flexibility in this sector, with the increased installation of PV systems being more prevalent and the need to be reliant on the grid less every day. PV have been shown that it can compete with equal footing with fossil fuels in areas located in the Sunbelt and with circumstances which allowed low-cost financing and correct type of policy frameworks [3]. The price of energy storage is also on the decline [3], this is also shown with the trend in Figure 3. Latest battery technologies have increased capacities, greater depth of discharge (DoD) and longevity of the batteries have increased immensely, thus maximizing consumer's self-consumption energy capabilities and control over when to utilise it.

Many electric grid infrastructures in the world are under stress, especially in third world countries. The increasing demand for energy in SA places strain on an ageing generation and transmission infrastructure, resulting in more operations and maintenance costs being incurred, subsequently resulting in the application for tariff increases to support the system. Energy demand in South Africa is predicted to increase by approximately 41.6% by 2030 [5]. Weather events are also becoming more severe, with related damages already running up to millions in cost annually for the replacement of transformers and transmission lines. Despite these challenges utilities are still expected to maintain or improve grid stability. Stricter environmental regulations and adherence to the IRP mean that adding traditional fossil fuel electricity generation capacity is less viable and that there is a need to achieve a target for renewable generation capacity of 4.68 Gigawatts by 2030 [5]. This has resulted in a stronger drive to deploy renewable energy, but this technology is inherently intermittent. This can result in a grid that is more difficult to keep balanced, energy pricing that is more volatile and greater risks to power reliability for commercial, industrial and residential sectors.

II. SMART EMBEDDED RESIDENTIAL MICROGRID PILOT

A. Problem Statement and Introduction

The prosumer revolution presents a huge opportunity to help address these issues through effective smart energy management and utility embedded generation in this sector. Renewables are clearly at the heart of the prosumer movement, but greener energy sources bring challenges of their own. These renewables systems require might more upkeep costs in terms of operation and maintenance and the upfront installation costs associated with capital investment can be high. There are also additional costs and technicalities involved with integration into the grid such as grid access costs, safety, standards and compliance.

The goal of smart energy management is to provide utilities with an alternative to building more power plants to meet capacity needs by partnering with the customer to install, operate and maintain roof-top PV systems and manage energy usage and production. This approach is mutually beneficial.

The customer benefits by having , green, resilient, continuous supply of electricity, with the benefits of lower tariffs during sun production hours and the additional benefit of trading excess energy across/ within the network with associated feed in tariff (FIT) rates.

The utility benefits by having utility managed embedded generation that can be used to inject back into the network during constrained/unstable conditions, as well as additional revenue streams from wheeling energy across/within the network as well as associated network charges for fed in energy.

Energy trading within the network can flatten the energy curve. The ring-fenced demonstration pilot in Lynedoch, Stellenbosch aims to demonstrate the effect of trading energy between different levels of energy consumers (living standards measure (LSM) groups 3-10).

Figure 4 shows the effect of leveling the total energy requirements under the curve (LSM 3-10) and offsetting by installing a Roof-top PV system of equal magnitude across all LSM groups, and the trading of excess energy from under the curve to above the curve, hence leveling the demand /supply profile.

While both utilities and prosumers can benefit from this new energy model – there are challenges to be addressed to enable a smooth transition. Before smart energy systems and energy trading program come to life, the utility will need to research whether or not the expense of these new services and technologies can be justified and improve the bottom line. The latter could also apply to the consumer. There is a risk of provisioning the use of one's roof space to the utility, which if not managed responsibly, could have negative impacts on the consumer. Turning on local rooftop embedded generation or turning off some customer loads (with an appliance control device or ACD) can put operational processes at risk, if not managed carefully.

Nevertheless, these challenges are certainly manageable and the utility is seeking better ways to engage with customers and manage and optimise these new levels of complexity associated with deploying such systems.

The beginning of the energy prosumer thus represents a significant change in how energy will be generated, distributed, and consumed in the networks of the future. The relationship will change between utilities and their customers, who are now able to monetise their generation capability and flexibility.

B. System Criteria and Scope

The Smart Embedded Residential Microgrid pilot project was selected using the specific selection criteria:

- A residential community of 30 Household from living standard measures (LSM) 3 to 10 across the selection.
- A community with "Green" attributes in terms of tendency towards renewable energy and environment friendliness.
- A direct Eskom customer electricity supply area.

Using this criteria, the residential village in Lynedoch , Stellenbosch was selected for the pilot. The initial pre-concept phase involved discussions with the community to explain the nature of the pilot program, discuss the initial energy requirements and obtain permission to allow RT&D full access to the roof structures for the installation of Eskom embedded generation assets, in this case roof top PV systems with battery storage. A weather station was installed in order to collect solar irradiation, wind speed and temperature data from the site Additional profile data in conjunction with the irradiation data was used to design the system. The data was analysed to determine the most appropriate distributed energy resources to be used. In this case the average solar irradiance for the site was >500W/m^2, and the solar irradiance was sufficiently high, hence solar PV was selected as the primary distributed energy resource.

C. System design and energy Trading methodology

The total energy requirements of the village was normalised over the year, and the total energy under the curve (shown in Figure 4) was calculated. This energy was levelised to calculate the size of the roof-top PV installation that will be fitted on every roof of the community. The same size system was installed across every roof. By design the lower LSM customer who used the lessor energy, now will have access to the levelised energy of his roof top system and will be able to trade this excess energy within the radial feed of the community electricity network to his/her neighbours.

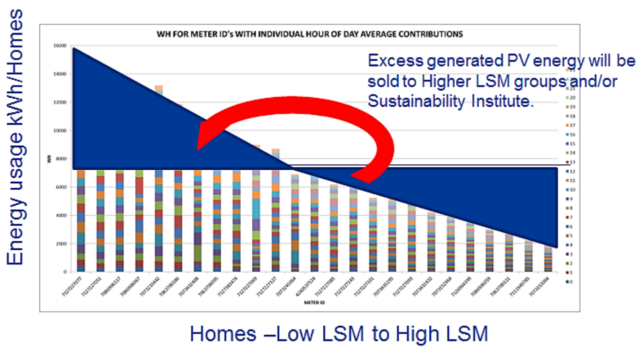

Figure 4: Energy Curve of Houses Sorted per LSM

The opposite concept applied to the higher LSM customer. The installed roof top system only accounted for a portion of his/her energy need and the deficit was imported across the radial feed from other lower LSM customers who had surplus electricity. A portion of the exported energy from the lower LSM customer is remunerated as revenue for initiating the trade.

An illustration of a possible example of a house with embedded rooftop PV generation is given in Figure 5. This house will include a small controller linked to/built in with the inverter, a battery bank and a range of possible electrical appliances or loads.

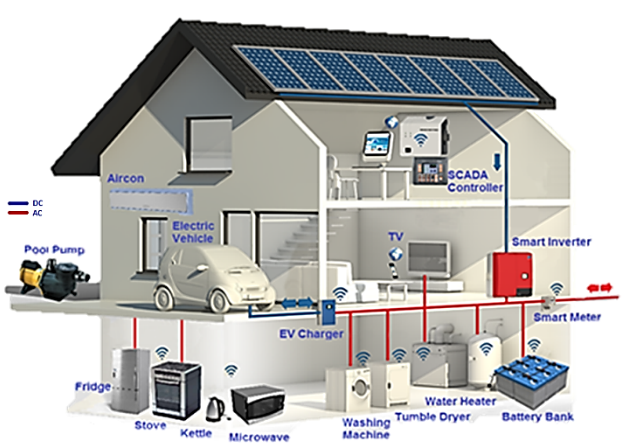

Figure 5: House with a Rooftop PV Generation System

A fixed set of rules were developed and a control methodology was created for the system operation and energy trading platforms. Figure 6 below shows the overview of the logical functional flow of the PV control system, which consist of battery storage systems, energy supply systems of each house and the power feedback process from a house into the microgrid infrastructure.

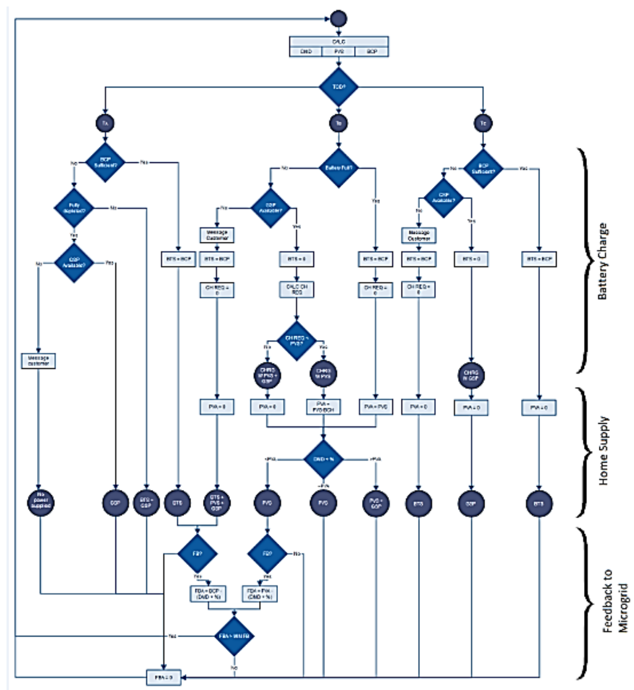

Figure 6: Overview of System Control Methodology's Logical Flow

D. Component Sizing

For each house a number of calculations were performed as part of the planning and design of the PV system per house. Examples of things that were considered were the amount of solar panels per house and system sizing, inverter output requirements and the total energy storage capacity required per house. Based on the fact that each house has a different LSM, each house's layout, size and space were taken into consideration.

E. Roof-top PV Components Integration

Integration of the renewable generation system to the house involved installing an IP65 enclosure outside the premises, for easy access to the inverter, battery storage and control modules. The roof top PV installation was initiated after a structural integrity assessment of the roof stricture was established and deemed satisfactory to proceed. The direct current (DC) cables were run within grounded shielded conduit to the enclosure and then to a second distribution box (DB) within the home. Two power meters formed part of the installation: the 1st being a 4 quadrant smart meter and the 2nd being a conventional prepaid meter before the DB within the home. The renewable system can inject energy between these

2 meters, so that the DB box could draw either from the Grid and/or the renewable system (and battery). This topology is shown in Figure 7.

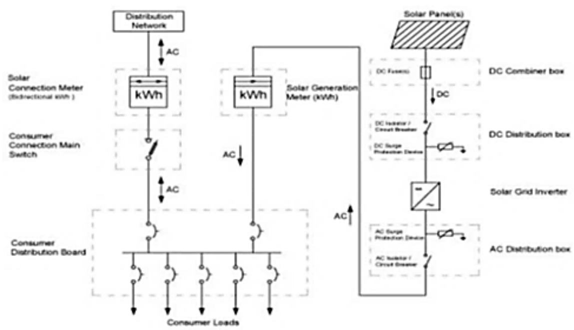

Figure 7: Smart Embedded Rooftop Microgrid Topology

F. Roof-top PV Implementation

The Roof-top PV demo and pilot project is currently in execution phase in terms of the project lifecycle management process it adheres to and examples of houses converted to smart embedded residential microgrid systems are shown in Figure 8. The pilot aims to offer valuable insights to the nature of the business model that the utility might consider in the near future.

Excess energy can be traded on site to other participating prosumers as required but currently energy trading are limited to the local area that the grid feeds into. Conventional power flow from the utility to the customer is still possible indeed the need arises however future results that will stem from this Eskom RT&D pilot project's site might focus on providing clarity for inter connected microgrid site energy trading and how it will be beneficial for the utility and customer. The currently allowed energy flow is indicated in Figure 9.

Figure 8: Photo of Houses Forming an Embedded Rooftop PV Residential Microgrid

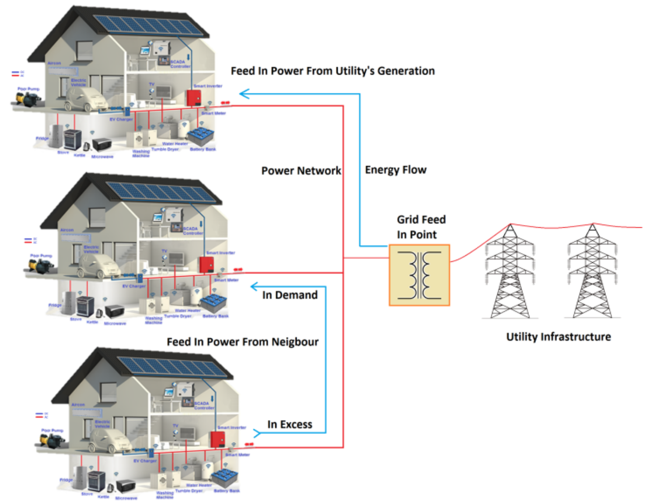

Figure 9: Energy Flow between Houses with Rooftop Generation Capacities

III. CONCLUSION

Various factors surrounding the viability of implementing residential rooftop photovoltaic systems were looked at and discussed. The concept of a smart embedded residential rooftop microgrid that is owned by the utility was introduced and the Eskom RT&D demo and pilot at Lynedoch aims to deliver results that prove that a microgrid system (based on renewable energy sources) can be utilised by a utility in future business models to reap benefits by embracing disruptive PV power generation technologies in a smart community of the future.

REFERENCES

[1] "Renewable Energy," [Online]. Available: http://www.energy.gov.za/files/esources/renewables/r_solar.html. [Accessed 24 August 2017].

[2] Ernst & Young (EY), "RECAI scores and rankings at September 2015," *Renewable energy country attractiveness index (RECAI),* no. 45, p. 45, 2015.

[3] IRENA, "Solar PV in Africa: Costs and Markets," 2016.

[4] ESI Africa, "ESI Africa: The competitive nature of rooftop PV in the African market," 2016.

[5] Department of Energy SA, "Draft IRP 2016," 2016.