CSIR Energy Autonomous Campus

Implementation of a Smart Microgrid

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***Abstract*— An Energy-Autonomous program has been initiated to make the CSIR's main campus in Pretoria, South Africa, energy autonomous in a 5 to 8 year time horizon by supplying its energy from three primary renewable energy sources: solar, wind and biogas from biogenic waste. The power generation will be combined with demand-side management, energy-efficiency improvements and electricity and heat storage including the integration of electric and hydrogen-driven vehicles, power-to-liquid and power-to-gas processes. The other CSIR campuses across South Africa will gradually become part of the program, where in the long-term supply and demand will be virtually balanced across all CSIR campuses. This program will stand as a real-world research platform for designing and operating a primarily renewables-based energy system at lowest cost. This platform will be used to demonstrate in a real-world setting of significant size how a future energy system that is based on a combination of fluctuating and dispatchable renewables can be designed and operated in the most cost-efficient manner in Africa. It will also at the same time allow technology demonstrators and technology development to aid the implementation of renewable energy systems in Africa. The aged campus electrical grid will be upgraded into a smart microgrid.**

***Index Terms*—Smart grid, microgrid, renewable energy, energy autonomous campus**

I. Renewable Based Microgrid Opportunities in Africa

A. *Renewable based energy system future*

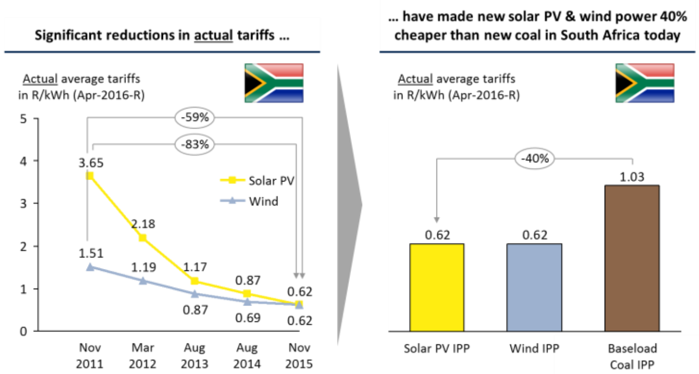

Fig. 1. Comparison of new Wind/Solar tariffs with Coal in South Africa [1]

CSIR analysis of the outcomes of the South Africa Department of Energy Independent Power Producer Program concludes that new wind/solar PV energy is now 40% cheaper than new coal in South Africa, as summarised in Fig. 1 (outcomes of the renewable energy IPP procurement program and coal IPP procurement program) [1]. Furthermore the CSIR scenario modelling of the South African Integrated Resource Plan (IRP) shows that the lowest cost future power system is primarily renewable energy based [1].

In matured electricity markets, renewables compete with an existing, steady-state energy system, primarily acting as fuel savers for the existing thermal power generation fleet. The historical thermal generation incumbents have business models based on "large, central" and in general suffer in terms of decreasing market share as the penetration of renewable energy increases.

In emerging markets, the context and opportunity for renewable energy is different. Renewables can be at the core of the energy-system expansion to service the substantial backlog in energy access in a sustainable and cost effective manner, including the opportunity for standalone systems and microgrids [2, 3]. In developing economies:

- Renewables compete with historical thermal new-built options to meet growing electricity demand. The CSIR analysis of the South African power system shows that the most cost effective new build solution to meet forecasted electricity demand is a predominately renewable energy based system [1].
- Renewables are more than just fuel savers. The distributed nature of renewables changes the entire paradigm on which energy systems were traditionally planned, designed, built and operated [1, 2, 3].

B. *The opportunity in Sub-Saharan Africa*

Sub-Saharan Africa consumes 94% less electricity per capita than OECD countries [4]. The annual energy consumption values summarised in Fig. 2 illustrate the substantial potential/need for growth in energy consumption on the African continent.

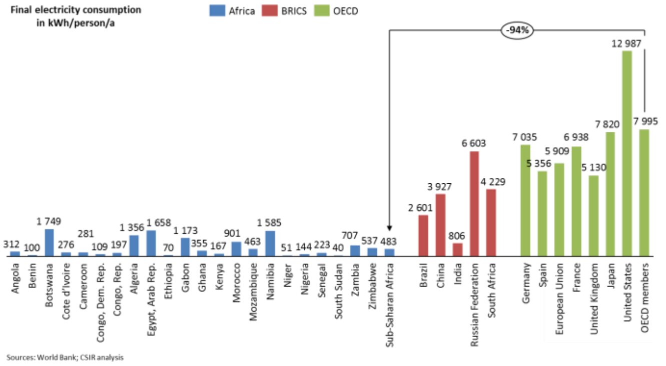

Fig. 2. Electricity consumption for selected African and OECD countries, plus BRICS [4]

Customer demand is generally distributed across wide geographic areas. Historically, this demand was supplied by large, central power generators with a high-voltage transmission backbone and medium and low voltage distribution grids, as illustrated in Fig. 3.

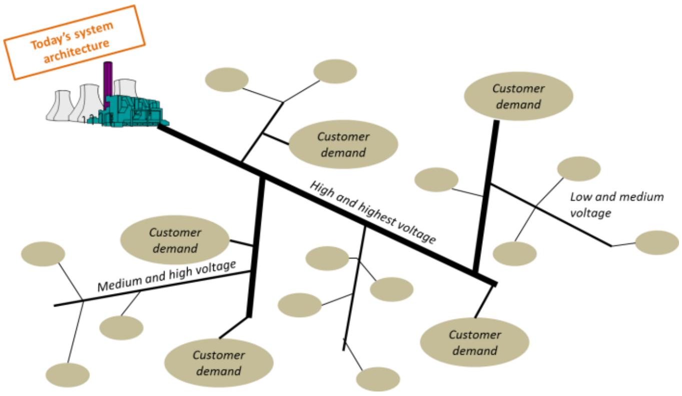

Fig. 3. Present system architecture

In the future, because of cost-competitiveness of distributed renewables, the system architecture is expected to include microgrids [2, 3], potentially grid interconnected as illustrated in Fig. 4.

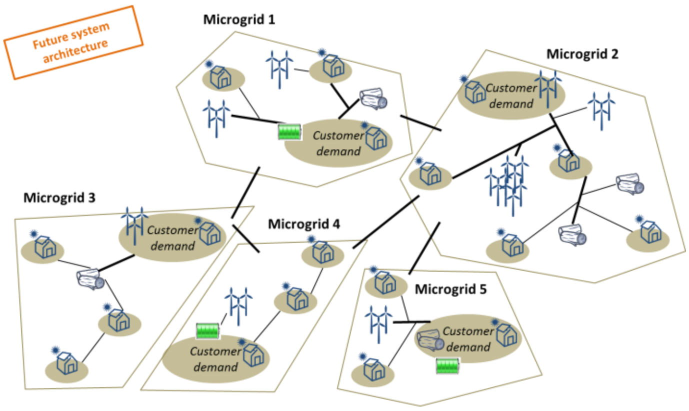

Fig. 4. Future system architecture

There is a substantial opportunity for Africa to leapfrog large-scale, central power system architecture directly towards a distributed, renewables-based system as summarised in Fig. 5. In such systems it is anticipated that microgrids will autonomously supply local customers, and that interconnection of the microgrids will improve reliability and reduce total cost.

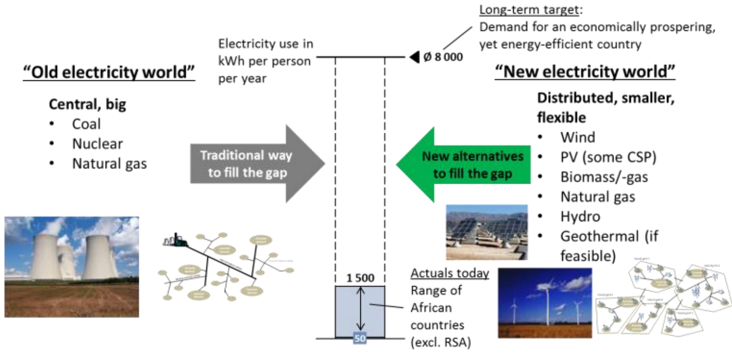

Fig. 5. Summary of the anticipated energy transition

II. CSIR Pretoria Campus

The CSIR campus in Pretoria South Africa consists of 52 buildings, spread over 170ha, and has an annual energy consumption of 30GWh. The campus baseload requirement is 3MW, and has a peak load of between 5MW and 6MW. A typical weekly demand profile is shown in Fig 6. The load is supplied by the local municipal electricity distributor (Tshwane Electricity) via a 132/11kV substation. The campus 11kV cable ring networks supply 11kV/400V distribution substations located in the campus buildings.

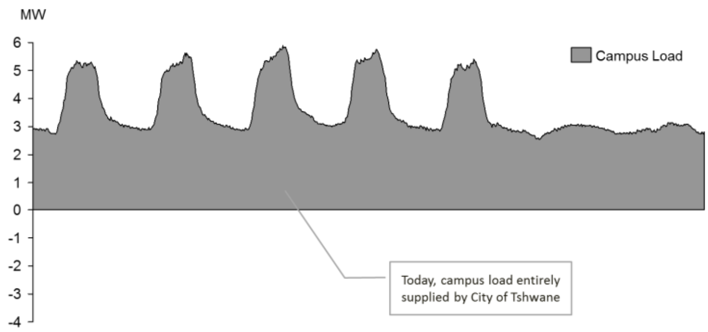

Fig. 6. Present CSIR Pretoria campus load

III. Program Objectives

The aim is to create an Energy-Autonomous Campus (EAC) by supplying energy from three primary renewable energy sources: solar, wind and biogas from biogenic waste. The power generation will be combined with demand-side management, energy-efficiency improvements and electricity and heat storage including the integration of electric and hydrogen-driven vehicles, power-to-liquid and power-to-gas processes. The other CSIR campuses across the country will gradually become part of the program, where in the long-term supply and demand will virtually be balanced across all CSIR campuses, which will form a virtual power plant.

This project will stand as a real-world research platform for designing and operating a primarily renewables-based energy system at the lowest possible cost. This platform will be used to demonstrate in a real-world setting of significant size (> 10 MW total installed capacity) how a future energy system that is based on variable and dispatchable renewables can be designed and operated in the most cost-efficient manner.

The research platform will attempt to address specific questions relating to grid-integration, optimal energy mix, energy tariff regimes, possible trading of energy between CSIR campuses and other potential customers who require green energy (using wheeling arrangements). The project will also address the demand-side component of the energy equation by identifying, developing and implementing energy-efficiency and load management initiatives.

It will also at the same time allow technology demonstrators and technology development in different renewable energy and associated technologies, different control/management philosophies, the functioning of a smart grid and its impact on the main electrical network.

The key questions being addressed include:

- What is the optimal energy mix and how can it be best/cost-efficiently implemented?
- What role does the demand-side play in the design and operations?
- What storage technologies are required and how to best integrate them into the system?
- What is the optimal design and what protocols/standards are required for a campus microgrid?
- How best to operate a microgrid and combination of microgrids (containing many supply and demand resources) as a virtual power plant?

IV. Program Scope

The major scope elements are as follows:

- Install approximately 8 MW of PV on all rooftops of the CSIR buildings at the Pretoria campus and another few 100 kW on rooftops at other CSIR sites across South Africa.
- Install approximately 3 MW of wind turbine(s) on the CSIR Pretoria campus.
- Install approximately 5 MW of biogas-fired gas engines, where biogas is produced through anaerobic digestion from municipal waste. The biogas will be stored on site for the gas engines to be able to provide the flexibility that is required to balance wind/PV supply.
- Conduct an energy efficiency audit across all CSIR facilities (current demand: 30 GWh of electricity per year) and implement energy efficiency measures.
- Identify dispatchable / non-essential loads that can be utilised as a demand-side management (proving flexibility) in system operations e.g. EVs and water heating.
- Model and simulate the entire CSIR virtual power plant across all campuses to optimise the mix of renewables and dispatch regimes.
- Identify need for energy storage in the form of batteries and heat storage and implement technologies.
- Operate the system as a commercially run virtual power plant.
- Use the operational system as platform to demonstrate technologies that are further away from commercialisation, e.g. large-scale electrolysers, subsequent power-to-gas and power-to-liquids processes.
- Connect the electricity and transport sectors by integrating electric vehicles into the CSIR car fleet and by establishing a hydrogen fuel station on campus for later integration of hydrogen-driven vehicles. In the long-term, establish a fuel station with carbon-neutral, own-produced synthetic diesel and petrol to supply to conventional CSIR car fleet (CO_2 + electricity from renewables + H_2O --> carbon-neutral synthetic fuels).

One week's electricity demand and simulated wind/solar PV on CSIR's Pretoria campus is illustrated in Fig. 7, and shows the major impact that variable renewable energy systems will have on the residual load of the campus, and the potential exporting of power into the local municipal network, or the potential to store excess wind/solar energy.

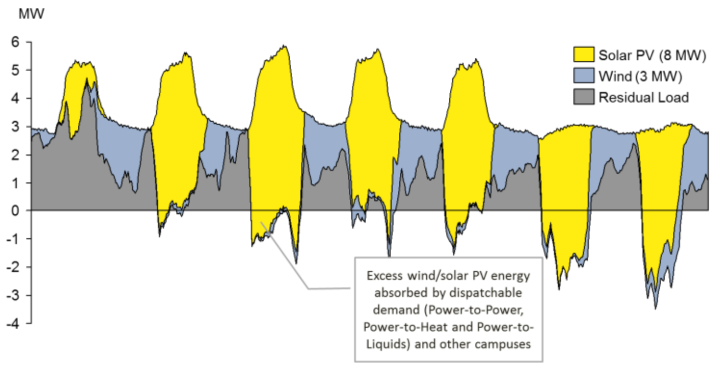

Fig. 7. Illustration of campus energy supply with a combination of renewable energy sources

V. PROGRESS TO DATE

Progress on the implementation of the scope is summarized as follows:

- A first phase electricity system model has been created for the Pretoria campus in Plexos ®. The model requires further enhancement to model additional supply and demand side options, and a range of energy autonomy boundary conditions. The model results indicate that 6MW of PV can be installed as a no-regret least cost option on the Pretoria campus. Further modelling is required to assess the economics of wind, biogas, energy storage, energy efficiency and demand response.
- 1MW of PV has been installed on the Pretoria campus, consisting of a 558kW single-axis tracker, a 200kW dual-axis tracker and 250kW rooftop PV installation. A further 1MW of rooftop PV is in the process of being procured, with additional rooftop PV installations to follow. Industry guidelines have been created to aid other entities in the procurement of similar PV systems [5]. The CSIR experience has been published to inform stakeholders on the outcomes and related learnings [6].
- An EIA for a potential biogas generation plant has commenced.
- Wind measurements have been performed to assess possible wind energy yields.
- An energy efficiency audit of the campus buildings and streetlights is underway.
- A small fleet of Nissan Leaf and BMW i3 Plug-in Electric Vehicles is being operated and charged on the campus.
- An electrical model of the campus grid has been created in DigSilent PowerFactory, and is undergoing further refinement.
- The asset management practices applied on the campus electrical grid are being assessed.

VI. SMART GRID ROADMAP

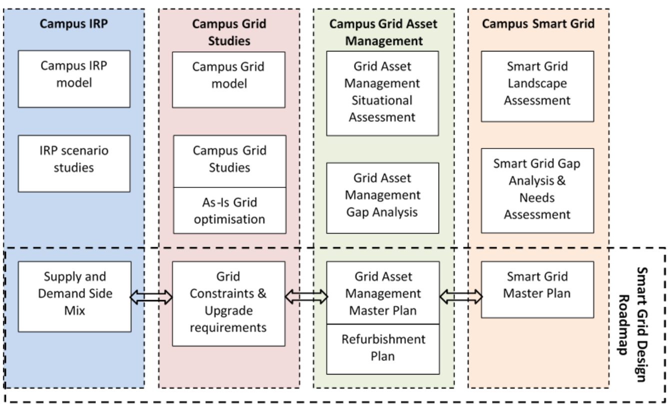

Fig. 8. Projects required to develop a Smart Grid Roadmap for the CSIR Pretoria campus

The integration of the planned renewable energy, storage and demand response technologies on the CSIR Pretoria campus will require the implementation of a Smart Grid enabled microgrid. As such a Smart Grid roadmap needs to be developed for the CSIR Pretoria campus, incorporating a range of interdependent projects as summarised in Fig. 8.

The **Campus IRP** (Integrated Resource Plan) will develop the optimal mix of supply and demand side solutions to meet the forecasted electricity demand, including energy storage. The Campus IRP informs the economic case and functional specifications for the technologies that are to be integrated into the Pretoria campus, and is hence an important input into the other studies that inform the campus electrical grid upgrades. The Campus IRP will initially focus on the electricity system modelling, but will expand into an Integrated Energy Plan (IEP) that optimizes all forms of energy on the campus, including heating (combined heat and power from potential biogas generation) and transport (electric and hydrogen powered vehicles).

The **Campus Grid Studies** will model the grid impact of integrating the supply and demand side technologies identified in the Campus IRP. A range of grid studies will be performed to identify constraints in connecting and integrating the Campus IRP outcomes. Alternatives to address the constraints will be modelled and assessed, as integrating with the grid refurbishment requirements and broader Smart Grid objectives. The envisaged grid studies include; steady state loadflow, fault level assessment, protection grading, grid code compliance assessment, loss minimization, reliability studies, voltage control optimization, reactive power optimization, harmonics and dynamic studies. The studies will need to assess the implications of the relatively small spatial footprint of the campus, and the anticipated variability in renewable energy output from PV and Wind, as are anticipated to be a key integration challenge [7].

The **Campus Grid Asset Management** assess the alignment of the campus grid asset management with the future needs of a Smart Grid. The refurbishment needs and network risks will be identified. Furthermore the asset management assessment will cover the following key areas; asset registers, geographic and facilities management spatial information systems and data, asset care plans, asset data, single line drawings, operating procedures and contingency plans, schematics, maintenance data/history and performance data/history.

The **Campus Smart Grid** project will establish the international developments and best practices in similar microgrid installations in terms of grid design, protection, visibility and control. The results of a Smart Grid Landscape Assessment will be used to perform a related gap analysis and needs assessment, the results of which will be used to develop a Campus Smart Grid Master Plan that integrates with the supply/demand mix, grid refurbishment and asset management needs and the identified grid constraints.

The outcomes of the individual projects will be integrated into a consolidated **Smart Grid Design Roadmap** for the campus. This roadmap will provide a phased capital upgrade plan that integrates the campus grid refurbishment, expansion, upgrade and Smart Grid requirements.

VII. Next Steps

The described projects are in varying phases of execution. Key to success will be to leverage international best practices, and develop and build relationships with other organisations, suppliers and stakeholders.

VIII. Conclusions

The implementation of a Smart grid enabled microgrid on the CSIR Pretoria campus has a number of core drivers:

- Development and establishment/construction of renewable energy plant(s)/source(s) to supply the CSIR campus and to provide a platform for research as regards different technologies, management and control methodologies and its impact on the grid.
- The research questions range from technology choices and grid integration to changes in the regulatory framework and pricing mechanism. The work will provide critical input to the energy policy direction to be decided on by the South African government and other countries in Africa.
- A fully functional energy-autonomous system is planned to be implemented on the campus by 2022, although some components thereof will be completed in phases prior to this milestone.
- The results will be used to develop best practice, and support the implementation of sustainable renewable energy based microgrids in the electrification of Sub-Saharan Africa.

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