2024 IEEE PES/IAS PowerAfrica

Modernization of the South African Power Grid

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***Abstract*—Although the demand for energy appears to increase perpetually, the methods by which energy is generated are changing. The sole dependance on utilities and municipalities for power is over and customers can generate and utilize their own power. Furthermore, they can store excess power and mechanisms are in place to sell excess power to the grid. Electricity still is the most efficient and widely used form of energy globally. Due to global warming and climate change, the methods of generation are moving away from fossil fuels towards more sustainable and thus renewable options. Many cities have thus taken it upon themselves to align to global targets of reducing their greenhouse gas (GHG) emissions. Coupled with the decreasing cost of renewable energy, the relaxation of regulations, and the current generation constraints, cities are considering generation from Independent Power Producers (IPPs). The power grid is evolving at the generation, transmission, and at the utility level. This is a trend amongst large cities globally and is now being seen within South Africa. Insights into the potential for renewables within SA, the current planning and forecasting methodologies are analyzed. The introduction of renewables into the grid has necessitated the grid to evolve, which is a trend that will continue given the current disruption within the energy sector.**

***Keywords*—Grid evolution, sub-transmission, greenhouse gas, generation, tariffs, power outage, Independent Power Producers, Integrated Resource Plan.**

I. INTRODUCTION

South Africa's energy supply is currently in a crisis as power outages or load-shedding has become a common occurrence. The shortage in generation capacity has led to Eskom to declare power-cuts as a measure to avoid the network collapsing. This has been the situation for the past 13 years, despite the cost of power quadrupling over the same period. Struggling with an aging coal fleet of power stations, troublesome newly built power stations and a huge financial debt, the utility is struggles to keep the lights on.

The increase in tariffs and the intermittent supply have forced customers to explore other forms of energy, as well as to explore other means. This has led to the growth in renewable generation within medium and low voltage networks. The increase in tariffs has reduced the financial payback periods over the last five years. Many commercial and industrial customers have installed generation for self-consumption and are reaping the financial benefit.

This has resulted in decreasing revenues for utilities, despite the tariffs increasing annually. Peak loading on the network still increases and the demand outweighs the generation, so the network operator must shed load to main grid stability. Eskom and eThekwini Electricity planning methodologies and data have been referred to in the paper.

II. ELECTRIC POWER GENERATION TRENDS

Electric power and energy infrastructure form a critical foundation which supports economic activity and growth across the country. It is required to be robust and adequate to supply residential, commercial, and industrial loads.

Fig. 1 provides a general overview on the current footprint of power generation in South Africa. It highlights the huge coal reserves that the generation stations have been built around and hence the network indicates the bias nature of the generation. The current net power flow is from the north-east to the south-west of the country. This status quo was established over 60 years ago and began to change after the grid opened to allow private generators access to connect.

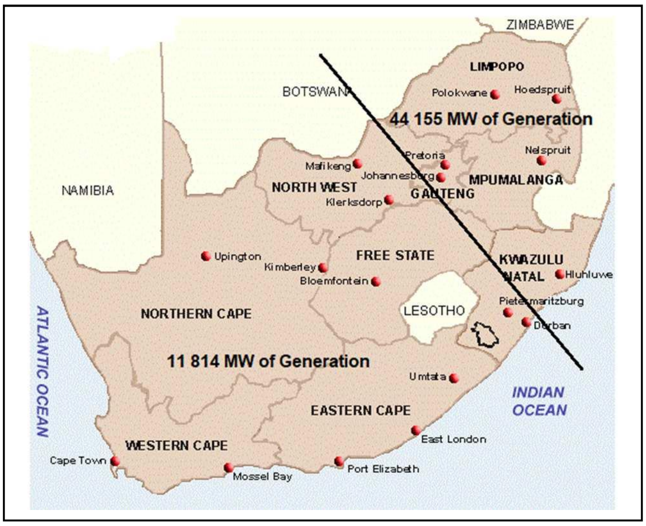

Fig. 1. The current SA generation footprint per area [1]

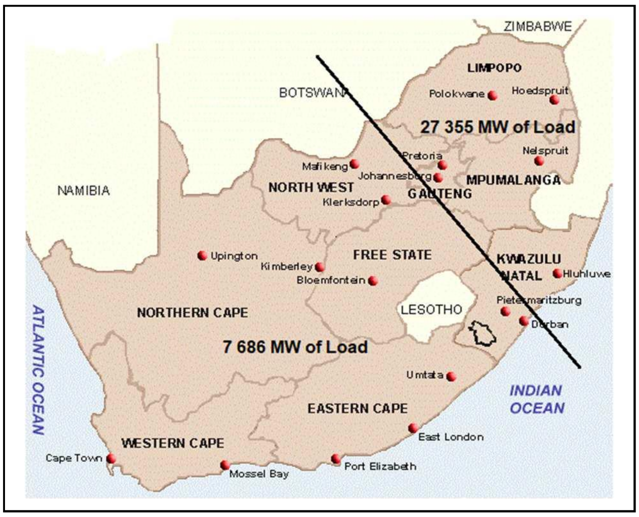

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Fig. 2. The current SA load footprint per area[1]

Figure 2 indicates the load in SA, which is concentrated over a similar area as a generation.

The economic hubs of the country. Gauteng and Durban are situated in the area with sufficient transmission transfer capacity. The National Development Plan [17] identifies the need for South Africa to invest in a strong network of economic infrastructure designed to support the country's medium and long-term economic and social objectives [1],[16]. According to the NDP, by 2030, South Africa will have an energy sector that provides reliable and efficient energy service at competitive rates, is socially equitable through expanded access to energy at affordable tariffs, and environmentally sustainable through reduced pollution [17].

The province of Mpumalanga hosts the major coal-fired power stations of South Africa. With the introduction of renewable energy independent power producer (REIPP) programme initiated by the Department of Energy (DoE), there has been a shift in the energy supply system. The DoE introduced the Integrated Resource Plan (IRP) in March 2011 the DoE, which formulates the nation's future energy [2]. About 6000MW of new generation have been procured from from 106 independent power producers (IPPs)

Table 1 shows the integrated resource plan for approved generation in South Africa, for the period 2018-2030

TABLE I. TABLE TYPE STYLES

	Coal	Nuclear	Hydro	Storage (Pumped Storage)	PV	Wind	CSP	Gas / Diesel	Other (CoGen, Biomass, Landfill)	Embedded Generation
2018	39 126	1 860	2 196	2 912	1 474	1 980	300	3 830	499	Unknown
2019	2 155					244	300			200
2020	1 433				114	300				200
2021	1 433				300	818				200
2022	711				400					200
2023	500									200
2024	500									200
2025					670	200				200
2026					1 000	1 500		2 250		200
2027					1 000	1 600		1 200		200
2028					1 000	1 600		1 800		200
2029					1 000	1 600		2 850		200
2030			2 500		1 000	1 600				200
TOTAL INSTALLED	33 847	1 860	4 696	2 912	7 958	11 442	600	11 930	499	2600
Installed Capacity Mix (%)	44.6	2.5	6.2	3.8	10.5	15.1	0.9	15.7	0.7	

Installed Capacity
Committed / Already Contracted Capacity
New Additional Capacity (IRP Update)

As part of the integrated resource plan, of the 18 000 MW of generation to be introduce into the grid, the bulk will be renewable energy (around 14 000 MW).

III. SA RENEWABLE ENERGY RESOURCES

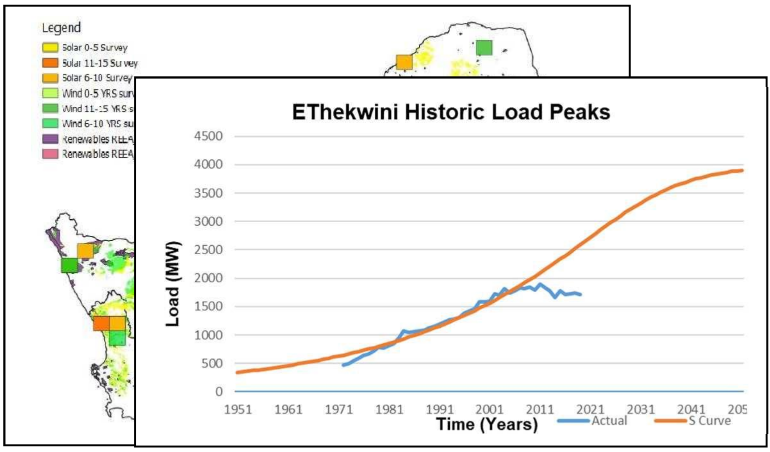
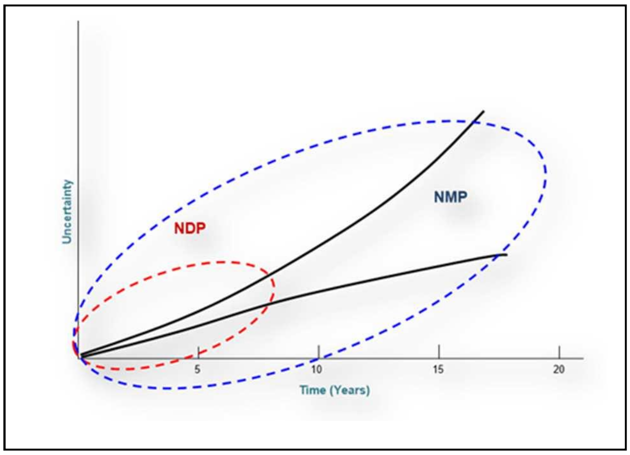


Fig. 3. Grid scale renewable energy potential in SA[3]

An investigation into the renewable energy potential reveals the map shown in Fig. 3. It shows the different types of generation plants that are likely to be established in the next 10 years.



The Northern boundary of the country is potentially where most of the solar generation plants will be establish. An assessment of the grid capacity in 2023 shows the Northern Cape corridor is highly constrained and cannot handle more generation than has currently been approved. The result is that the Northern cape has become a net-exporter of the power. There is likely to be a shift in the direction of power flow from west to the east of the country once these IPPs are connected to the grid.

IV. FORECASTING LOAD DEMAND

Previously, load forecasting was determined using historic trends and known events or planned future developments. Geographic load forecasting (GLF) has been used in recent times by electric power utilities and municipalities. The data derived from this model are inputs to the GLF program, while the output data depends on the input hence the need for quality data. Fig. 4 shows the measure of uncertainty against time.

Fig. 4. Forecast uncertainty over time [4]

Grid integration of renewable energy has had a vast impact on the electrical power system. This has led to either self-generation or import into the network. Industrial customers are

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now able to generate power from existing processes. Small to medium customers have become more energy efficient and are using much less electricity. Electricity tariffs have seen an overall increase of 59% levied over the last decade. Fig. 5 is a plot of historical load data against an S-curve. S-curves are used to trend loads over time; accordingly, a load reaches a point of saturation.

Fig. 5. The historic demand graph for eThekwini

The decrease in load demand [4] can be attributed to the following factor:

- Eskom tariff increases
- Power outages
- Customer awareness and DSM (demand side management)
- Embedded generation

This trend is likely to continue with these factors not showing signs of subsiding soon.

V. THE HISTORY OF THE ELECTRIC POWER GRID

Since the first DC transmission line installed by Thomas Edison in 1882 the current super large-scale complex AC, DC and hybrid power grids, power systems have evolved with the progress of human industrial civilization. The evolution of power grids involves a great deal of carefully implemented optimization design. In practice, power grid planning and construction is the gradual increase in electric generation capacities, power transmission capacities and to sufficiently meet the load levels, utilizing the best available data at that time and allowing for contingencies. The electricity industry has undergone major disruption with grid integration of RE or embedded generation. The grid has had to adapt and evolve to accommodate these changes. Transmission networks are rigid and robust and use N-1 contingency [4].

Transmission and distribution grids are becoming integrated and going forward there will no longer be a few generation pools of high-density generation but rather many generation areas throughout the country, which will be dependent on the availability of renewable resources. Hence the concept of the distributed generation (DG). New transmission infrastructure must be constructed to connect DG to the national grid. OHTLs are preferred for long distances and since energy resources are generally away from the load centres these would have to traverse long distances. Challenges may occur in acquiring servitudes and environmental authorization, especially within build-up areas.

Furthermore, upgrading of existing OHTLS pose challenges in that the existing load need to be maintained while the upgrades are being carried out.

The transition to the future grid is described by Grellings et al. [8] is shown in figure 6.

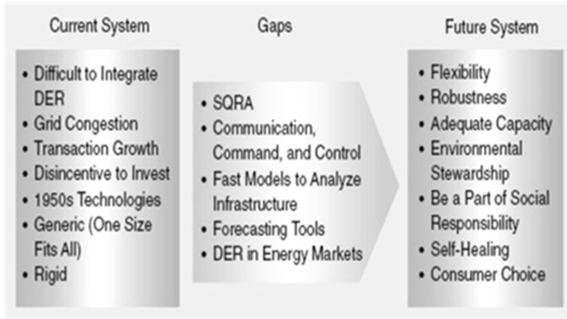

Fig. 6. The transition from the traditional grid to the future modern grid (SQRA: Security, Quality, Reliability and Availability; DER: Distributed Energy Resources) [9]

The future electric power system is required to enable utilities to carry out the following [10]:

- Competitive using excellent strategies
- Provide better customer service
- Achieve better return on investment in assets.
- Extend equipment life using innovative strategies and diagnostics
- Implement reliability-based maintenance

Embedded generation as a part of the solution, should be planned and practically assessed along with conventional generation sources [11]. The drivers for the transition of networks are [16]:

- Rapid urbanization: Takes place with little planning and place services under strain [16]
- Embedded generation (EG) costs have been decreasing steadily. An uncontrolled surge in EG will affect the networks [16]
- Smart mobility and the reduction in fossil fuel-based vehicles together with the move towards electric and autonomous vehicles would increase the demand for power and change the conventional daily load curves [16]
- The cost of battery storage is decreasing, and this could be a game-changer soon [16]
- Climate change and it impact on infrastructure will test power system resilience [16]
- Customers are becoming more discerning as to the products they purchase and the services they receive, hence products and services must become more customer centric [16]

VI. CURRENT DEVELOPMENTS

Since the introduction of Eskom's IPP Program, there have been a large number of generation plants that have been commissioned and are suppling power the national grid. As indicated in Table I, gas/diesel, wind and solar plants are lead have the highest installed capacities. Analysis of the transmission grid is illustrated in figure 7 [18].

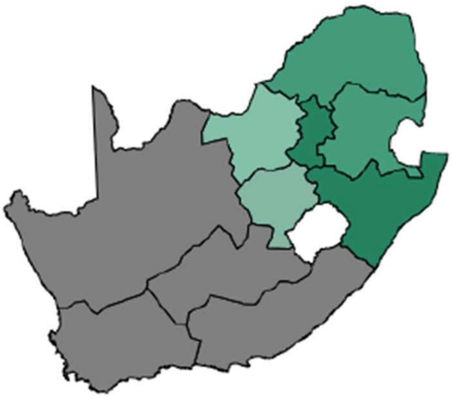

Fig 7: Transmission grid capacity (grey; no capacity; green: the darker the colours indicate more capacity)

Approximately 50% of the country, by area, have reached transmission grid capacity. Based on the load forecasting, curtailment would have to begin from 2025 for solar generation and from 2027 for wind generation [18]. Evacuation of the power from these areas require new transmission infrastructure to be constructed and commissioned. Battery energy storage (BES) would assist to prevent the curtailment enable the usage the much need the renewable energy.

VII. Evolution of the Smart Grid

Electric power systems have been evolving and more connected at the high and medium voltage levels, as well as introduction of information and communication technologies. These findings are summarized in the World Economic Forum’s Grid Edge Transformation Initiative [14].

Electric utilities need to understand the trends within their network to that these can be catered for. Opportunities should be explored in the renewable energy (RE) space depending on what resources are available within the supply area and outside that may be imported through the transmission network through wheeling agreements.

The transmission grid can no longer be considered as infrastructure that would be constructed and maintained; more dynamic operation of the grids must take place. In many cases the gris would have to be transformed to enable bi-directional operation of the network. That is, to enable the export of the renewable power during their generation periods and still have the ability to import energy from the grid when this is not sufficient to supply loads within their load area.

VIII. Conclusions

The electric power grid is not only made up of generation and transmission infrastructure, but forms ecosystem of asset owners, equipment manufacturers, service providers, electric power utilities, government, and the customers. These all need to all work harmoniously optimize the operation of the most expansive pieces of infrastructure the world [14].

It is pertinent that all stakeholders work to ensure that this infrastructure is flexible, agile, open, and interoperable. Public private partnerships (PPP) are the new paradigm. Technology innovations such as big data, machine learning and artificial intelligence should be harnessed to solve current and future network challenges in network planning, system operation, and routine or periodic maintenance of power systems; to ensure adaptability, resilience, and flexibility.

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