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Enabling Universal Access to electricity in developing economies

Modelling an electrification connection strategy – An Eskom case study

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SUMMARY

Modern advances in the electric power grid hardly demonstrate parity when compared with lack of basic electric services on most of the African continent. With electricity having being discovered more than 100 years, it seems that the widening Gini coefficient is predictive of leaving Africa as the “Dark Continent” for the foreseeable future. Urbanization has concentrated human settlements in centres that leave forgotten rural and deep rural areas. While cities densify, infrastructure and services become constrained and accelerated towards tipping points.

Electrification of de-concentrated centres will ensure the restoration of the balance between densification and service delivery and ensure economic growth and development that seek to grow a larger productive population, thereby broadening the economic base.

The case study into the determination of electrification needs in the Eskom areas of supply can be used as a baseline model for extensions to rural municipality’s and neighbouring African countries. Geographical information systems allow for web scalability to crowdsource engineers, financiers, strategist and policy makers to inform their decision making based on near real time information.

Integration of geospatial forecasting layers with power systems analysis results facilitates technical classification of network characteristics. This allows for grid extensions; introduction of renewables - based on a renewable resource map; adoption of mini-grid and off-grid solutions can be analysed in a collaborative nature from the power systems engineers to the think-tank strategists. Developing a unified electrification connection model will ensure an orderly expansion of the electric grid that is underpinned by strategic long range plans recommended by calculated scenarios. Expansion of the grid by any other means leads to chaos in both the engineering and financial world.

KEYWORDS

Electrification Planning, Network Planning, Constrained Network visualization, Distributed Energy Resource Planning.

INTRODUCTION

Energy industries in emerging economies are often faced with a dichotomy between philosophies' of urban centre supplies and that of rural supply areas. Given the history of the African continent and SA in particular, large portions of the country have only recently been electrified to provide basic electricity services to low income households / dwellings. Population densities in rural and deep rural areas become costly to provide universal access. Traditional network expansion planning & operating philosophies and performance indices such as SAIDI & SAIFI; reliability based planning [1] with; firm supplies and adequate back feeding strategies are financially difficult to justify.

Traditional planning methods are certainly being challenged by disruptive technologies (DTs), such as distributed energy resources (DER) with storage that warrant a more adaptive planning philosophy. Multi-sourced energy flows on medium voltage networks require network topologies that deviate from traditional one-way source to sink energy flows. Traditional network designs of tapering cross-sectional conductor area from source to sink, have been challenged by multi-source DER that require single feeder designs to mimic network or system designs. Assurances by network planners require adequate fault levels, sufficient back feeding and reliability of supplies to ensure optimal sizing and placement of DERs. This that will extend the supply range for rural and deep rural areas that otherwise could not be reached without distributed energy resources.

Electrification of large rural and deep rural areas have "stretched" utility MV networks beyond their design criteria resulting in the decrease of performance related criteria. Minimum tail-end voltages have violated technical and statutory voltage constraints. Increased thermal demand has placed limitations on designed upstream network current-carrying-capacity. Reliability criteria of maximum exposed line-length and increased customers connected have affected performance indices. Tracking and mapping of constrained networks at a national scale has tactically supported the operational connection plan.

An adaptive planning approach is required to inform a planning methodology, specifically for modelling the impact of electrification connections. The development of the strategy is based on and Eskom case study which can be extended to neighbouring countries. The strategy employs the availability of a national Geographic Information System (GIS) with visualization, interpretation and analysis of core layers. These core layers include but are not limited to the SPOT Building Count (SBC) [2], Electrification projects completed, constrained networks, networks demonstrating DER hosting capacity derived from the EPRI DRIVE tool. These layers will inform an adaptive planning approach in defining SMART towns [3], which are essentially expansions of electrification villages with grid tied capabilities.

AN ADAPTIVE MODEL FOR ELECTRIFICATION PLANNING

Medium Voltage electric networks typically evolve incrementally based on where connections are required. Capital constraints prevent firm and reliable supplies to low density rural area as these may not be financially sustainable. Networks are often electrically constrained for not meeting statutory requirements such as National Rationalised Specifications NRS [4] in South Africa. Due to funding limitations and commissioning delays, to mention a couple, utility planners require alternative solutions to support network extensions for electrification connections. Planners need visual and advanced analytics to ensure that critical connections are not constantly dependent on late projects. Disruptive technologies need to be included in the planning process to inform these decisions and not cascade the dependencies of new connections being dependent on already late projects.

An adaptive model uses elements of MVCN (Medium Voltage Constrained Networks - MVCN); areas of high growth based on SPOT building count (SBC); DER Hosting Capacity to inform the optimal size and location of DG for the development of SMART towns to sustain electrification connections in rural and deep rural areas.

Application of SPOT building count for Electrification Planning

A method to determine electrification connection requirements in South Africa given that the Universal Access Plan (UAP) expired in 2012, proposes the use of SPOT building count to support this methodology. Statistics SA recorded the SA population in 2015 at 54,490,406 – Fifty Four million Four hundred and Ninety thousand Four hundred and Six people. Applying a national average of 4.2 people per household places the total expected national household count at 12.973 million connections. National averages are inherently flawed as no weighting across demarcation boundaries or demographics and social classes are applied. Too much aggregation and suppositions are applied in the current method and a new way of thinking is required to identify and reduce the number of households that do not have access to electricity.

The method proposes a spatial assessment of dwelling proximities to the medium voltage electric grid. The spatial approach recommends the deployment of SPOT building count (SBC) and Eskom MV networks as two core data sets in analytically determining the electrification backlog.

The current method of determining electrification backlog has failed to continuous inform decision makers of the rate, extend and capital requirements necessary to fulfil the UAP dream of the presidency. The proposed spatial method allows for the categorization of the backlogs into green-fields, in-fills, potential non-grid and potential micro-grid. This categorization enables plans of action to address the backlog given the funding constraint.

Eskom's medium voltage networks cover more than 90% of SAs supply area excluding Metropolitan and selected Municipality areas of supply. Spatial recognition of medium voltage networks is necessary for deducing dwelling connections to the grid in the absence of low voltage network information.

Eskom produces a yearly-curated SPOT Building Count (SBC) imagery that identifies "dwellings" and "non-dwelling" points. The proximity of these dwelling points is used to determine the likelihood of a connection to the network, through the spatial buffering of the MV networks. The method of determining the electrification backlog follows.

1] Using the Eskom MV networks, provide a spatial buffer of 750m and 500m of all 22KV &11KV MV networks, respectively.
2] Using the SBC dataset, identify dwellings (representing households) that fall inside and outside the buffers. Assume hereon, that all dwellings inside the buffer are connected to the grid provided that:
2.1] Quarterly comparisons on actual connections (as per the Gov. Gazette indicating number and location) are performed as a validity check for those connections that do not strictly adhere to the buffer parameters.
3] Identify clustered dwellings that fall within 5, 10, 15 Kms and beyond from boundary of the MV network buffers.
4] Utilize available datasets not limited to the Digital Elevation Models (DEM) to evaluate terrain for "ease of connection" identification.
5] Categorize these connections for infills, green-fields, off-grid (micro-grid) supplies.
6] Maximize the demand side connection plan based on latest average cost per connection.
7] Perform network planning to optimize the supply side plan.
8] Develop an Electrification Development Plan Approval (EDPA)
9] Promulgate the EDPA with the national electrification stakeholders.
10] Implement EDPA through the normal "Acquire Customer Business Processes".

Figure 1 below shows the concept of IN BUFFER and OUT BUFFER used in the spatial analysis.

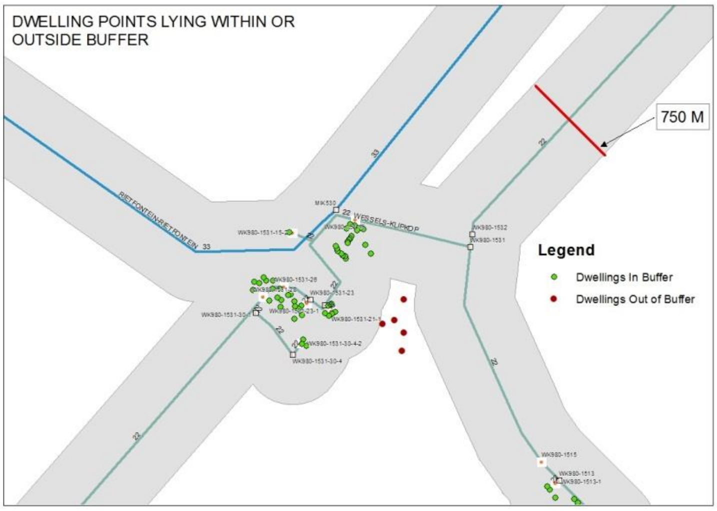


Figure 1: IN BUFFER / OUT BUFFER Concept

According to SBC – 2013, there are 11,861,961 dwellings in SA. These are distributed across the Eskom provincial boarders as shown in Table -1: SBC in 2013.

Table -1: SBC in 2013

OU	Total
LOU	1 906 782
MOU	1 189 074
KZN	1 826 466
EC	1 973 374
WC	1 232 696
NC	418 042
FS	869 237
NW	974 908
GP	1 471 382
Total	11 861 961

Table - 2: 2013 SBC – Spatially Reference to Eskom Networks

OU	INBUF	OUTBUF	Total
WC	461453	771243	1 232 696
EC	1189972	783402	1 973 374
KZN	878276	948190	1 826 466
MOU	834429	354645	1 189 074
LOU	1 617 954	288 828	1 906 782
NW	659879	315029	974 908
GP	139752	1331630	1 471 382
NC	203509	214533	418 042
FS	391834	477403	869 237
Total	6 377 058	5 484 903	11 861 961

Spatial recognition of the dwelling proximity to the MV networks are performed to reveal the suggested grid connections (INBUF) to the potential grid connection (OUTBUF) as illustrated in Table - 2: 2013 SBC – Spatially Reference to Eskom Networks

Graphical representations for Eskom boundaries classified for IN / OUT buffer per OU and shown below.

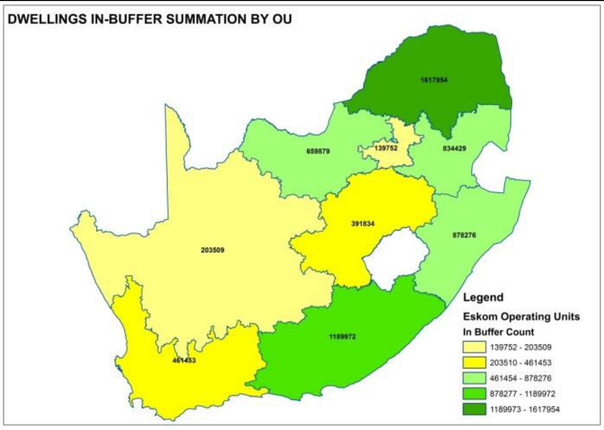


Figure 2: IN – BUFFER per OU

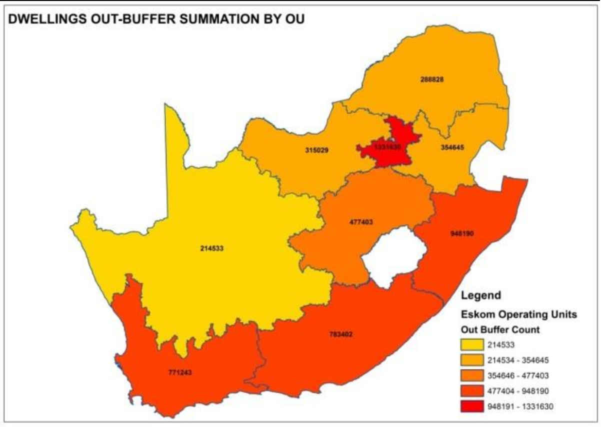


Figure 3: OUT – BUFFER per OU

Application of Medium Voltage Constrained Networks

Medium Voltage Constrained Networks (MVCN) is an annual report produced for network planning to ensure that year-on-year benchmarking can be performed with the aim of identifying networks that are flagged as constrained in terms of Eskom's set criteria, (Methodology for Identifying MV Constrained Networks – 240-75909025). Typical control measures are shown below in Figure 4 and Figure 5.

Editable Critical values	Values
Min MV voltage at end of feeder is at critical limit if(<=93%), colour is red	93
Min MV voltage at end of feeder is at medium limit if (>93% & <95%), colour is orange	
Min MV voltage at end of feeder is at acceptable limit if (>=95%), colour is green	95
Max thermal Backbone loading is at critical limit if(>=95%), colour is red	95
Max thermal Backbone loading is at medium limit if (>85% & <95%), colour is orange	
Max thermal Backbone loading is at acceptable limit if (<=85%), colour is green	85

Figure 4: Voltage / Demand Control Parameters

Editable Critical values	Values
Reliability indices (Line Length)	
CAB Networks are orange if (11KV AND >= 20km) otherwise green	20
CAB Networks are orange if (22KV AND >= 30km) otherwise green	30
OHL Networks are orange if (11KV AND >= 25km) otherwise green	25
OHL Networks are orange if (22KV AND >= 70km) otherwise green	70
Reliability Indicies (Customer No.)	
CAB Networks are orange if (11KV AND >= 2000 customers) otherwise green	2 000
CAB Networks are orange if (22KV AND >= 2800 customers) otherwise green	2 800
OHL Networks are orange if (11KV AND >= 3800 customers) otherwise green	3 800
OHL Networks are orange if (22KV AND >= 5000 customers) otherwise green	5 000

Figure 5: Line length / Customers Connected Control Parameters

Report outputs geographically illustrate networks that are constrained by voltage, thermal demand, line length and customer count based on external and internal planning criteria. **Error! Reference source not found.** to Figure 9 illustrate these for a previous year.

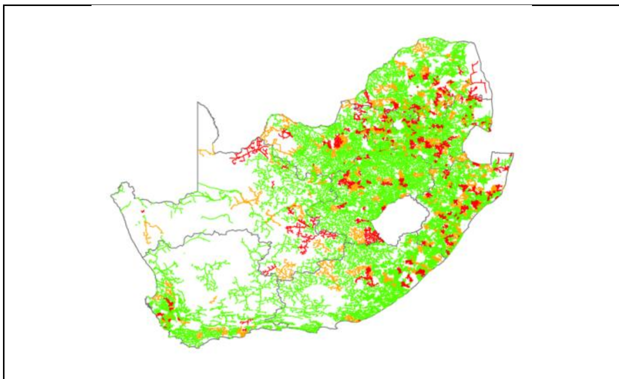


Figure 6: MVCN by Voltage

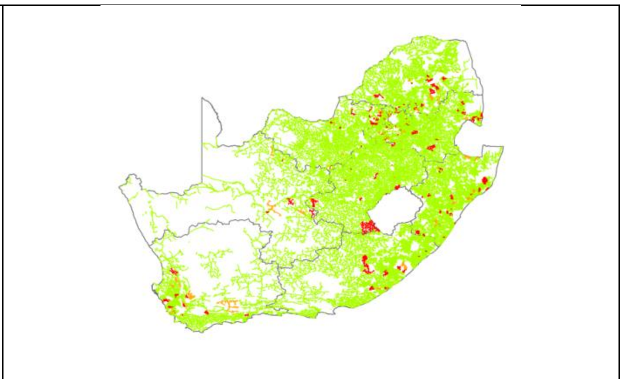


Figure 7: MVCN by Demand

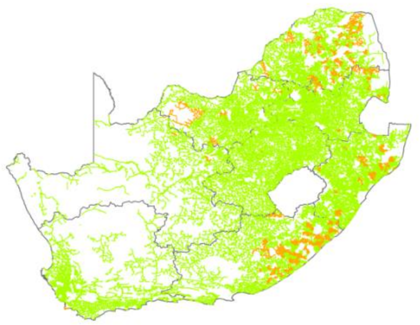
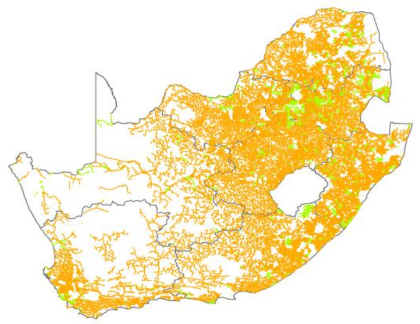
	

Figure 8: MVCN by Customer Number	Figure 9: MVCN by Demand

Whilst there are sporadic violations of voltage, demand and customer number connected, it is clear that line lengths have been exhausted and extended beyond their design limits. This implies that there must be a clear strategy to reduce line lengths either by adding new substation capacity, which is unaffordable, or by introducing multi-sources DER generation. While this will not shorten the line-length it will remove the criteria of line length, which will no longer be required for constraining networks, but will serve as a proxy for determining Hosting Capacity classifications. Whilst the relationship between the design parameters of long lines and poor performing lines are not yet fully understood, a further layer illustrating performance in relation to line length will be added in further to improve this adaptive methodology and model building.

These visual classifications demonstrate network limitations and opportunity networks for engineering solutions in a capital constrained environment. Opportunities may exist in long networks where fault levels are low, to install solar PV DG for voltage support. Dominant load types can be analysed to match the impact of solar PV required for mini-grid or off-grid solutions with grid tied capability. Herein lays the concept for SMART villages to support electrification areas that may be relative far from adequate network supplies.

To ensure that appropriate DG is cited for network sustainability and support, mini-grid and off-grid solutions are planned. A resource capability map overlay further enhances and supports the adaptive methodology.

<u>Solar PV Resource Mapping</u>

This paper covers the potential solar resource mapping [5] to support the modelling of integrating DG into electrification planning. Other forms of resource mapping for wind and bagasse will improve the quality of decision making in utilities where adequate resources are available. Solar irradiance is measured via satellite at 15 minute intervals for a defined pixel size in the country. Statistical analyses of matrix arrays provide probabilities for year-long solar irradiance patterns. Intersection of feeder supply areas with probabilistic irradiance patterns provide for optimal location of solar PV installations.

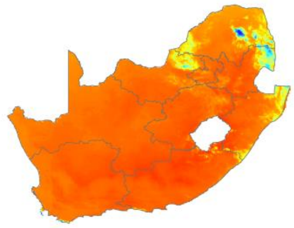
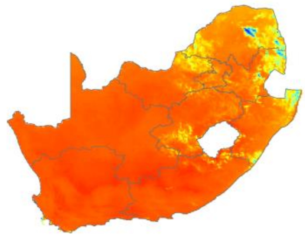
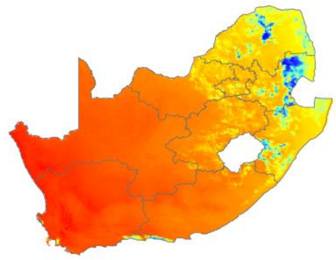
		

Figure 10: Solar Irradiance on 20120101 at 11:05	Figure 11: Solar Irradiance on 20120101 at 12:05	Figure 12: Solar Irradiance on 20120101 at 15:05

Statistical analysis of raw satellite data is manipulated to derive minimum, average and maximum values across a given historical time series. This will inform the highest probability for optimally locating solar PV. Identification of optimal resource based on fuel location [6] precedes the application of sizing of solar PV on the GRID. The following time series segmentation of solar irradiance is shown in Figure 13.

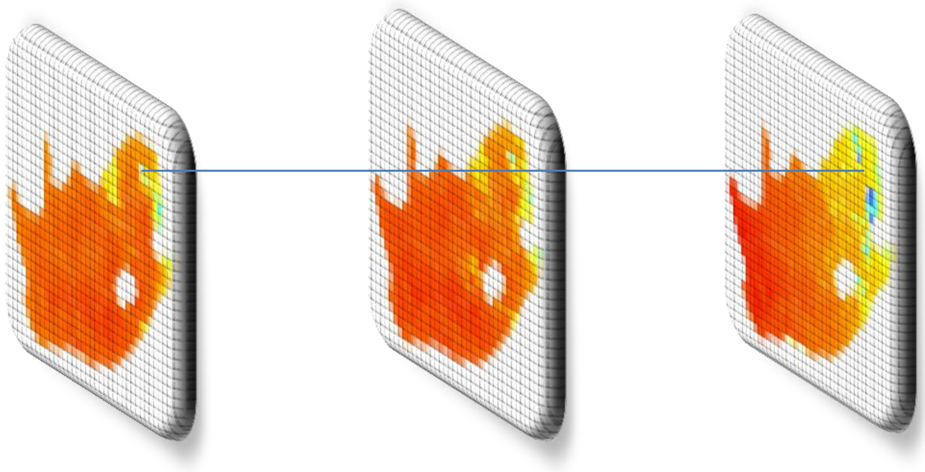


Figure 13: Time Series Segmentation of Solar Irradiance

EPRIs DRIVE – Hosting Capacity Solution

In order to select the optimal size of Distributed Energy Resources with the optimal resource allocation for solar PV, the use of EPRIs Distribution Resource Integration & Value Estimation (DRIVE) tool is employed. This tool has been delivered to Eskom under Programme 174 funding. For more detail refer to Mobolaji Bello's paper under these proceedings. In essence the DRIVE tool allows for analysis and extraction of salient power flow information from a power systems analysis tool (such as DIgSILENT PowerFactory). By simulating the injection of unity, leading and lagging power factor generation, DRIVE assesses the range of DER at various network locations. The results are displayed geo-schematically through an interactive interface. The illustration below in Figure 14 shows a typical result from DRIVE.

Correlation between the maximum allowable hosting capacity from DRIVE and the potential for delivering the capacity from the resource allocation map, ensures that the equipment rating of the solar PV are closely matched.

Figure 14: Typical DRIVE Results

<u>An Adaptive Model for Electrification Planning</u>

The consolidation of application results as described across multiple technologies is used in a single planning model to strategically and tactically inform the adaptive model. Operation within an enterprise wide GIS platform is critical to enabling geographically displaced planning departments the ability to develop operational plans as a single collective.

The methodology is applied in a logical flow process as follows.

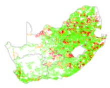
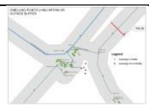
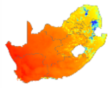
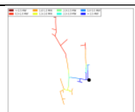
MV Network Repository GE Smallworld Engineering Database ⬇	
Analysis in Power Factory for Constrained Network Analysis ⬇	
SPOT Building Count Analysis in ESRI Arc Server ⬇	
Solar PV Resource analysis ⬇	
DRIVE Analysis (EPRI DRIVE, PowerFactory, ESRI Arc Server) ⬇	
Optimization of Grid, Off Grid, Mini Grid Electrification Planning	

Figure 15: An Adaptive Model for Electrification Planning

Application of a fundamentally robust model allows for the extension of such models in strategic economic and scenario based thinking-systems. By its nature, systems-thinking ensure collaboration by the collective based on individual contributions.

CONCLUSION

It is the vision of the Planning Centre of Excellence in Eskom's planning and GIS department to commission and implement such a model for the benefit of the planning community and the business. Whilst successes in individual processes have been achieved, consolidation and operation at a system level requires much work.

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[1] A. A. Chowdhury, S. K. Agarwal, and D. O. Koval, “Reliability modeling of distributed generation in conventional distribution systems planning and analysis,” in *Industry Applications Conference, 2002. 37th IAS Annual Meeting. Conference Record of the*, 2002, vol. 2, pp. 1089–1094 vol.2.

[2] “SPOT Building Count supports informed decisions,” *EE Publishers*, 06-Sep-2010. .

[3] M Bello, R. Smit, C. . Carter-Brown, and I. E. Davidson, “Power Planning in a Smart Grid Environment-Case Study of South Africa,” 2012.

[4] “Electricity Supply - Quality of Supply - PART 2,” National Rationalized Specification Ed. 3, Dec. 2007.

[5] R. Munzhedzi and A. B. Sebitosi, “Redrawing the solar map of South Africa for photovoltaic applications,” *Renew. Energy*, vol. 34, no. 1, pp. 165–169, Jan. 2009.

[6] S. Szabó, K. Bódis, T. Huld, and M. Moner-Girona, “Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension,” *Environ. Res. Lett.*, vol. 6, no. 3, p. 034002, 2011.