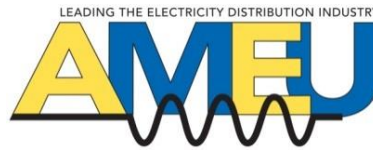


ELECTRICAL MASTER PLANNING FOR THE 4TH INDUSTRIAL REVOLUTION



Author & Presenter: HA Baartman, PrEng, BScEng Electrical – Director of GLS Consulting

Co-author: AFW Steyn, MEng Electrical – Electrical Engineer at GLS Consulting

1. Introduction

Smart Cities, driven by the 4th Industrial Revolution (4th IR), seems to be the buzzword in infrastructure development and procurement today - but what informs these decisions, and are we making smart ones? Existing methodologies are outdated and not sufficient to address long-term planning for the ever-changing power system.

A modern methodology for developing a full master plan, from LV- up to HV level, is presented in this paper. The master plan is developed in a modern software package which combines and consolidates several datasets into one geospatial master model viewer. Load analysis, demand patterns, the network model and GIS are combined into one tool to develop a comprehensive master plan using data aggregation and analytics. Load forecasting and analysis is done through analysis of the utility's billing system and MDs and ADMDs are thus based on the utility's own data. Each stand in the utility is geospatially linked to a supply point in the network model. The master plan is then finally presented through an auto-generated master plan report with projects and costing of said projects. All of this can be viewed on an online web view platform which enables users to interact with the master plan, instead of it just being a simplistic pdf document.

2. The 4th Industrial Revolution

The 4th industrial revolution centres on the communication, processing and analysis of large datasets to make informed decisions. The power system of the 4th IR is one that has constant monitoring via Internet of Things (IoT) devices, and is self-healing through supervisory- and control systems with built-in intelligence. Furthermore, in the future power system *consumers* can become *prosumers* through small-scale embedded generation (SSEG) with intelligent control units. Smart metering is also being rolled out to bulk-, credit- and prepaid consumers which allows for more accurate consumption- and demand statistics to be accumulated.

The status quo is that long-term power system planning, or master planning, is being done by utilising various independent systems with minimal data integration between the datasets. These processes over time cause several datasets, created for different purposes, to be developed as opposed to the development of one multi-purpose central database. This creates a situation where data analytics can only be applied to a limited extent on current planning datasets.

Traditionally, master planning has also focused on long-term power system infrastructure planning only. However, master plans for the power systems of the future should consider many more factors. These include:

- Load forecasting from a reticulation level upwards
- Operational and maintenance planning for existing infrastructure to enhance asset life
- Asset management plans which incorporate the underlying master plan data as well as additional asset failure & life cycle information about the assets

- Asset replacement prioritisation plans which look at the risk of power system infrastructure failing and the consequence of failure
- Revenue analysis and enhancement

The above-mentioned factors or outputs are currently produced haphazardly and not from the same underlying dataset. The 4th IR has a large emphasis on data centralisation and this should be the main driver behind the master plans of the future. The need therefore exists for tools that centralise both our offline and online data into common, interchangeable datasets [1]. Master plans of the future should ultimately allow us to make smarter decisions on our infrastructure operations, maintenance and planning.

The World Bank reported that South Africa is ranked 109th in the world in terms of “Getting Electricity” in their annual “Doing Business” report. [2] On average, it takes about 112 days from application until installation for a new electricity connection. This is in part due to the lack of facilitating processes and systems.

There are thus the following areas of concern to address in terms of master planning in the 4th IR:

- How do we ensure maximum benefit from the various data sources we have?
- What is the optimal balance between risk and funds available to upgrade and renew our existing asset base going forward?
- Are our current load models telling us the full picture and can we plan our networks more effectively with more (and more representative) data?
- How do we raise the funding for the necessary plans of the future, when considering that the “kilowatt hour business” is dying?

This paper aims to explore these themes and in particular looks at how they are interrelated.

3. The Master Model

A master model combines all our various data sources and integrates into various other systems as an output. The master model proposed in this modern software package solution is a fully geospatial model which is formed with data sourced from the utility through various interactions. The master model must ultimately pull and push data from and to various other systems. Current master models are created in different, unconsolidated systems, resulting in out of sync datasets with limited benefit. Utilities need to invest into one consolidated master model which will deal with various planning needs. With advancement of technology, the master model should also interact and integrate with various other systems. For example, the master model must be able to export the full model or parts of the model into a format that can be imported into power system analysis tools as per Figure 1. Ultimately, the master model must be a digital twin of the real-world network and should include the LV network where, arguably, the largest changes are happening and will continue to happen in the light of the onset of SSEG.



Figure 1: Master Model Concept

4. Asset Management Planning

South African distribution & reticulation networks are fairly aged and in most cases need urgent upgrading. However, utilities have limited budgets and still have to ensure reliable power supply to their customers. Going forward, utilities need to ensure that budgets are optimally allocated for:

- Asset Creation
- Asset Operations & Maintenance
- Asset Replacement Prioritisation (ARP)

Traditional master plans only speak to the asset creation and to a degree, asset upgrades as well some refurbishment. However, a holistic view of the replacement prioritisation that should be in place to guide capital expenditure is not place. A technique to develop a replacement priority risk index has been developed. The asset replacement priority index score is:

$$ARP_{total} = LF_{total} \times CF_{total}$$

Where

$$LF_{total} = \sum_{i=0}^{n-1} LF_i \times QF_i$$

And

$$CF_{total} = \sum_{i=0}^{n-1} CF_i \times QF_i$$

This asset replacement priority index is informed by various weighted factors according to the relative severity of the factor. Some influencing factors include:

- Plant condition
- Current loading
- Future loading
- Age

- Theft
- Failures
- Cost of replacement

Asset operations and maintenance can be done more accurately once all of the asset condition information is captured in a centralised system with a clear plan on the maintenance requirements of the assets. If existing systems are in place with data for the asset operations and maintenance, then it is suggested that the O&M system integrate with the master model and plan. The outcomes of the ARP methodology provides a risk matrix as shown in Figure 2 [3].

The ARP risk score should thus inform capital expenditure on upgrades, refurbishments or renewals for the utility over a predetermined planning period. This, however, cannot be done in isolation of the master plan as the two datasets need to inform each other.

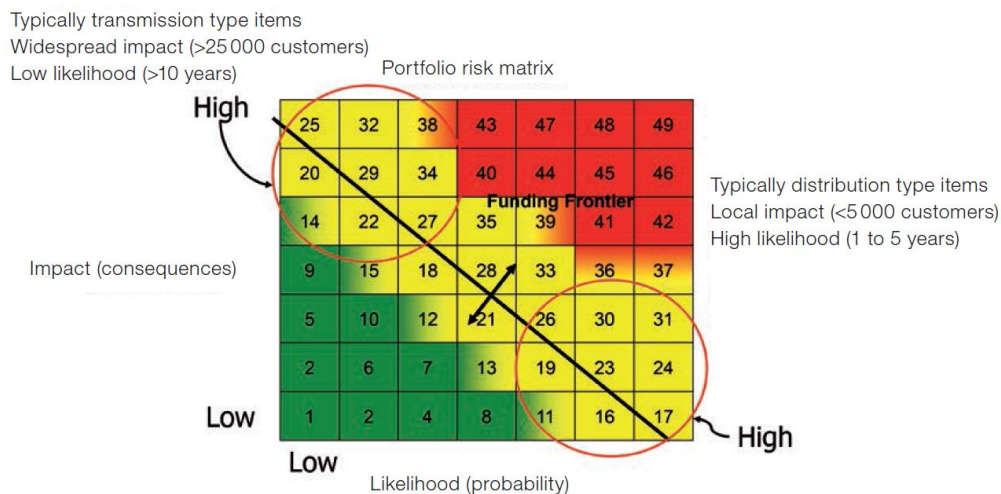


Figure 2: Asset Portfolio Risk Matrix [3]

5. Load Modelling and -Forecasting

Load modelling is an established area of research in South Africa with various major contributions such as the NRS034-1 residential load models and the Herman Beta method [4] [5] [6] [7].

The design and planning of networks are done with the after diversity maximum demand (ADMD) of a load class or usage group. This ADMD is fundamental to the sizing of the load and thus has a significant impact on the final design and consequent funding required to supply the load. The development of the load models has been based on a probabilistic method where the ADMD of the load is estimated based on the estimated energy consumption of a particular load class over a month. Energy consumption is related to demand (kVA) as shown in Figure 3 and Figure 4. [7] [8]

The current geospatial load forecasting (GLF) method is not always as accurate as expected as per [9], but becomes more accurate with finer spatial subdivisions [9] [10]. Modelling on a per stand/erf basis is the most granular and consequently most accurate spatial subdivision.

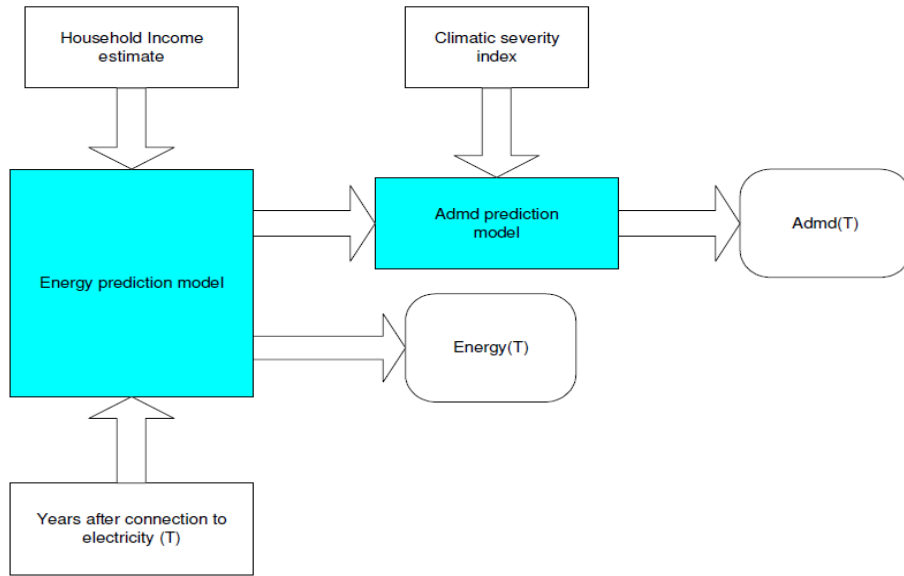


Figure 3: Energy Prediction Model as Input to ADMD Prediction Model [7]

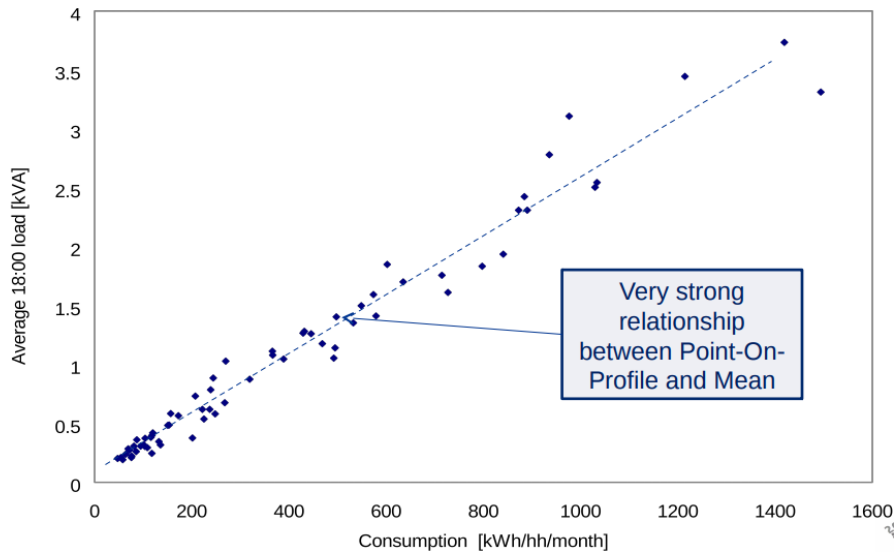


Figure 4: Correlation Between Consumption (kWh) and Demand (kVA) [8]

A proposed method to obtain the demand of a customer in a network, is now presented. This proposed method is summarised in Figure 5. Energy consumption is metered at a house or stand level with either credit- or and prepaid meters. Credit meters can give a clear indication of the consumption pattern, on a monthly basis, of a particular customer. Prepaid customers' purchase history is analysed over a period of at minimum two years to determine their average energy usage. The Average Annual Daily Consumption (AADC) per stand is calculated to obtain a base energy value for a typical 24 hour day for a customer. Average load shape libraries from the GLF standard is used [4]. Some of the advantages of using a utility billing system database is that this typically also provides valuable information such as:

- Land use of the registered erf
- Zoning of the registered erf
- Usage and demand of other utility services such as water

At the onset of the forecasting model population, each stand within the utility supply area is populated with an AADC value and load class with a standard 24-hour load profile shape assigned to each stand. A key difference to the standard methodology is that where fixed apparent power (S) peak values are

assumed for each load class, this methodology does not assume a peak value per load class, but rather calculates the peak value for each stand, in relation to the stand's actual, metered energy consumption (AADC) data.

The maximum demand or MD for each stand is calculated as per the equation:

$$MD (kVA) = \frac{AADC (kWh)}{LF \times PF \times 24h}$$

A particular problem with South African LV networks is the lack of LV network data, and consequent lack of visibility in LV networks. Network SLDs are typically only captured up to the level of MV/LV minisubs, which leaves uncertainty as to which stands are supplied by a particular MV/LV minisub. The new proposed solution addresses this issue by employing a stand-to-minisub cross-referencing feature, which spatially maps each stand to its closest minisub or MV/LV transformer. Figure 6 shows an example of the spatial mapping technique applied to a minisub. Figure 7 shows a network view of the spatial mapping of stands to minisubs. A very useful extension of the capability of this feature, is that the same cross-reference mapping technique can be applied on LV networks, in order to map each stand to its nearest LV kiosk. This promotes the capability to model and perform studies on LV networks.

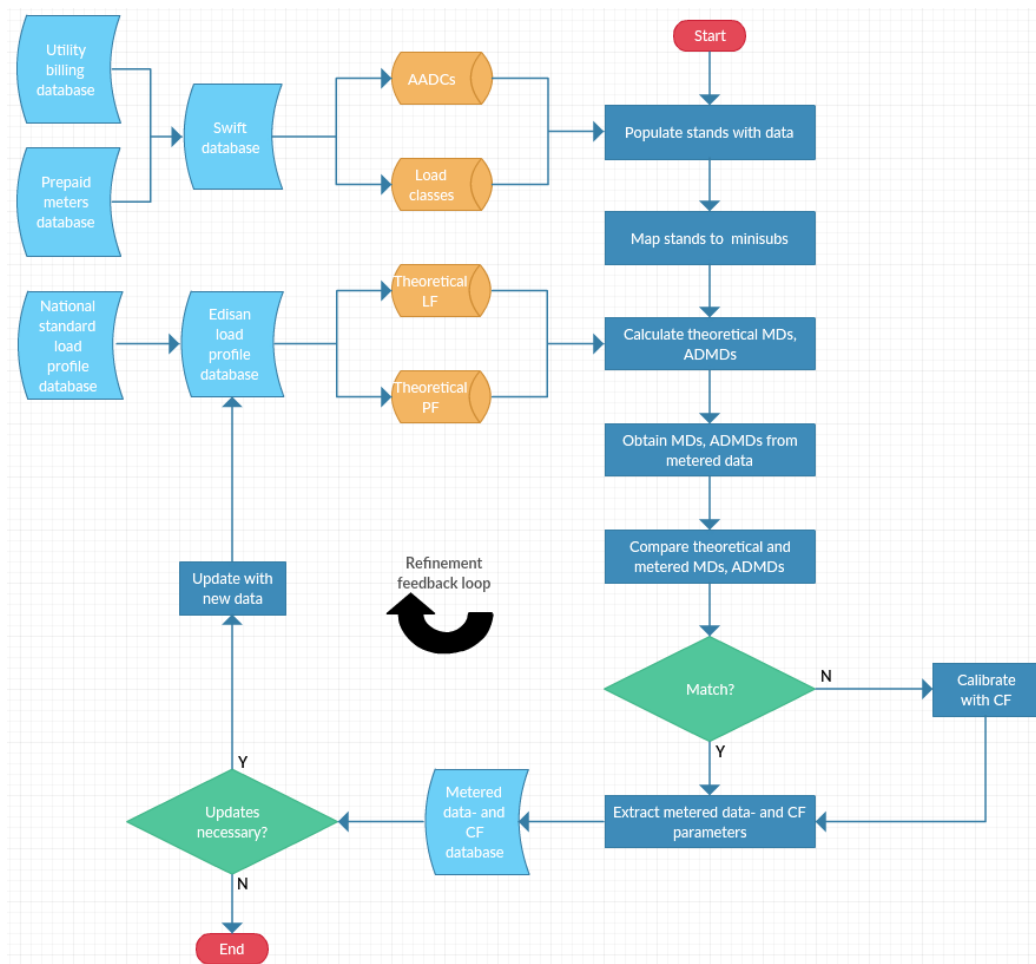


Figure 5: Geospatial Load Modelling Process Flowchart

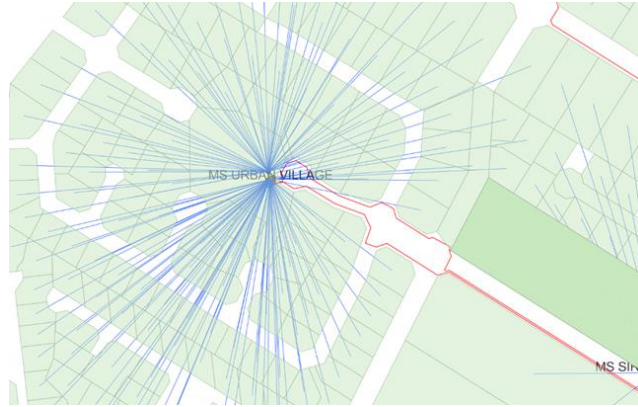


Figure 6: Local View of Spatial Mapping of Stands to a Minibus

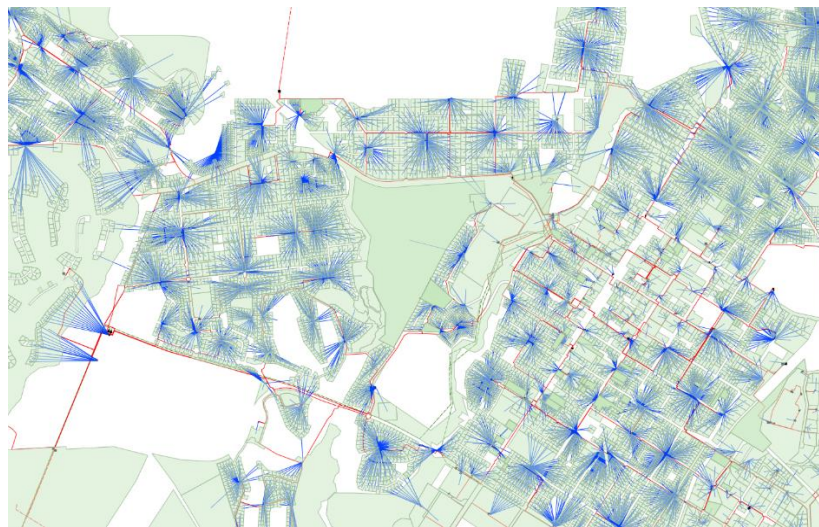


Figure 7: Network View of Spatial Mapping of Stands to Minibuses

A composite or aggregated load profile can then be viewed at a minibus- or other supply point level (switching station, substation etc.) with improved accuracy in the load mix representation, since estimation errors introduced by estimating the representation of load classes in a broad area is reduced. **Figure 8** and **Figure 9** demonstrate this aggregation concept.



Figure 8: Graphical Example of Combined Load Profile at a Common Supply Point

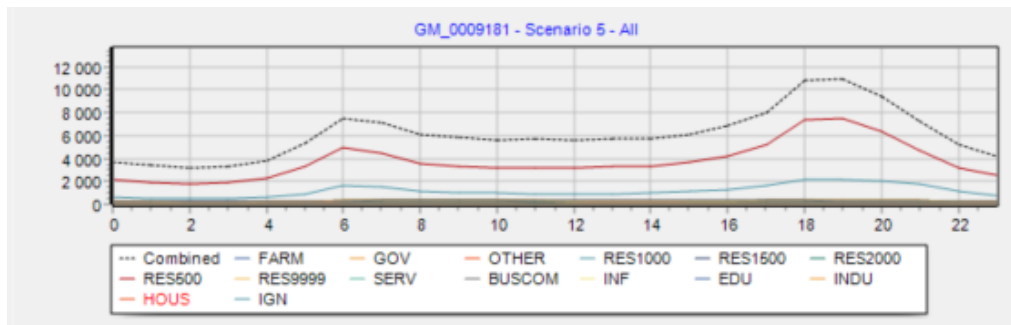


Figure 9: Example of a De-aggregated View of a Combined Load Profile

The last step in the derivation of the network MDs and ADMDs is to calibrate the modelled aggregated load profile with that off the measured peak load of the network. The lowest point in the network where load data measurement is typically available, is at the HV/MV distribution substation, where 5- or 30-minute resolution data is typically monitored. The load mix and the amplitude of the downstream loads are then calibrated to balance with the actual measured profile. Once calibrated, a set of ADMDs for each load class in a specific zone is available. This zoning can be done on various levels of granularity, such as the entire supply zone of an HV/MV distribution substation, the supply zone of an MV switching station, the supply zone of a minisub, or even as granular as the supply zone of an LV kiosk.

The forecasting is done after establishing the network MDs and ADMDs. The municipal spatial development framework, growth trends, electrification-, housing- and other plans are all analysed and consolidated into a spatial layer which is superimposed onto the existing network model within a GIS environment. This allows one to visualise future growth pockets. All future developments are assigned a commencement year, a development duration, an associated growth curve and a corresponding land use and load class. Furthermore, a saturation scenario is considered where all stands within an area is occupied. The forecast is done for both outright demand as well as future projected energy consumption. This energy forecast is crucial to inform the funding of the master plan and system maintenance into the future.

6. Master Planning from the Master Model

The master model introduced earlier in this paper allows the creation of a centralised system master plan, from one consolidated dataset, within one software tool. All necessary information can be easily layered, themed, visualised and analysed in this tool. Future projects can be sized from the future development geospatial shapefile which also allows for preliminary servitude requirements to be identified as demonstrated in Figure 10. Various maps, plan books and spatial drawings can be generated via the tool, creating particular benefit for operations teams that require visibility on where infrastructure or assets are located.

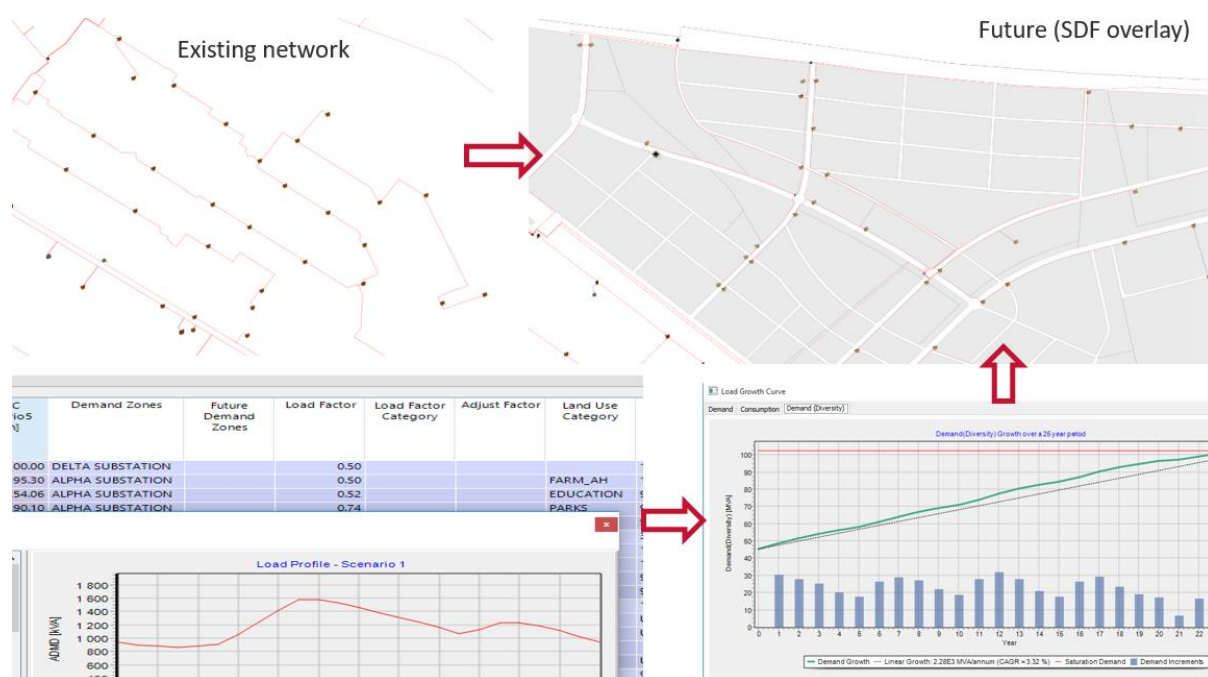


Figure 10: Master Plan with Preliminary Design and Load Growth

7. Funding the Future

Master plans have traditionally considered and provided a capital expenditure plan. However, there is very little informing where these funds would come from, considering the various threats utilities are facing in terms of revenue. Consumption trends across the country have shown that customers use less energy due to the high cost of energy. The high cost of energy and uncertainty in reliability of supply has also seen financially able customers opt to navigate towards distributed renewable energy technologies.

The master plan identifies the capital expenditure plan in terms of creation, upgrading, refurbishment and renewal of network assets. Funding of this expenditure plan should be funded through the revenues the utilities collect in the future. Various scenarios of the uptake of technologies such as solar PV and price elasticity should be considered for the estimated revenue over the planning period for the utility.

Utilities can ill afford to lose revenue they are supposed to collect and this makes loss prevention, or rather *revenue enhancement*, central to the sustainability of the utility. The same underlying data that informs the load modelling and -forecasting can be used to identify loss recovery opportunities as well as future tariff requirements. The load forecast, due to its nature within this new integrated way of planning for utilities, will forecast the potential energy consumption in the network. This allows for various future scenarios to be tested with various tariff combinations which speak to the funding requirements of the utility. Furthermore, this same dataset should identify improvement areas that the utility can look at in terms of revenue collection and minimisation of losses. Figure 11 demonstrates the use of a themed cadastral map to identify stands with meters but no consumption and various other anomalies. These themed maps make it easier to identify loss hotspots and allows for targeted revenue enhancement interventions.



Figure 11: Consumption and Meters Mapped to a Themed Cadastral Map

8. Conclusion

This paper has looked a new way of absorbing the existing datasets we have and has proposed a master geospatial model solution for master planning in the 4th IR. The 4th IR will require integrated systems and planning. The paper puts forward an Asset Replacement Prioritisation risk score index which makes use of various influencing factors to assist the utility to spend their limited budget for asset renewals and upgrades, optimally.

A new load modelling method that uses existing energy consumption of users in a utility network is proposed. The method uses billing system information to relate the energy consumption to the absolute demand of each stand. The land use and stand size is used to inform the load class of the stand and a load profile is then assigned to the stand. In turn, the stands are then linked to the closest supply point through the use of spatial correlation. The load profiles are then aggregated up to higher supply points in the network such as switching- or substations.

The load forecast is therefore based on MDs and ADMDs that are derived from the utility's own dataset. The future developments are captured in a shapefile as a layer to the master model to point out where growth will occur, what kind of growth and how fast that growth will be. The first saturation scenario tested is for all stands to be fully occupied. Future forecasting is then done for both absolute demand (VA) as well as energy consumption (Wh).

A master plan is then developed from the software with easily themed drawings and maps clearly showing the infrastructure requirements. Plan books can be generated easily for ease of use by the electricity operations or planning teams.

A new addition to the master plan is proposed which looks at where the funding for the networks of the 4th IR will come from. The proposed addition is to conduct an energy consumption forecast and use this as basis for the calculation of various tariff combinations with particular emphasis given to the new disruptive technologies such as solar PV, batteries and electric vehicles.

Future developments for the 4th IR master planning solution include:

- Integrating IoT device downloads into the dataset.
- Using mathematical constraint models to calibrate the energy consumption, peak demand and profile shape of the stand loads in a zone to the measured historical profile and peak of the zone's load higher up in the network.

- Calculation of the peak month daily consumption or peak month consumption and use these as basis for the energy model going forward.
- Machine learning to be used to enhance the algorithm for the replacement prioritisation tool.
- Using weather and micro- as well as macro-economic data to enhance forecasting of the load (algorithms can be used).

The possibilities are, in fact, endless.

9. References

- [1] USA Dept of Energy, "QUADRENNIAL TECHNOLOGY REVIEW: AN ASSESSMENT OF ENERGY," US Dept of Energy, 2015.
- [2] The World Bank Group, "Doing Business," The World Bank Group, Washington, 2019.
- [3] IEC, "Strategic asset management of power networks," IEC, 2015.
- [4] Eskom Holdings SOC Ltd, "DGL 34-1284: Network planning guideline for geo-based load forecasting," Eskom, 2012.
- [5] SANS507-1:2007 NRS034-1:2007, "Electricity distribution — Guidelines for the provision of electricity distribution networks in residential areas," Standards South Africa, 2007.
- [6] Department of Human Settlements, The Neighbourhood Planning and Design Guide, South African Government, 2019.
- [7] S. Heunis and M. Dekenah, "MANUAL FOR ESKOM DISTRIBUTION PRE ELECTRIFICATION TOOL (DPET)," Eskom, EOH Enerweb, 2014.
- [8] S. Heunis, *Domestic consumption and demand profile estimation: DT PET and DT Profile*, Eskom, 2014.
- [9] M. Soni, "Quantitative Assessment of Geographical Based Load Forecast Technique at Eskom Distribution: Forecast Error and Impact on Infrastructure Execution," in *CIGRE 8th Southern Africa Regional Conference*, Cape Town, 2017.
- [10] H. L. Willis, *Spatial Electric Load Forecasting*, Marcel Dekker Inc, 2002.