Ring-Fencing of Electrical Networks to Ensure Improved Measurement & Effective Balancing of Energy Flows

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Abstract

The Ringfence and Balance work stream of the Energy Losses Management Programme in Eskom Distribution looks at the measurement and accounting of energy flows through the various electrical networks. This involves the optimal creation of statistical metering plans and its implementation for the ringfenced networks, improvements in feeder balancing initiatives and the determination of acceptable loss levels for optimal operations. The paper provides an overview of the approach used in the implementation of the Ringfence methodology, the proposed energy losses analysis model and highlights some key applications.

Key Words **– Energy Losses, Non-technical losses, utilities, statistical metering, energy balancing**

1. Introduction

Electrical utilities around the world constantly face the pressure of reducing operational costs while also improving the quality and reliability of supply. Energy losses contribute considerably to the operating costs thereby impacting future network planning and design strategies for the utility. Compounding the energy loss situation is the increasing motivation from customers, stemming from rising energy prices, to reduce their electricity bill by illegal methods. Thus energy losses comprise a significant portion of the utility's revenue loss, which in turn, greatly impacts its bottom line. Losses incurred in electrical power systems are generally characterized by two components: technical losses and non-technical losses [1].

Technical losses are caused by the physical properties of the components of the power system which can be computed, measured and brought under control [2]. They can be further divided into copper losses (I^2R) and iron losses due to the core magnetization in transformers; copper losses comprising the major portion.
Non-technical losses are caused either by actions external to the power system, or by loads and conditions the technical loss computation failed to consider. In general non-technical losses are characterized by the delivery of energy that has not been accounted for in the energy sales or the technical loss. Studies have shown that of the numerous sources, the dominant component is that of electricity theft and non-payment. This can be broadly defined as a conscious attempt to reduce or eliminate the amount of money owed to the utility for

electric energy consumed [2]. Theft of electricity is an internationally acknowledged problem and has become the focus area for the majority of the utilities [3]. Experience has shown this to be a complex problem to address or attempt to isolate from the total losses incurred.

The foundation for reducing energy losses rests on the ability to adequately measure, meter and monitor the various energy flows within the network. Therefore the initial and main objective of any losses reduction plan is to understand the magnitude of the problem and then proceed to define the plan of action to be implemented. Assessing the extent of the problem requires an indication of the utility's current total losses, the split in technical versus non-technical losses, the problematic customer classes and the reliability of existing data. The approach should address the definition of the acceptable loss levels for the utility and the identification of high loss areas. If the utility is unable to determine the aforementioned, developing mechanisms and approaches to measure the extent of the problem becomes the initial and most critical priority.

Technical losses are calculated using load flow simulations with appropriately modeled distribution network and load models. Ideally, technical loss can be accurately estimated when a comprehensive coverage of statistical meters (stats meters) exists across the network [3]. Comprehensive coverage should lead to more accurate indications of energy flow measurements and peak demand related information. In reality however, comprehensive information of this nature is not readily available. Non-technical losses, on the other hand, are not measureble using traditional power system analysis tools and can only be determined as the residual loss after subtracting technical loss from total losses. Total losses are estimated as the difference between recorded energy purchases and energy sales [3].

Once all the necessary and sufficient measures are in place, the utility needs to develop and implement a plan to target losses and in so doing provide the foundation for the effective recovery and protection of revenue going forward. This plan should incorporate meter installation, energy audits, energy balancing techniques, data purification, data integrity checks and communication initiatives to ensure successful implementation.

In this paper, the approach employed within the Eskom Distribution environment regarding statistical meter installations, energy balancing initiatives, energy accounting and the development of an energy losses analysis model to determine 'acceptable energy loss levels' is briefly outlined. Section 2 reviews the approach to improve measurement capabilities and accuracy through the ringfencing of electrical networks. In section 3, the Energy Losses Analysis model is presented. This model works towards the identification of areas that need focus and determination of room for improvements by assessing what constitutes an acceptable level of losses for each area. In section 4, the outputs of the analysis are used to determine the targets for Total losses, customization of Opex spend in terms of audits and budget allocations. Section 5 provides some concluding remarks.

2. Eskom Distribution Background

The Eskom Distribution business is divided into six regions; each region operates as a separate entity in terms of their respective energy purchases, sales and losses. The regions are further broken down into Customer Service Areas (CSA) and Technical Service Areas (TSA) on the basis of geographical boundaries of the networks and customers. Each region buys the majority of its power from the Transmission Division and distributes energy at line voltages ranging from 132KV to 44KV in the Sub-transmission level, 33KV to 11KV in the Medium voltage (MV) network and networks operating at voltages of 6.6KV and below [4].

The entire customer base is categorized into three main customer classes known as Large Power Users (LPU), Small Power Users (SPU) and the Pre-paid Users (PPU). These classes can be grouped into the Residential sector (PPU and small SPU) and the Non-Residential sector (LPU and Large SPU). In terms of number of customers, the PPU sector is the largest; however this sector consumes the least volume of energy. The LPU customers on the other hand are few in number but consume the largest amounts of energy. The majority of the energy purchased from the Transmission division is consumed in this environment.

The energy losses problem has been identified as a key risk for the utility in terms of revenue lost, increased operational costs and impacts on service delivery. The formulation of a tailor-made approach to reduce losses for the utility is essential in order to resolve these risks. Within the Eskom Distribution Business, the Energy Losses Management Programme was rolled out with this specific intent [3]. The Programme comprises of various streams with key focus areas aimed at impacting critical aspects of the losses problem [4]. The Network Ringfence and Balance stream is one of the streams within the programme and is responsible for the accurate measurement and accounting of energy flows on the electrical networks.

3. Measurement of Network Energy Flows

The Ringfence stream acts as the measurement arm of the entire energy loss management process. The intent of this stream's activities is to identify the extent of the loss problem through effective measurement. These activities are broadly focused towards the following;

- Implementation and monitoring of the statistical metering
- Accounting for energy flows within regions and cross borders
- Total loss measurements
- Energy balancing initiatives
- Determination of acceptable levels of losses

In order to monitor and measure the energy distributed amongst the various customers, it is paramount that adequate statistical metering be optimally allocated. Currently in Eskom Distribution adequate coverage exists at the Sub-transmission voltage levels to carry out technical loss measurements. At the MV feeder levels and LV networks only moderate coverage prevails. Greater coverage in this environment is essential since the majority of the customers in the SPU and PPU domain are supplied at these levels. Hence the need to optimally install stats metering in this domain is critical.

Regional Total loss calculations are carried out on a monthly basis by the Regional Energy Trading departments, which deals with the Purchase and Sales of Energy. The Network Optimisation department measures the technical losses incurred on the networks within the region [4]. The loss calculations that are performed are limited at regional level and the determination of losses further down to a CSA level is often not possible owing to limitations in statistical metering coverage. This is a serious issue as the majority of non-technical energy loss occurs in this domain predominantly made up of SPU and PPU customers.

To overcome this issue and focus on certain high loss areas within the Residential segment, where high levels of tampering and by-passing is prevalent, the roll out of energy balancing modules (EBM) was encouraged. In the EBM approach, customers in the residential sector are geographically ringfenced into boundaries termed as projects and each of the customers within the project area are assigned a specific code. The energy delivered into the project could be through either a single feeder, or in most cases, more than one reticulation feeder that supplies energy into the area. Strategically placed statistical metering is installed on the feeders that supply energy into the area in order to measure the energy flows into and out of the project. In this manner, the losses per project area can be determined.

This methodology has now evolved into the Feeder Balancing Module (FBM). In the FBM methodology, the focus shifts from balancing energy using geographical boundaries to balancing energy at individual feeder levels. In other words, the energy delivered on a single feeder is compared to the sales for that specific feeder alone. This method overcomes the issue related to the management of energy direction flow, multiple meter failures per project and incorrect allocation of project codes to customers. Efforts to both improve this method of balancing as well as increase the number of feeders balanced using this approach are currently in progress.

The installation of statistical meters and the ability to comprehensively balance energy and locate losses on the networks is a long term objective of the Business. While implementation of plans to increase the insufficient coverage are underway, novel and cost effective mechanisms to determine losses and loss areas are necessary in the interim. Here suitable models that make use of existing and available data within the business need to be developed and employed to determine losses at an area level..

4. Energy Losses Analysis Model

The definition of "acceptable energy loss levels" for a particular utility is a challenging yet critical aspect of its specific loss reduction strategies. Benchmarking against international standards or companies can often prove useful in understanding the factors that influence energy losses across the world but care must be taken since there are many factors that influence energy losses. Such factors include customer base, customer types, network configurations, network related measurements, customer sales and billing information, equipment maintenance cycles, infrastructure spend and network expansion plans that need to be carefully understood. These aspects are considered from a utility perspective, whereas from an environmental perspective, factors such as a country's economy (GDP), socio-political climate, law enforcement levels and regulatory support are also critical in the formulation of an approach.

In an ideal situation, to determine 'what is acceptable', where all the necessary factors that need to be considered are readily available the approach is often simple and easily defined. It would involve obtaining an accurate measurement of the entire networks technical losses for the utility. Apply suitable network strengthening mechanisms to cater for the technical loss reduction component. The remaining non-technical loss component would require application non-technical loss reduction strategies to curb the remaining component of Total losses. Often across the world in various utilities this is not necessarily the case. Information pertaining to utility specific network configurations, customer groupings, customer base, unavailability of comprehensive network related measurements and inadequate accurate sales data complicate the possibility of using strictly clear-cut theoretical approaches.

Within the Eskom Distribution environment as well, a similar situation exists whereby it is critical to determine acceptable levels of losses within Eskom Distribution. Here the lack of comprehensive statistical metering coverage of energy flows, inaccurate customer linking of sales and inability to accurately determine technical losses down to an individual customer level calls for innovative approaches to be employed to estimate these acceptable levels. The adopted approach would require certain key assumptions that would need to be made in the development of the model. These assumptions are predominantly based on the Revenue Protection experience within the Business and other extrapolation techniques.

Key Assumptions

To estimate the energy losses for various levels and areas, certain key assumptions have been made in the model to ensure consistency in the approach and to overcome the inadequate energy measurement data. These are:

- The entire customer base is categorized into Non-residential (LPU and Larger SPU) and (Smaller SPU and PPU) Residential classes based on their respective Notified Maximum Demand (NMD) characteristics
- Total losses of 15% will be deemed as acceptable in the Residential customer domain
- No losses of a non-technical nature are deemed acceptable in the Non-residential sector
- There is a 50:50 split in the Technical vs Non-technical split in Total losses
- The loss percentage per CSA is determined as the average of the Residential projects balanced in the area
- EBM reports are used as the basis for loss percentage calculations at an area and project level
- Average cost of SPU and PPU audits are used in all calculations

These assumptions considered are based on the Revenue Protection audits that are carried out as part of normal business whereby experience has shown that the costs involved in trying to limit losses in the residential sector to below 15% often outweighs the benefits. In the EBM projects balanced, the results of all the projects balanced under EBM in all the CSAs for an entire financial year are taken into consideration in the exercise. Audit costs are assumed as a National average in terms of actual audit costs for the SPU and PPU customer classes to ensure a simple and consistent approach.

Data Used

The data used is extracted from the Energy Balancing Model (EBM 1) reports that are used by the Business in terms of residential losses measurements. Here the focus is limited to the identification losses for customers in the residential sector. The energy delivered into the project is measured through the strategically placed statistical metering to obtain the energy measurements for the period in consideration. The Sales data for the relevant period is obtained from Distribution's Customer Care and Billing (CC&B) system for the specific customers that are assigned the project's code. The key outputs of the report provide the total energy delivered, total sales data, technical losses component, the non-technical losses, and total customer numbers for the specific project for the period under consideration.

Total Losses at Regional levels are obtained from the Energy Trading Reports from the Energy Trading departments [4]. Regional Technical losses values are obtained from the Network Optimisation departments in the form of Technical loss reports for the period under consideration. At a Distribution level a consolidated view of the Total losses are determined by the Energy Trading Corporate department on a monthly basis [4]. All consumption data used and respective customer number related information per area are extracted from the CC&B system for the period considered. All the data used was for the financial year 2007 – 2008.

Adopted Approach

The key objective is to gain an understanding of acceptable Total Losses to the Eskom Distribution Business. Methods are required to identify and highlight key focus areas and customer classes. Funds would then need to be allocated in a optimal manner to ensure significant impact on non-technical losses. The chosen approach would require taking into consideration the current statistical metering coverage, the data availability and the immediate need for an understanding of key focus areas for loss reduction activities to commence. Hence, it was decided that the approach applied should be simple, easily replicable and uses readily available critical information within the specific environment of operation. The model used employs such an approach that eventually provides an indication of losses at an area level, what is acceptable or ultimately achievable, key focus areas, room for improvement and the cost versus benefit analysis for the money spent per area.

The Model categorizes the losses for either Distribution as a whole or at regional level into three key components. In other words, regional total losses comprises of three key components which are:

- Losses in the Residential Sector
- Technical Losses
- Losses in the Non-Residential Sector

In the Residential sector, data analysis and suitable data manipulation techniques are employed to determine the Total losses per project balanced. The results of the projects are extrapolated first to a CSA, then regional and finally to the Distribution level. This entails using average percentage loss values per project for the entire period in consideration. Next the average losses for all projects balanced within the CSA are determined and taken as the average for that particular CSA. Similarly the averages for all CSAs within the Region are calculated in a similar fashion and then finally these averages are extrapolated to a Regional level. The Residential sector losses thus determined are expressed as a percentage of the Regional Total losses using the actual GWh equivalents represented in percentage format.

The technical losses component is determined from the Technical losses report sourced for each region. This provides an understanding of the contribution of technical losses to the overall picture. These measurements are carried out by sophisticated network simulation techniques using powerful Power System Simulation Tools (PSST) to determine the technical losses at Sub-transmission voltages which comprise of the majority of losses incurred on the networks. These losses are then aggregated for the MV and LV networks.

The remaining component, the losses in the Non-residential sector, is determined as the difference between the regional Total losses and the sum of the losses in the Residential sector and the technical losses. This constitutes energy that is lost in a sector consisting primarily of LPU customers and larger SPU customers. It is difficult to breakdown the losses further to a CSA level as there are no projects being balanced in this environment. Also the nature of the customer installations varies so drastically that it becomes difficult to categorize them further at this stage.

In this manner, it becomes possible to zoom into the specific problematic areas in the Residential category down to a CSA level and express it as a percentage contribution to overall Regional Total losses. Similarly, in the Non-Residential category the percentage contribution of the combined consumption for all the CSAs can be depicted. The need or lack thereof to invest and employ loss reduction plans to curb the losses in these areas can then be determined. It also gives an indication of the target loss levels that need to be attained or the room for improvement that a Region would need to strive towards achieving. Based on the average cost per audit the GWh lost in a particular environment, it is possible to estimate the return on investment for that area. This view is also obtained at the Distribution level in order to gain an overall understanding of the contribution of each region's sectors towards the overall Distribution losses. This then facilitates the determination of the respective Region's room for improvement and key focus areas for the entire business.

5. Further Applications of the Model

Once the spread of losses is known and an estimate of the amounts per area are determined, the business can both effectively structure their loss reduction strategies as well as monitor progress of the efforts directed towards these reduction strategies. The outputs from the ELA model provides vital information in terms of the losses split in the Residential and Non-residential sector, their corresponding room for improvements and the overall contribution of the individual region towards the entire Distribution picture. This detailed view enables targeted and effective audits and loss reduction strategies to be rolled out by the business.

The key outputs that are currently being driven are briefly described as follows:

Social Marketing Focus Plan

As mentioned earlier, one of the factors contributing to the energy losses problem is the socio-economic climate of the country. Social marketing is a useful vehicle that can be used to educate the public on their responsibility in minimizing losses. Additionally it can help curb non-technical losses by changing consumer behavior and encouraging reporting of offences and perpetrators. In order to roll out such an exercise, it is always useful to conduct market research. Insight into the actual situation of the losses spread and the key areas that need immediate focus on immediately are critical to the success of this programme. The business can then strive to streamline the social marketing campaigns in areas where the Revenue Protection plans are being rolled out. This heightens the focus on the public so that they can relate to the social marketing campaigns as well as observe the actions carried out by the utility. It will also instill in the public how serious the utility is about the issue and the initiatives undertaken to curb the problem.

Total Loss Target Setting Principles

The outputs of the model can help in setting loss reduction targets and budgeting loss reduction expenditure. In general the target for reduction of Total losses is decided at the board level for the Distribution business as a whole. This target percentage decrease in losses will then need to be filtered down to the regional level. The regional targets are set based on their current status, room for improvement and overall contribution to the Distribution losses level. Targets are set keeping in mind the complexity involved in reducing losses. Thus the business strives to set targets that are practically achievable in a given timeframe to ensure consistency and fairness among all regions.

Customized Audit Targeting Approach

In general, within the Distribution environment, audits are carried out either through blanket audits or through targeted mechanisms such as the Customer Stratification methodology [3], Revenue Protection insight, system reports and whistle blowing. Faced with the need to improve the efficacy of project expenditure, especially in the midst of a global recession, maximizing returns assumes great importance. Ensuring that audits are focused on areas of probable high losses, the budget allocation needs to be customized per area, customer grouping, and number of audits required. Budget allocation is determined taking the following factors into consideration: Distribution's entire residential losses, residential loss percentages for each region and the contribution of each region to the total. This allows the business to determine the number of LPU, SPU and PPU audits that need to be conducted for a given period. Audit targets are also closely linked to the loss requirements set in terms of the regional targets. Thus a relationship is established between targets and activities.

6. Conclusion

Ultimately, it is clear that energy losses are an identified problem that negatively impacts the bottom line of utilities in the form of lost revenue and damaged equipment. Hence there is an immediate need to be able to accurately measure and account for the energy that is supplied to the end users. Improved measurements using statistical metering and effective energy balancing mechanisms play a vital role in any utility's loss reduction strategy or energy loss management program. Simultaneously, simple, structured and cost effective efforts aimed at determining key areas that need attention from a losses perspective are also crucial, in the absence of comprehensive metering coverage, to achieve the desired state.

In this environment, a trade-off between complexity and accuracy would need to be made. Often, improvement in accuracy requires the use of very complex methods in order to understand the extent of the problem. In cases where a finer picture is required, models that investigate the technical losses component accurately needs to be developed and then customized according to the availability and reliability of existing data in the utility. Alternatively, simple cost analyses that determine the potential benefits of losses detection and prevention would assist utilities in deciding whether to go ahead with a proposed strategy. Once the key areas of high losses have been identified, the subsequent steps would involve adequately strategizing a loss reduction plan for the area. Here the available budget, customer base, audit teams required and the level of losses play an important role in the success of the proposed strategy.

7. References

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