TRU Energy Monitoring for Potential Cost Saving in Electricity Bills for Cathodic Protection Units: South African Case

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***Abstract*—Reducing the electricity bill in the industrial sector is an important problem worldwide. This study focuses on the awareness of industries to Cathodic Protection (CP) energy conservation and on the potential of reducing electricity bills by a change of tariff or making use of renewable energy. Due to the frequent increase in energy cost at a significant rate, many indusial consumers are looking for ways to reduce the monthly electricity bill. The study aims to identify if it will be possible to use options such as renewable energy to supply CP systems, or if a change of tariff can help reduce the monthly bills. To achieve this, a real-time energy-monitoring device "Efergy E2" was installed in one of the Transformer Rectifier Units (TRU), the monitored TRU is located at Ndwedwe reservoir 2 in the areas of Durban. Among other benefits, the hourly load data analysis can provide the detailed characteristics of load demand, define the consumption patterns and can help to identify where the consumer could reduce the electricity bill. The results indicate that the load is almost constant throughout the day and changing to Time of Use (TOU) tariff does reduce the bills. However, the fixed charges amount to 11 times energy charges, hence the best way is to make use of renewable energy rather than changing a tariff.**

***Index Terms*—Cathodic protection, electricity bill, energy monitoring, industrial consumer, time-of-use, TRU**

I. Introduction

In South Africa, due to long distances and extensive stray currents, all buried metallic pipelines (including water, oil, gas and other hazardous pipelines) need to be protected against external corrosion by the application of an external coating and Cathodic Protection (CP) [1]. These pipelines run all around the world, some in remote areas and others in areas populated with power lines. Hence, there is an availability of electricity which contributes to an accelerated rate of corrosion due to stray currents [2]-[5].

Cathodic protection is achieved by the supply of sufficient direct current to the external pipe surface so that the steel-to-electrolyte is lowered to values at which external corrosion is reduced to an insignificant rate [1], [6]. In South Africa to be specific, most cathodic protection systems are done using Impressed Current Cathodic Protection (ICCP). ICCP is currently implemented through Transformer Rectifier Unit (TRU) [7]. TRU's are supplied by Eskom power and most of them are outstations. They have their meters, and they are billed separately. Their bills include standard fixed; service and administration charge of R25.20 per day, network capacity charge of R30.35 per day, network demand charge of R0.2839/kWh, ancillary service charge of R0.0044/kWh and Energy Charge of R1.1363/kWh as per Landrate tariff. Therefore, this study aims to identify and evaluate the behavior of TRU in terms of energy consumption to reduce bill charges. To achieve this, a real-time energy-monitoring device of electrical energy consumption was being used. The main findings from the read data were: the TRU units used for CP don't consume a lot of energy, based on the TRU consuming about 4.5kWh a day. Secondly, it was found that the user is paying 11 times more for tariff fixed charges than for the energy used. Lastly, it was clear that a change of tariff can help reduce the bills, however, making use of renewable energy was seen as a better option.

The work presented in this paper, therefore, forms preliminary results of the project, which is being carried out to evaluate and develop an economic solution for energy costs supplied to cathodic protection units. The layout of the paper is as follows: Section 2 describes the selected TRU unit and its geographical site and study methodology; Section 3 explains how energy collection is being done; Section 4 analyses the profile depicted from the recorded energy consumption; Section 5 evaluates and discuss the change of tariff to TOU and other potential savings techniques.

II. Description of the Selected TRU and Methodology

The CP TRU unit identified for this case study is in Durban, KwaZulu-Natal at Umgeni Water Reservoir 2 of Hazelmere to Ndwedwe bulk water distribution line. This specific study site was chosen merely due to its security, excess and that it is where permission to use was granted for research purposes by Umgeni Water. Fig. 1 shows the geographical data for the study site. This is a typical

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South African TRU unit used for CP systems; the series of figures below indicate the load profile for various periods. From the read load profiles and demand perspective, the load demand profile is the most significant factor in the optimization process [8]. This is critical for accurately designing an optimal system. The optimal system should satisfy the power demand at any given time and avoid further costs due to under or oversizing the supply system.

Fig. 2 shows the TRU unit where the monitoring device "Eferyg E2 Classic" will be installed. This unit was installed by paradigm projects and it is the property of Umgeni water, the unit was manufactured by Cathtect engineering for corrosion prevention.

The methodology to implement this study will be, to first identify the insulation or study site which is explained above. Secondly, the current energy bills for the selected will be requested and analysed. Thirdly, the energy monitoring device will be installed on the selected with its software to analyse the behaviour of the load. Lastly, the obtained data will be used to evaluate the proposed energy-saving techniques and recommend the most effective one.

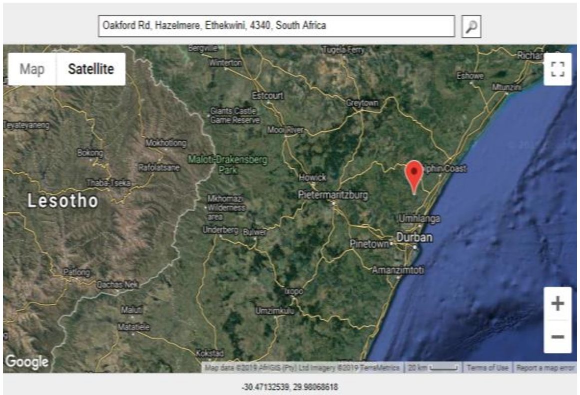

Fig. 1. Geographical site indication on the MAP.

Fig. 2. Selected TRU for this study.

Fig. 3. Efergy wireless electricity monitor and data logger.

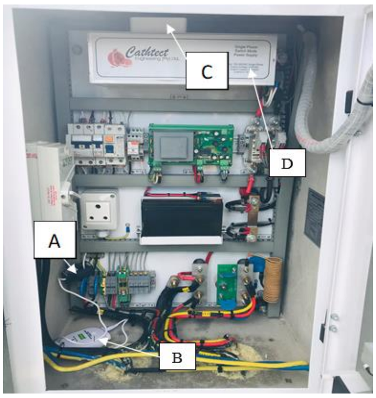

Fig. 4. Efergy installed in the selected TRU.

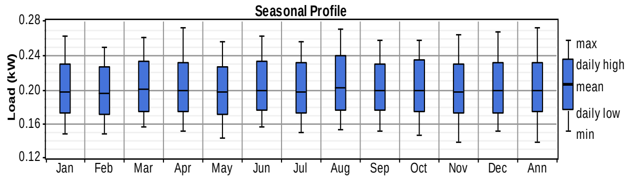

Fig. 5. Acquired annual TRU load demand using Efergy monitoring device.

III. Energy Data Collection

The recorded consumptions presented in the following sections were achieved using an energy monitoring device, measuring the energy consumption in real-time. Fig. 3 shows various components forming the Efergy E2 metering set, where (A) shows the current transformer which senses the load current and sends the data through the wireless transmitter; (B) is indicates the data transmitter, transmitting data to the recording and display unit; (C) points out the record-keeping and display unit, showing the Kilowatt-hours (kWh).

Fig. 4 shows how the Efergy monitoring set was installed in a TRU, where, (A) indicates the Current Transformer (CT) installed just after the main circuit breaker, feeding the whole unit. (B) shows the transmitter, which is connected to the CT, such that it reads the information, sent by the CT and transmitter it to the monitoring display unit (C). (D) shows the TRU control unit.

Fig. 5 shows the annual load data for 2019. The graph shows that the average peak demand during the recorded year (2019) was 1.56kWh/d, with an average peak consumption of 240W. The load consumption was constant during both the winter and summer months.

IV. Energy Consumption Analysis and Discussions

ICCP systems supply DC current to the pipeline to prevent corrosion, these systems run 24 hours a day [9]. However ICCP is implemented by use of TRU units, TRU units take AC power to convert it to DC and supply it to the pipeline through anodes [7]. Below is the record of TRU consumption over some time.

A. Hourly Energy Analysis

When referring to Fig. 6, it can be seen that the TRU unit consumes an equal amount of energy at all times. Fig.

6 shows the record of the TRU energy consumption for Wednesday of 02/10/2019, the energy consumed on this day amount to 4.74kWh. The peak energy demand on this day was 230W, which was at 05:16. The hourly load consumption trend is in a table form, which confirms a constant uniform consumption. Total energy on this day amounted to R5.39 with fixed daily charges of R56.92, which is 11 times the energy charges.

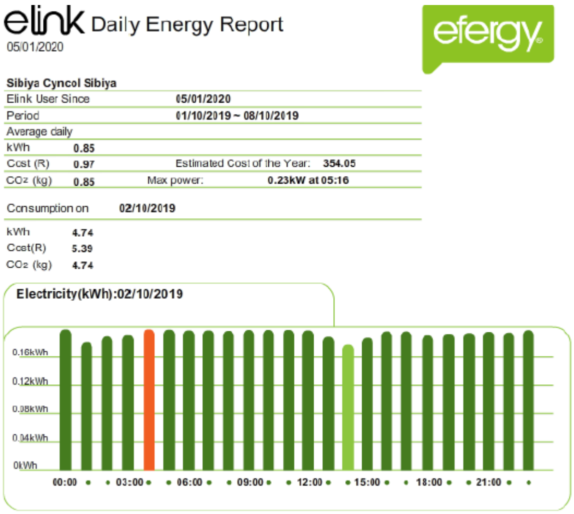

Fig. 6. Hourly load profile of a TRU for 02/10/2019.

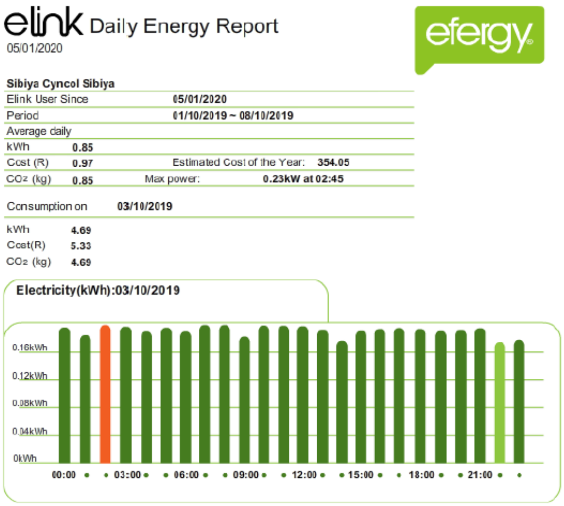

Fig. 7. Hourly load profile of a TRU for 03/10/2019.

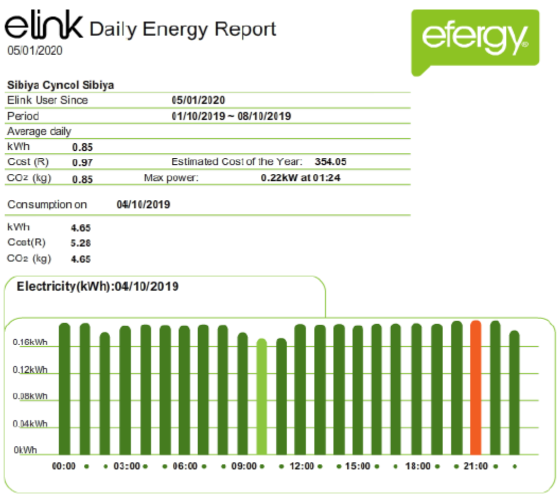

Fig. 8. Hourly load profile of a TRU for 04/10/2019.

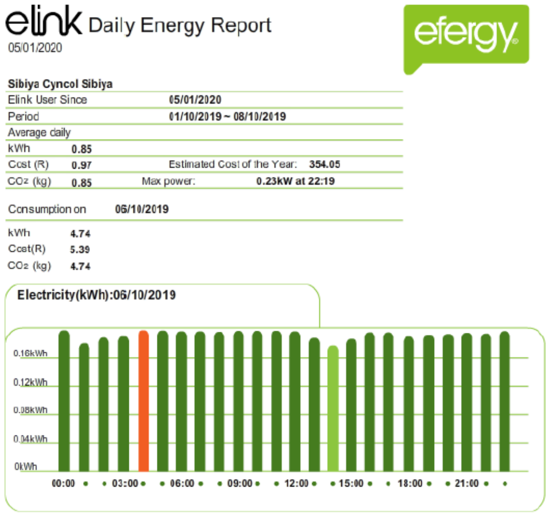

Fig. 9. Hourly load profile of a TRU for 06/10/2019.

Fig. 7 shows the hourly load consumption recorded on the 03/10/2019. It can be seen that the peak load demand on this is 230W which is the same as that of the previous day. Furthermore, 4.69kWh which is only 0.05kWh units less compared to the previous day 02/10/2019. The energy cost for the day is R5.33 with the hourly consumption amounting to almost the same value.

With reference to Fig. 8, the total energy consumed for the day of 04/10/2019 is 4.75kWh, 0.09kWh for the 02/10/2019 and 0.4 kWh for the 03/10/2019, with the cost of energy amounting to R5.19. The peak load demand recorded is 220W which is only 10W less than the previously recorded peak load demand values, and it was recorded after 10 pm.

Fig. 9 shows the hourly load profile recorded on the 06/10/2019. It can, therefore, be seen that the peak load demand is 230W and it was recorded around 4 am. The total energy consumed on the day was 4.74kWh amounting to R5.39, which is roughly the same as the cost of energy consumed for the previous days. Hence from the above-recorded energy consumptions, it can be seen that the TRU unit consumes energy in a fairly uniform manner.

B. *Daily Energy Analysis*

The obtained daily energy consumption data is presented in this section below. Where the behavior of the load is analyzed and discussed as per the load profile obtained.

Fig. 10 shows a 7-day load profile for a selected site TRU unit and it can be seen that the peak demand was 230W on Tuesday. This will be used as the Load demand for this study. Furthermore, the daily average consumption looks constant throughout the day as supported by Fig. 11 and Fig. 12. The unit consumed 36.69kWh in 7 days and using the current rate of R1.23 at the time of the study, the total amount for the used energy is R45.13 (ZAR) at 36.69 kg of carbon emitted.

The recorded consumptions above were achieved by using an energy monitoring device, that measures the energy consumption in real-time. It can be seen from Fig. 12 that the weekdays' consumption average is a bit higher than that of weekend consumption average. Furthermore, reading from the 00h00 hours mark it is noticeable the unit consumes it is highest. The two trends weekly average and weekend average are almost following the same pattern, which confirms the behavior of the load as a fairly constant load.

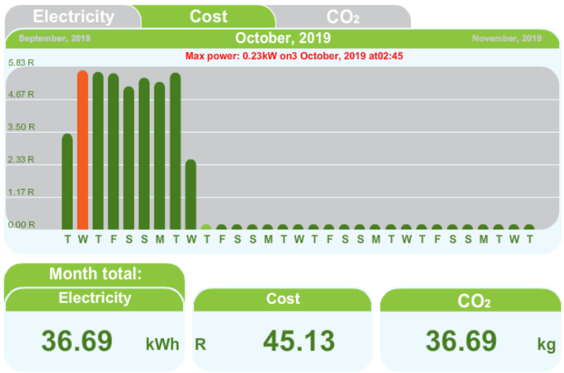

Fig. 10. Daily load profile of a TRU recorded for a week.

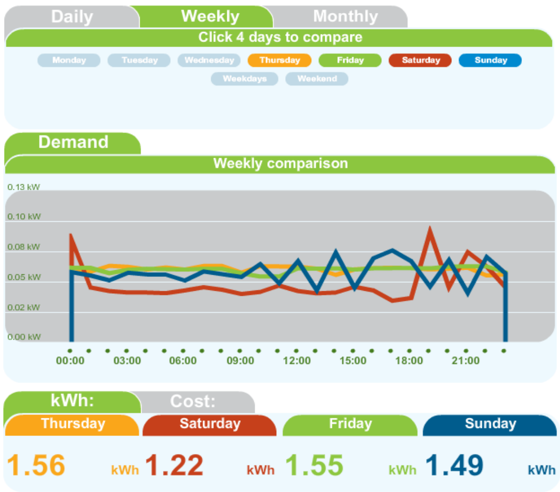

Fig. 11. Load profile of a TRU for weekday's comparison.

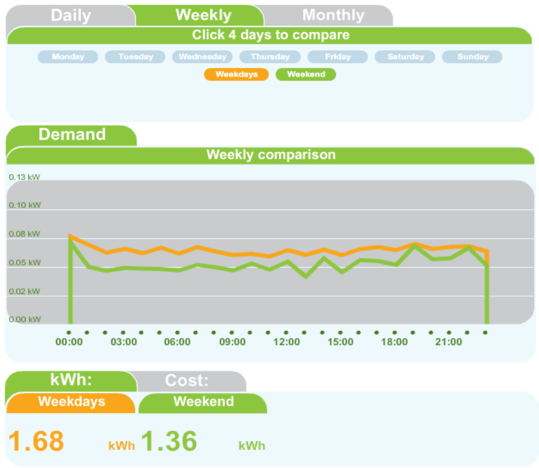

Fig. 12. Load profile of a TRU for weekdays and weekend comparison.

V. Potential Energy Cost-Saving Technique Evaluation, Results and Discussions

This section evaluates the potential energy cost-saving techniques to determine the one that will make the most savings. The results from each are discussed following the evaluation of the technique in the same section.

A. Time of Use (TOU) Tariff

This selection will evaluate, analyze and check if a change of tariff can help reduce the bill for TRU's. This exercise is mainly based on the recently approved customer choice to subscribe to either flat rate or TOU tariff [10]. The advantage of this tariff is that customers are charged based on the time at which they use the energy, these rates differ depending on the season and time of day. However, the rates during off-peak are lower than those of standard rates. The TOU tariff periods are shown in Fig. 13.

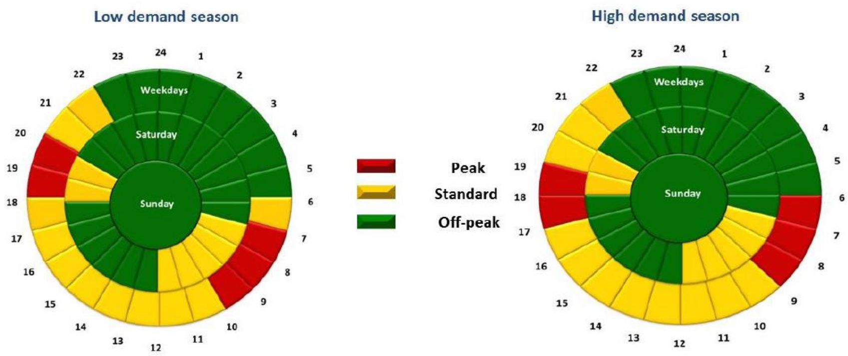

Fig. 13. Periods of time-of-use tariff [12], [13].

According to Eskom Tariffs and charges 2019/2020. If the tariff can be changed from Landrate 1 to Ruraflex non-local authority rates. Ruraflex is TOU electricity tariff for rural customers with dual and three-phase, provided the Notified Maximum Demand (NMD) is from 25 kVA with a supply voltage <22KV [11]. Change the tariff will offer lower energy charges most especially during Low Demand Season (LDS) with the highest electricity rate being R1.3 during peak hours. On the High Demand Season (HDS), the electricity rate will be R3.97 during peak hours. Moreover, it has a lower charge for Network capacity charge, which is R11.7 less than that of Landrate Tariff. A service charge rate, which is R6.42 less than that of landrate, tariff a day. However, Network demand charge and Ancillary service charge are the same for both tariffs. Hence charging the tariff will bring savings in electricity bills.

With reference to Fig. 13, it is clear that for the application where a TRU has constant consumption the change from low demand season to a high demand season will not make must difference since for both we have 5 hours of peak hours, 11 hours of standard consumption hours and 8 hours a day.

B. Battery Energy Storage Systems

With TOU tariff, energy gets cheaper during off-peak. However, consumers might not need energy during these hours. Nevertheless, this allows consumers to use Battery Energy Storage Systems (BESS) to reduce their electricity bills. Reference [14] indicates that it is possible to reduce the cost of energy consumed by the load by up to 52%. This can be accomplished by storing the energy into batteries through charging during the off-peak periods and only use it during peak periods where the electricity prices are high [15]. This section will focus on evaluating whether or not the BESS strategy benefit of electricity cost reduction is enough to compensate for storage costs.

The more widespread and most commonly used electrochemical technology is the lead-acid batteries [16]. However, these have a short lifespan, low energy density and slow cycling rates. Nevertheless, they are the most popular and the least expensive. More details of BESS can be found in [17]. For this study, a GEL battery will be evaluated to supply a 230W peak load during peak hours. This is due to the energy costs being the highest during this period since it is R3.97/kWh during HDS and R1.30/kWh during LDS. This indicates that in terms of rates it will be of more benefit during the HDS, simply because the current tariff (Landrate) energy charge is R1.30/kWh. Furthermore, during HDS the energy cost is 65 c/kWh during the off-peak period with is more than two times less compared to the normal cost of energy on the current tariff.

Peak periods last for about 5 hours a day, which accounts to 1.15kWh amount of energy needed a day to supply the CP system selected. With 50% Depth of Discharge (DOD) and considering system losses, the BESS capacity size should be 3kWh. If the BESS system is configured for 24V, the battery bank should have at least 96Ah capacity. The BESS will have an initial cost of about R5300 [18], giving a saving of about R19.85 a day on TOU tariff during HDS which is R3573 saving for every HDS. Furthermore, as much as energy is much lower during LDS the use of BESS can still make a huge saving. This is due to the energy cost being 56 c/kWh during off-peak and R1.30/kWh in both the current tariff and in a TOU tariff.

C. Hybrid System

The use of renewable energy resources for CP systems have been proposed in ref. [19]. CP systems, however, require a constant reliable supply of energy. Hence, combining two or more Renewable Energy Sources (RES) to form a hybrid system will eventually give an advantage in supporting the shortcoming of electrical energy, and give strength to unpredictable renewable energy resources [20]. For this study solar and wind power are considered, due to the great interest being shown in these two RES in literature [21], [22]. Furthermore, they are the most affordable and highly growing in the market, with governments in many counties including South Africa, encouraging cleaner and more sustainable energy sources [23], [24].

Based on the evaluations done in the previous section, it is clear that the use of a hybrid system with BESS will be the most economical way of supplying Power to CP systems. This is due to the selected site having adequate solar irradiance and wind resources. However, the system will have to provide power to a peak load of 230W for 24 hours a day. The peak daily energy required is 4.74kWh according to Fig. 6 and Fig. 9, Hence the BESS capacity should be 10kWh considering system losses and 50% DOD. Taking a 24V system, the BESS capacity should be at least 420Ah. A combination of a few solar panels and a wind turbine can supply power to the CP unit successfully. This can result in no paying of electricity bills and a CP system running on an environmentally friendly and cost-effective off-grid hybrid system.

VI. Conclusion and Future Work

An energy audit methodology and the results of the recorded TRU load profile is presented in this work. A single-phase Efergy Wireless Electricity Monitor and data logger were installed in a TRU unit to record the energy consumption for one full year. The results reveal that the unit consumes uniformly throughout the day with the peak load demand not far from the unit normal hourly consumption. The results obtained from this study indicate that for cathodic protection energy saving will not be possible, this is due to the load being uncontrollable. However, it was important to monitor the behaviour of the load to have a better view and to develop a better understanding of the load.

It has been observed that the load behaviour patterns of TRU and its consumption has a uniform tend and could not be reduced. However, changing the current tariff to TOU could make a significant impact on the electricity bills.

Below are some areas for future work that will help to manage the electricity bills for TRU units:

- An exercise of tariff changes, evaluating which tariff applicable to TRU's can significantly offer reduced electricity bills.
- Conduct Studies to evaluate if battery and hybrid system under flat tariff and TOU can be used to supply ICCP systems adequately and cost-effectively.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Cyncol A. Sibiya conducted the research, developed the model and wrote the paper; Bubele P. Numbi analyzed the data, edited the paper and contributed to the development of the model; Kanzumba Kusakana analyzed results, expanded the model and reviewed the paper; all authors had approved the final version.

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