TECHNICAL AND FINANCIAL IMPACTS OF SSEG ON THE MUNICIPAL ENERGY SECTOR

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1. Introduction

The traditional national power system has electricity delivered to passive consumers in a municipal area from a centralized generation power plant. Local municipalities with distribution licenses procure most of their electricity from Eskom and are responsible for providing sustainable, affordable, safe, and reliable energy supply within their networks. To achieve this, municipalities require healthy and reliable electrical infrastructure, now and into the future. There have been disruptions to the classic centralized generation power system with the rising presence of distribution generation in the form of small-scale embedded generation (SSEG) systems. The growth of the SSEG market is mainly attributed to the rising electricity tariffs, decreasing costs of embedded generation, mainly solar photovoltaic (PV) systems and the need for energy security. As a result, many customers are installing grid tied SSEG systems, mainly solar PV systems to reduce their electricity bills.

The continued growth of the SSEG market in South Africa pose technical and financial threats to local municipalities. The increasing uptake of SSEG customers may be unfavourable for many municipal distributors since a decrease in energy sales could erode municipal income if not regulated and charged accordingly. Decreasing energy sales further result in less funds available to maintain the distribution grid as well as less funding to cross-subsidise the poor consumers. It is therefore imperative for municipalities to adjust their tariff structures in such a way that safeguards their revenue stream whilst maintaining a good business case for the electricity consumers.

Distributed generation is characterized by power generated at or near the consumer load and varies with the availability and variability of primary energy. Power flow in distributed generation is bidirectional. Addition of distributed generation to already established traditional local municipal power systems therefore pose a potential threat of power quality problems, degradation in system reliability, reduction in the efficiency, over voltages and safety issues [1]. However, distributed generation can contribute towards reduced transmission losses due to their proximity to the consumer loads and improved voltage support. Thus, distributed generation should be added to the power system with consideration to various limits to ensure its stability and avoid poor voltage profiles, voltage flickers, harmonics, and damage to equipment.

Both technical and financial impacts of distributed generation within a municipal electrical network are critical to ensure a just transition of its energy sector. This paper presents a case study of technical and financial impacts of integrating SSEG systems into a typical local municipality.

2. Network Supply Area

The study area is a typical local municipality in Western Cape with a distribution license. The municipality supplies electricity to the larger part of the municipal town whereas Eskom services the rest of the area, mainly the outskirts. Figure 1 shows a section of the electrical network managed by the municipality used in this study. The 66/11kV Main Substation intake supplies electricity to more than 353 consumers via a main 11kV feeder passing through a Switching Station and a Ring Main Unit (RMU) to the various distribution mini substations (MS). Most of the consumers are residential customers with a few commercial customers and a government institution. The Main Substation reaches its peak demand at 19h00.

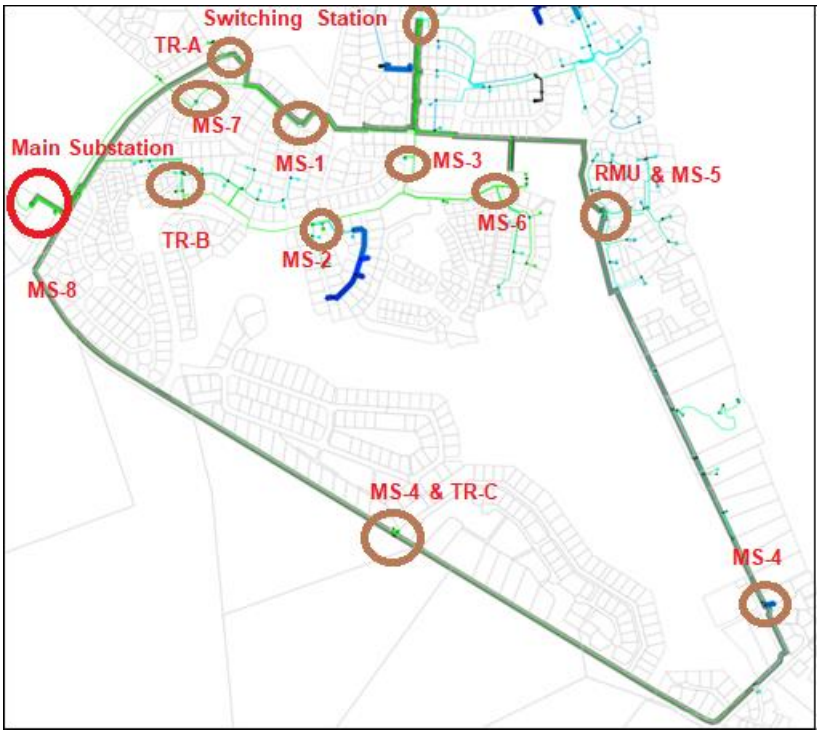
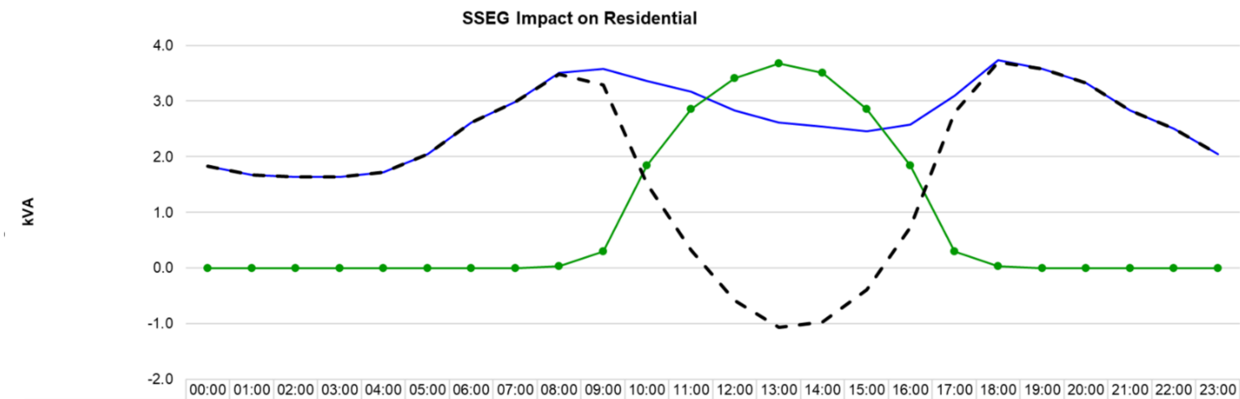


Figure 1: SSEG Impact Assessment Study Area

Of all the renewable energy resources in the study area, solar PV is the most productive technology with an excellent performance comparable to the country's average. It is therefore expected that the SSEG installations are largely rooftop solar PV. However, based on the observed PV profile in the area, rooftop solar PV does not generate electricity before 09h00 in the morning and after 17h00 in the evening. Figure 2 illustrates the residential and PV profiles, and the effective combined profile of a household with rooftop PV. It is observed that rooftop PV does not impact (or at least not in a meaningful way) the peak demand of a residential customer in the study area. The impact of the excess generation at the peak of the PV output on the MV/LV network is assessed later in the study.



	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00
Res Profile	1.83	1.68	1.64	1.64	1.72	2.05	2.61	2.98	3.51	3.58	3.36	3.17
PV Profile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.30	1.84	2.85
Combined Profile	1.83	1.68	1.64	1.64	1.72	2.05	2.61	2.98	3.48	3.28	1.52	0.32

	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Res Profile	2.83	2.61	2.54	2.46	2.57	3.10	3.73	3.58	3.32	2.83	2.50	2.05
PV Profile	3.41	3.68	3.50	2.85	1.84	0.30	0.03	0.00	0.00	0.00	0.00	0.00
Combined Profile	-0.58	-1.07	-0.97	-0.39	0.73	2.80	3.70	3.58	3.32	2.83	2.50	2.05

Figure 2: Impact of Rooftop PV on Residential Load

3. Technical Analysis

As a point of departure, the impact of SSEG penetration as per the capacity limitations specified in the NRS 097-2-3 [2] as illustrated in Figure 3 was considered. Although NRS 097-2-3 recommends a connection limit of 15% of the MV feeder peak load, 100% and 200% penetrations were considered for this study. These were chosen arbitrarily, however, the aim was to assess the impact of higher penetration of rooftop PV on the MV/LV network.

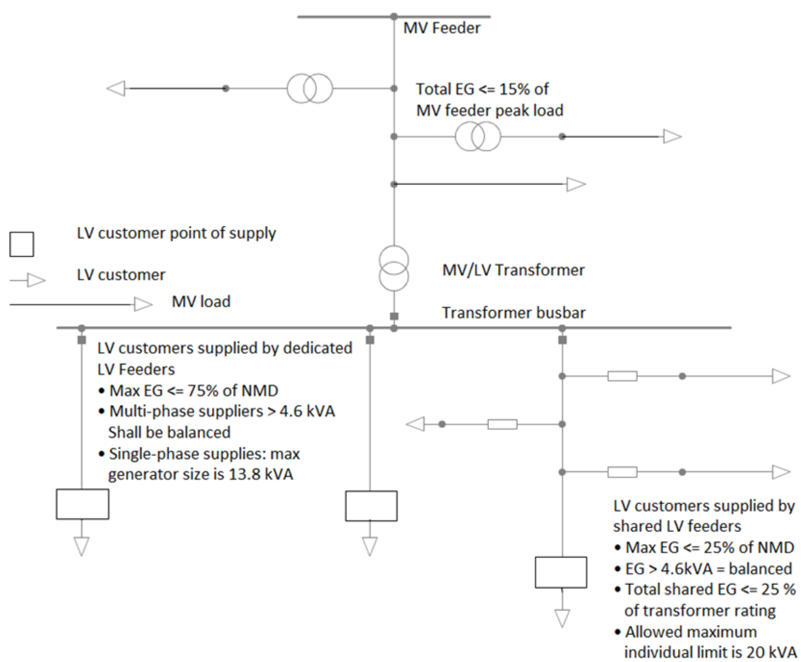


Figure 3: NRS 097-2-3 Simplified Connection Criteria

The maximum demand of the main 11kV feeder is 1.3 MVA. A 15% SSEG penetration (in the form of solar PV) has a total of 195 kVA. With a solar PV rating of 3.68 kVA, about 53 installations are required to achieve a 15% PV penetration. Similarly, 100% PV penetration sums up to 1.3 MVA which is achieved by 353 PV installations. 200% PV penetration sums up to 2.6 MVA with about 707 PV installations. Table 1 shows the number of solar PV installations per supply point per each SSEG penetration level considered.

Table 1: Network loadings and penetration levels

Supply Point	Transformer loading	15% SSEG Penetration		100% SSEG Penetration		200% SSEG Penetration	
	kVA	kVA	No. of Installations	kVA	No. of Installations	kVA	No. of Installations
MS-1	144	22	6	144	39	289	79
TR-A	144	22	6	144	39	289	79
TR-B	108	16	4	108	29	217	59
MS-2	108	16	4	108	29	217	59
MS-3	108	16	4	108	29	217	59
TR-C	108	16	4	108	29	217	59
MS-4	108	16	4	108	29	217	59
MS-5	108	16	4	108	29	217	59
MS-6	108	16	4	108	29	217	59
MS-7	144	22	6	144	39	289	79
MS-8	108	16	4	108	29	217	59

3.1. 15% SSEG Penetration

Table 2 outlines the impact of SSEG on the different voltage levels and feeder loadings at 15% PV penetration. Solar PV installation slightly improves the line loading of each conductor. There is no significant impact observed on the voltage of the HV and MV conductors. However, there is minimal impact on the LV conductor.

Table 2: SSEG Impact on feeders at 15% PV Penetration

Conductor	Nominal Voltage [V]	PV Installation	Loading [%]	Voltage [p.u.]	Voltage Change [%]
Supply to Main Substation	66000	Without PV	21%	1.00	0.0%
Supply to Main Substation	66000	With PV	20%	1.00	
From Switching Station	11000	Without PV	8%	0.99	0.0%
From Switching Station	11000	With PV	6%	0.99	
To RMU	400	Without PV	8%	0.93	0.9%
To RMU	400	With PV	6%	0.94	

Figure 4 show the impact of SSEG on the voltage and thermal loading profiles, respectively, by comparing the results with and without PV penetration. From Figure 4 it is observed that the voltage profile improves somewhat with PV installed. Similarly, there is some improvement of the thermal loading profiles with PV installed.

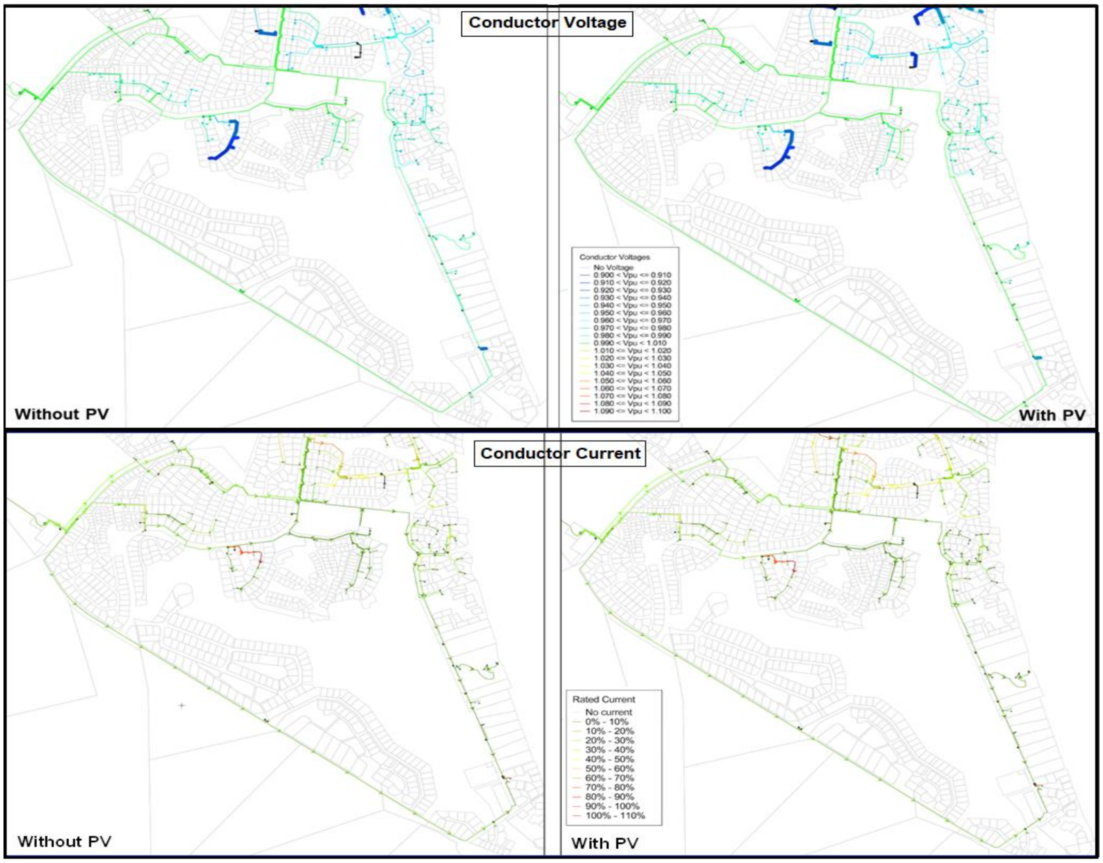


Figure 4: SSEG Impact on network voltage and current at 15% Solar PV Penetration

3.2. 100% SSEG Penetration

Table 2 outlines the impact of SSEG on the different voltage levels and feeder loadings at 100% PV penetration. The installation of the SSEG systems improves each conductor loading. There is minimal impact on the voltage of the HV and MV conductors. However, there is significant voltage impact on the LV conductor with 5.6% change.

Table 3: SSEG Impact on feeders at 100% PV Penetration

Conductor	Nominal Voltage [V]	PV Installation	Loading [%]	Voltage [p.u.]	Voltage Change [%]
Supply to Main Substation	66000	Without PV	21%	1.00	0.1%
Supply to Main Substation	66000	With PV	16%	1.00	
From Switching Station	11000	Without PV	8%	0.99	0.2%
From Switching Station	11000	With PV	6%	1.00	
To RMU	400	Without PV	8%	0.93	5.6%
To RMU	400	With PV	6%	0.99	

Figure 5 show the impact of SSEG on the voltage and thermal loading profiles, respectively, by comparing the results with and without PV penetration. It is observed that both the voltage and thermal loading profiles improve with the installation of solar PV installed. In this instance, the power flow direction changes because of excess electricity from PV generation going upstream.

Figure 5: SSEG Impact on Voltage and Current: Without PV vs With PV at 100% Penetration

3.3. 200% SSEG Penetration

Table 4 outlines the impact of SSEG on the different voltage levels and feeder loadings at 200% PV penetration. There is still minimal impact of the voltage on the HV and MV conductors. However, there is significant impact on the LV conductor with a 10.1% voltage change.

Table 4: SSEG Impact on feeders at 200% PV Penetration

Conductor	Nominal Voltage [V]	PV Installation	Loading [%]	Voltage [p.u.]	Voltage Change [%]
Supply to Main Substation	66000	Without PV	21%	1.00	0.1%
Supply to Main Substation	66000	With PV	12%	1.00	
From Switching Station	11000	Without PV	8%	0.99	0.3%
From Switching Station	11000	With PV	18%	1.00	
To RMU	400	Without PV	8%	0.93	10.1%
To RMU	400	With PV	18%	1.03	

Because of the PV generation exceeding maximum loading, there is much more increase in the loading downstream the feeder, albeit with reversed power flow direction. There is further reduction of loading upstream the feeder, closer to the substation. Figure 6 show the impact of SSEG on the voltage and thermal loading profiles, respectively, by comparing the results with and without PV penetration.

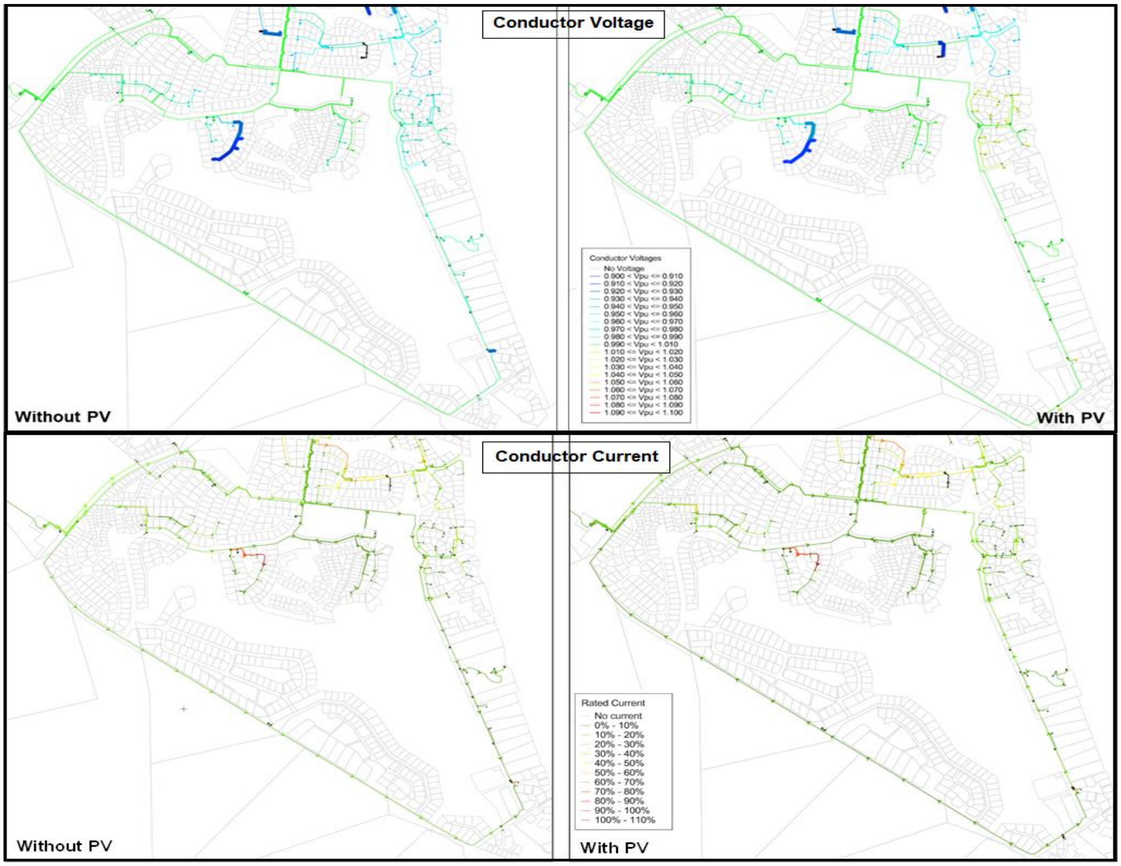


Figure 6: SSEG Impact on Voltage and Current: Without PV vs With PV at 200% Penetration

In all the different SSEG penetration levels considered at LV level, it was observed that there is considerable impact on the voltage and thermal loading profiles of the LV level compared to the HV and MV levels.

4. Revenue Analysis

The impact on the potential collectable revenue by the municipality from the sale of electricity is assessed in this section. The monthly billing information from a sample area with the properties supplied by the 66/11 kV Main Substation was assessed. The billing data was used to simulate the changes in the potential collectable revenue. As in the Technical Analysis section, the impact on the potential collectable revenue was simulated using different SSEG penetration ratios of 15%, 100% and 200%. A list with the current PV installations was provided and the typical PV size used in the municipality is 3.68kVA. This capacity was used to determine the monthly PV generation along with the PV generation profile for the province. The monthly consumptions for the individual properties in the supply area for 12 months was used as a base case for the analysis. From the customers listed in the billing information, no customer was on a SSEG tariff.

Table 5: Sample area customer numbers

Customer Class	Number of Customers
Domestic Prepaid	261
Domestic Conventional	1162
Commercial Prepaid	6
Commercial Conventional	55
Bulk User	36
Single Phase SSEG	0
Three Phase SSEG	0
Total Customers	**1520**

The PV penetration was translated to the number of properties as shown in Table 1 through random selection. The monthly consumption of these selected properties was recalculated based on the PV yield for the province, and the generation profile based on the season where the months fall under. The applicable seasonal PV generation profiles were utilised to determine the generated energy for each consumer. The consumptions for the properties were used to calculate the collectable revenue from the energy charge and the basic charge based on the respective tariff charged to the customer.

The monthly consumption was broken into the blocks as indicated in Table 6 where the respective inclining block tariff was applied. This new consumption was used to calculate the potential collectable revenue from the sample area of properties in the Main Substation supply area. For each penetration simulated, a supplement scenario was computed where the existing tariff for the property was then changed to the relevant SSEG tariff which would be charged had the property registered it's PV installation. This analysis did not include any export tariff chargeable, where an export of energy may occur due to surplus energy generated, the properties consumption was read as zero for the month.

Table 6: Electricity tariffs billed to the sample area properties in a financial year

Inclining Block Tariff	Block 1 (0-50kWh)	Block 1 (51-350kWh)	Block 1 (351-600kWh)	Block 1 (>600kWh)	Basic Charge
Customer Class	**R/kWh**	**R/kWh**	**R/kWh**	**R/kWh**	**R/month**
Domestic Prepaid	1.0185	1.3231	1.9112	2.2911	308.04-1068.57
Domestic Conventional	1.6992-1.7274				290.65-2533.35
Commercial Prepaid	1.7255-1.7541				885.9-2437.5
Commercial Conventional	1.6992-1.7323				532.56-4460.67
Bulk User	0.78145-4.2218				1059.16
Single Phase SSEG	1.4468				472.68
Three Phase SSEG	1.4468				1074.95

4.1. Revenue Impact Results

The result of the revenue impact analysis is revealed below in Table 7.

Table 7: Summary of revenue analysis results for the sample area

	Total Consumption (kWh)	Total Basic Charge Revenue	Total Energy Charge Revenue	Total Revenue
Base Case	**637,469.75**	**R10,174,550.40**	**R651,177.88**	**R10,825,728.28**
15% Penetration	572,147.71	R10,174,550.40	R583,420.61	R10,757,971.01
15% Penetration SSEG Tariff Change	572,147.71	R10,071,060.84	R607,746.41	R10,678,807.25
100% Penetration	414,826.47	R10,174,550.40	R408,721.04	R10,583,271.44
100% Penetration SSEG Tariff Change	414,826.47	R9,651,208.56	R532,251.47	R10,183,532.03
200% Penetration	404,772.04	R10,174,550.40	R398,364.40	R10,572,914.80
200% Penetration SSEG Tariff Change	404,772.04	R9,738,690.60	R553,977.04	R10,292,667.64

Table 7 shows the potential collectable revenue in the sample area within the Main Substation supply area. The decrease in energy charge is seen as the penetration levels increase. This is mainly due to the decrease in chargeable energy consumed by the customers with the increase in SSEG usage. When comparing the case where the properties where the PV installation is registered leading to a tariff change versus the case where the customer fails to register the installation, it is clear to see the higher potential collectable energy charge. This contrasts with the potential collectable basic charge.

As more properties switch over to a SSEG tariff, the less revenue the municipality collect in the form of basic charge. This is likely due to the change in the basic charge charged to the property and is potentially an indication of an inefficient SSEG tariff structure. In the base case and as seen in Table 6, the basic charges vary with the customer class and the amperage of the meter installation, this is not the case with the existing SSEG tariffs, where all single phase SSEG connected properties and three phase SSEG connected properties pay a set basic charge monthly irrespective of the amperage of the connection.

From the revenue impact analysis, it is seen that the potential collectable revenue generated from the energy sold in this case study area as the penetrations increase is higher when the customers are placed on a SSEG tariff. This stresses the importance of the municipality being aware of the properties with SSEG installations to ensure the customer is being charged the correct tariff and the required revenue can be collected from that customer. Municipal SSEG programmes and policies need to be aimed at educating customers on the importance of registering SSEG installations. Further on, the result shows us the need for a cost reflective SSEG tariff to ensure sufficient revenue can be collected in the form of a basic charge which will cover both the provided network and service charges to the varying customers in the network. This is key as a municipality will continue to pay Eskom network related and service charges which will not decrease as the energy required decreases.

5. Conclusion

This paper presented a case study of technical and financial impacts of integrating SSEG systems into a typical local municipality in the Western Cape. The study assessed the baseline electricity consumption and revenue patterns of different customer classes. This was aided by use of a geospatial analytical tool that interrogates the municipal electricity billing database to compute average seasonal consumption and associated maximum demand values for each customer. Furthermore, SSEG installations at MV / LV level were simulated on the electrical network at specific network points of different classes, ensuring technical viability considering the area specific seasonal capacity factors and typical system size installations of solar PV technology. Using each customer's established electricity consumption baseline, net electricity obtained from the municipal network was computed after the SSEG integration. The difference in grid consumption presented the change in municipal electricity sales and subsequently, impacted on its revenue. The municipality should be aware of the properties with SSEG installations to ensure the customer is being charged the correct cost reflective tariff and the required revenue can be collected from that customer. A secure and optimal energy transition should always strike a balance between protecting municipal earnings and presenting a lucrative business case for the SSEG customer.

6. References

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