Probabilistic Impact Assessment of Residential Charging of Electric Motorcycles on LV Feeders

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***Abstract*—Motorcycles form a popular mode of transport in East African countries, and policies in countries like Rwanda are encouraging a transition to electric motorcycles (EMs). This paper aims to identify the impacts of EM charging on a low voltage residential distribution network in future high uptake scenarios. A stochastic-probabilistic analysis is conducted on a residential network, looking at the effect of EM charging on voltage level, voltage unbalance as well as cable and transformer loading. The Monte Carlo Simulation method is used to account for the randomness in the placement of EMs along the network while the extended Herman Beta transform is used to account for the variability in the residential consumer loads. This paper found transformer overloading to be the limiting factor with regard to EM uptake for the sample network modelled. A sensitivity analysis then highlighted the effects that the feeder properties, transformer size as well as EM and residential load model had on the simulation outcome. The sensitivity analysis found the results most sensitive to the residential load modelling as this affected the transformer loading prior to any EM charging.**

Keywords*— Rwanda, electric motorcycles, impact assessment, residential charging, stochastic-probabilistic analysis

I. INTRODUCTION

With a global transition towards a cleaner and greener environment many countries have set national targets with regard to electric vehicles (EVs), with the implementation of EV policies worldwide [1] and campaigns such as EV30@30 launched by the Eighth Clean Energy Ministerial in 2017 [2]. As the world moves towards electric mobility, it is anticipated that the movement from carbon-based fuel motorcycles towards electric motorcycles (EMs) will follow suite. There are millions of motorcycles in East Africa, with between 20 000 and 30 000 in Kigali, Rwanda [3]–[5]. This makes countries like Rwanda a good basis for information to use in case studies regarding the impacts of EMs.

Ampersand, an EM company, with a mission to "build affordable electric vehicles and charging systems for the three million motorcycle taxi drivers in East Africa, starting with Rwanda." plans to extend to Uganda and Kenya in the near future [6], [7]. In May 2019, Ampersand launched their pilot programme with 20 EMs to test its battery swap out system [8]. The system makes use of three battery swap out stations where users exchange their fully or partially depleted battery for a full one and only pay for the battery capacity consumed [4], [8]. In August 2019, Paul Kagame, president of Rwanda, announced the movement of the entire country towards EMs stating "We will find a way to replace the ones (motorcycles) you have now" and implored current motorcycle operators to help with the "phase-out process" [3], [4]. Since then, the waiting list of users for the Ampersand EM grew from 1 300 to 7 000 [7]. Ampersand is planning to build 500 more EMs in 2020, however the government wants them to build 5 000 more [7], [9].

Following this, Safi Motors - a local EM company in Rwanda - launched in late October 2019 [10]. Safi Ltd does not make use of a battery swap out system, and were the first company to install EM charging stations in Rwanda [11]. To reduce the downtime due to charging and to accommodate different financial positions, charging works similarly to filling up with fuel, where one can charge depending on how much time or money one has available [10]. The first phase of the launch introduced 60 EMs and three charging stations located next to fuel stations, allowing a total of six EMs to charge at a given moment [12].

A variety of impact assessment studies have been done focusing on the impacts that EV charging and discharging has on the grid [13]–[16]. A study has also been done looking at the economic and environmental effects of each section of the EM life cycle, from manufacture, operation, to end of life [17]. However, the technical impacts of EMs on the distribution network have not been explored. This is likely due to the fact that EM loads may be considered smaller than EV loads and the possible negative effects deemed insignificant. With little research done to assess the technical impacts of EMs, it may not be sufficient to simply assume that the effects of EM charging are negligible. This paper explores whether, with high uptakes of EMs, the effects of these loads may be significant when superimposed onto residential consumption loads, especially during periods of mass simultaneous charging.

The aim of the paper is to investigate the technical impacts of EM charging on LV residential feeders. The paper proposes a stochastic-probabilistic approach that is implemented to address the diversity in customer loads and EM loads, and the uncertainty in EM allocation. The approach makes it possible to analyse an extensive set of EM penetration scenarios: varied scenarios of EM location and size, and varied penetration limits per household. The performance of the studied networks, and the respective hosting capacity are determined based on the conditions of four technical variables: voltage-deviation, unbalance, thermal loading of conductors, and transformer loading.

The next section describes the simulation methodology while the case study simulation inputs, considerations, method and parameters of interest are discussed in section III. The simulation results are reviewed in section IV. This is followed by a sensitivity analysis of the simulation inputs in section V. The paper then concludes.

II. SIMULATION METHODOLOGY

A stochastic-probabilistic approach, as explained in [18] lists considerations for the inputs required to conduct impact assessments of dispersed energy storage systems (ESS) - in this case EMs - on distribution networks. The following considerations for the inputs and simulation method were noted:

- the uncertainty and variability in the residential and ESS loads need to be accounted for.
- informed, accurate and appropriate modelling of the network, residential load and dispersed ESS load model applied.
- the uncertainty in the size and randomness in location of the dispersed ESSs needs to be addressed.
- an appropriate penetration percentage definition should be used.

The stochastic-probabilistic approach consists of two components, which are now discussed in detail.

A. *Simulation of EM placement*

A stochastic approach accounts for randomness. In the case of dispersed ESSs, the unknown and random location of these devices along a feeder is due to the unpredictability of which residents will adopt ESSs. Instead of assigning ESSs to residents in a specific pattern or even a worst-case scenario method, an approach that aptly mimicked the randomness of ESS uptake is used.

At a selected penetration rate, the corresponding number of EMs is allocated randomly to phase and node using a Monte-Carlo simulation (MCS). This is done repeatedly, with replacement, and within the permissible uptake limit per household set in the simulation, until all EMs are allocated. The MCS random selection is based on a uniform distribution, resembling equal EM uptake potential between customers. In this paper, 1,000 MCS scenarios of EM allocation are performed at each penetration level. For each scenario, the corresponding feeder performance is determined using the Herman-Beta extended (HBE) probabilistic transform.

B. *Calculation of the load flow using the HBE*

This paper proposes using a probabilistic load flow (PLF) approach above a deterministic one. A deterministic approach cannot explicitly represent the variability in the loads and generation and therefore input uncertainty is not factored in the results [19]–[21]. The HBE transform is an analytical PLF approach that allows the loads and generation to be modelled using beta probability density functions (PDFs) to account for the associated uncertainty [22]. The HBE method is built on the current prescribed method for the design of LV feeders in South Africa [23]. Using this approach, feeder performance in terms of voltage-deviation, unbalance, and thermal loading can be easily assessed factoring in design risk.

This stochastic-probabilistic analysis approach was therefore deemed more appropriate as both the variability and uncertainty in loads, and the randomness in the location of EM loads are addressed. A schematic of the overall simulation program flow is shown in Fig. 1.

A more detailed look at the inputs, considerations, method and parameters of interest is found the following section.

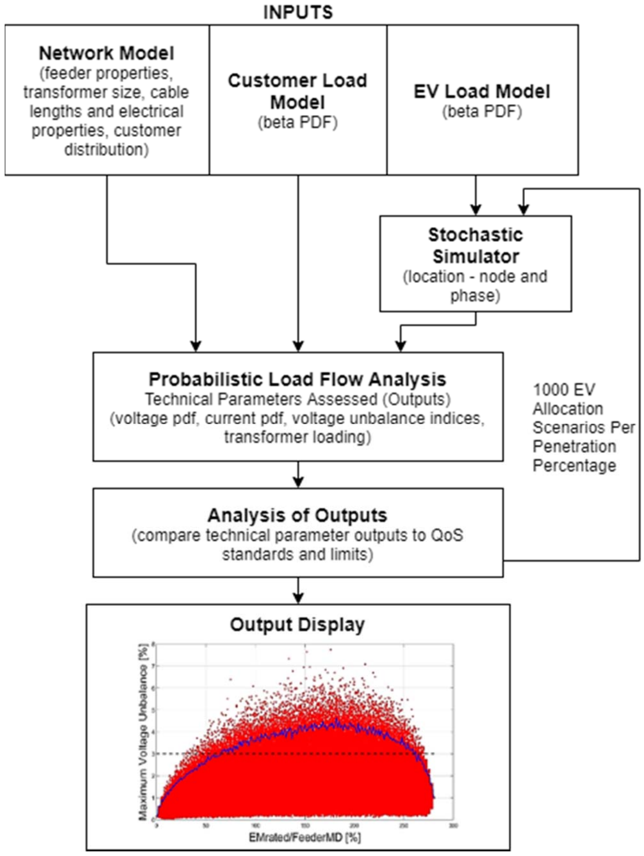

Figure 1: Overall Simulation Program Flow

III. CASE STUDY

The MCS-HBE approach is now used to investigate the impacts of addition loads due to EM charging on residential feeders. The simulation is focussed on quantifying the impacts and the maximum capacity of EMs that can be hosted on existing feeders. Therefore, the interval of interest is one in which the feeders are most loaded leaving little headroom for additional loads. The coincidence of EM charging with high feeder load is anticipated to be the determining factor to the hosting capacity (HC) of a feeder. For LV feeders, the peak load is usually experienced during winter evenings where there is a high coincidence of heating elements. For this reason, the influence of distributed generation on HC is not included. The characteristics of the conducted simulations are described below.

A. *Simulation Inputs*

1) *Network Model*

The initial business model of companies like Ampersand and Safi Motors appears to be based on battery exchange schemes and/or central charging stations. As countries like Rwanda progresses towards a fully electric motorcycle sector the assumption is made that the primary EM charging method will move towards charging at a residential level, as seen in the EV sector [24], [25].

Although the need and relevance of such studies is motivated by countries like Rwanda, a more generalised case study in which a practical LV residential topology typically used in low-income, medium density urban areas in South Africa is modelled in the simulation. A single branch three-phase four-wire, 10 node network, 30 m apart with a 150 kVA

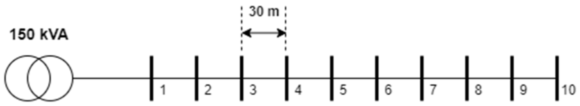

Figure 2: Simulation Network Model

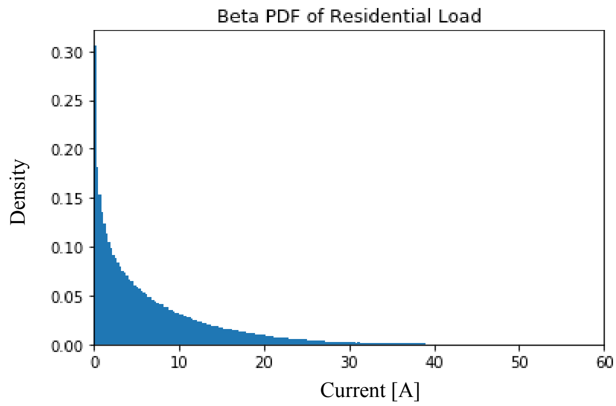

Figure 3: Beta PDF - Residential Load Model

transformer supplying 50 customers was modelled and is shown in Fig. 2 above. The conductor lines were modelled as having the following electrical properties; a resistance value of 0.282 Ω/km and an X/R ratio of 0.3034.

2) Residential Load Model

For the case study, the impacts of EM charging on South African networks are tested. In South Africa domestic consumers are groups according to their living standards. This allows for customers in a specific area to be grouped according to an expected residential load. The residential load modelled was that of a class 4 (township area) consumer [26]. For the simulation, the load was modelled probabilistically using a beta PDF shown in Fig. 3. The load parameters used relates to a recently electrified area (electrified for about 7 years) having an after diversity maximum demand (ADMD) of 1.56 kVA and shape parameters alpha = 0.692, beta = 5.437 and a scaling factor C = 60 amps. This load model is based on 5-minute readings of load currents during the interval of maximum demand, on a winter, week-day evening.

3) Electric Motorcycle Model

The following assumptions and simplifications were made regarding the exact EM charging and battery specifications. The Super SOCO TC-Max was chosen as representative of the EM to be modelled for this simulation [27]–[29] since its non-electric motorcycle equivalent is a typical 125 cc motorcycle similar to the ones in widespread use in Rwanda [29]. The driving range is about 97 km and charge rate 3.5 kW, fully charging in 4.5 hours [28], [29]. The EM load was modelled as a current using a beta PDF, with a residential voltage level of 230 V [30] resulting in a current of 15.22 A. The alpha and beta parameters affect the shape and skewness of the beta PDF. For the simulation, the alpha and beta values were set equal and high to model the load symmetrically about a specific value (3.5 kW) and with little diversity.

B. Simulation Considerations

1) Placement Strategy

With a fully electric motorcycle sector it is assumed that this could become the primary mode of transport in densely populated areas and is likely that each household will at least own one EM.

The placement of EMs in the residential network chosen for the simulation was allocated at random, with a maximum of two EMs per household.

2) Penetration Percentage Definition

The penetration percentage definition used in this paper is based on a measure of the loadability of the feeder, which is dictated by its electrical characteristics and configuration. The maximum load the feeder can handle without violating quality of supply limits, termed the feeder maximum demand (FMD), is used as an indicator of the feeder's loadability.

Expressed in mathematical form, the electric motorcycle penetration percentage (EM PP) definition is as follows:

$$EM\ PP = \frac{Cumalative\ Power\ of\ EMs\ Allocated\ [kW]}{Feeder\ Maximum\ Demand\ [kW]} \times 100\% \qquad (1)$$

C. Parameters of Interest

1) Voltage level

In South Africa the Nersa 048 standards state that the residential supply voltage level should be 230 V ± 10% [31]. It is anticipated that mass simultaneous charging of EMs will cause the voltage along a residential feeder to drop as seen with EVs in [13], [32]. The lower limit of the supply standard is therefore a parameter of interest. The upper limit of the voltage level may also be of interest due to the effect that unbalance may have on the voltage level as shown in [18].

2) Voltage Unbalance

Voltage unbalance, due to the random single-phase placements and therefore possible unbalance of loads across the three phases, is expected. According to the South African supply standards, voltage unbalance should not exceed 3% [31].

The following equation based on the quantile values was implemented to calculate the voltage unbalance:

$$UB = \frac{Max.Deviation\ of\ Phase\ Voltages\ from\ Average}{Average\ Voltage} \times 100\% \qquad (2)$$

3) Cable and Transformer loading

It is not likely that these newly introduced loads from EM charging was a consideration during the initial low voltage distribution network planning. It is hypothesized that existing loads augmented with mass simultaneous charging of EMs would overload the transformer. The maximum cable and transformer loading were therefore parameters of interest that were recorded during the simulation.

D. Simulation Method

The simulation procedure can be broken down into the following five steps.

I. Determine the FMD by loading winter loads and linearly incrementing the load until the first occurrence of QoS violation.

II. Reset the load to winter loads, and add EMs randomly using the MCS guided by the penetration level under analysis and the limits per household.

III. Perform the HBE and record the worst-condition of each technical variable based on 2.5% risk.

IV. Repeat II and III for 1,000 scenarios

V. Increment the penetration level and repeat processes II-IV until every node has maximum penetration.

IV. RESULTS

For each penetration percentage, 1 000 different placement scenarios were analysed and the minimum voltage, maximum unbalance, maximum transformer loading and maximum conductor current along the feeder for each scenario was recorded. The simulation was run until an EM penetration percentage of about 281% was reached. This penetration percentage related to each household along the feeder having the maximum (in this simulation it was restricted to two) number of EMs assigned to it.

Fig. 4 shows the minimum feeder voltage. The blue line indicates a risk margin included in the representation of the results. At each penetration percentage there is a 95% chance that the minimum voltage along the feeder will lie above the blue line. Therefore, when including risk in the interpretation of the results and allowing a 5% chance of violating the lower limit of the supply voltage level, the feeder can handle a penetration percentage of 111%.

Violations to the lower limit of the voltage quality of supply standards start at about 56% if no risk factor is allowed for. There were no violations to the upper limit of the voltage level and the graph is not shown.

In Fig. 5 initial violations to the allowable voltage unbalance percentage is recorded at penetration percentages as low as 31%. When taking risk into account, the feeder could handle penetration percentages up to 66%. The bell shape indicates how unbalance initially increases as random unbalanced allocation occurs. The unbalance eventually decreases as the number of EMs assigned increases, reducing the level of diversity in EM loads between customers. At the extreme end of the penetration range, every customer has the same number of EMs hence the initial conditions of unbalance (without EMs) are retained.

When looking at Fig. 6 the transformer is overloaded at about 26%. Fig. 7 shows that the cables exceed its maximum current carrying capacity at 24% without risk and 31% with a 5% risk of exceeding the current carrying capacity. The 5% risk is comprised of a 2.5% that is incorporated in the PLF analysis mentioned in the Simulation Method section and an additional 2.5% in the analysis of the stochastic results.

The results show that the feeder is thermally constrained and the limiting factor for the penetration of EMs that this feeder can handle is the cable loading followed by the transformer loading.

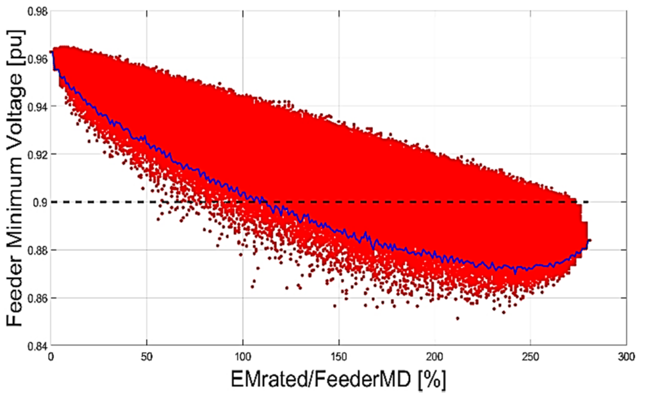

Figure 4: Lowest voltages along feeder with increasing penetration of EMs

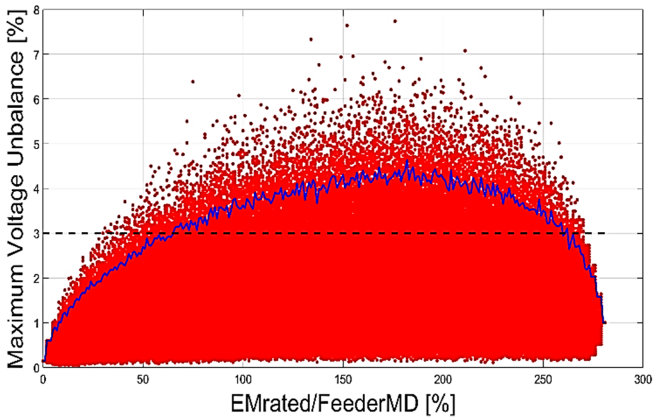

Figure 5: Highest voltage unbalance along feeder with increasing penetration of EMs

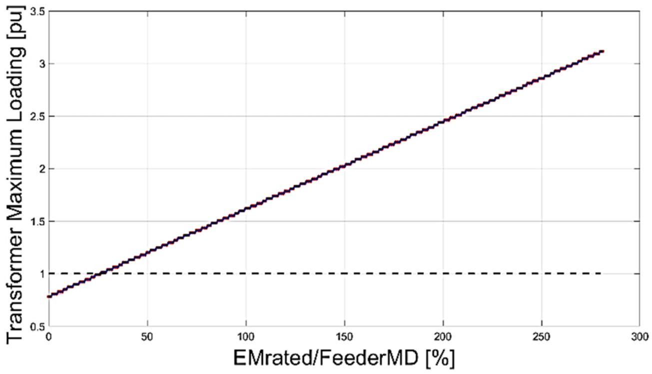

Figure 6: Highest transformer loading along feeder with increasing penetration of EMs

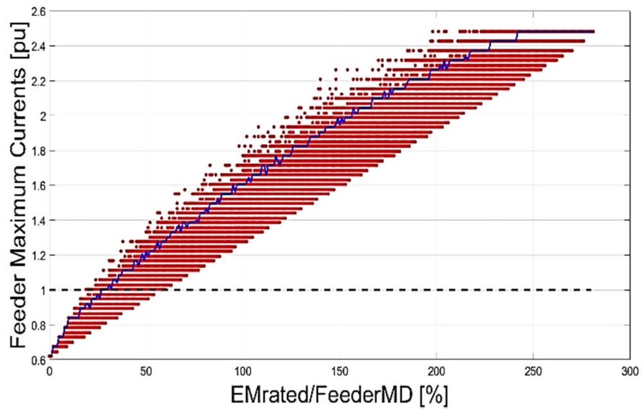

Figure 7: Highest conductor currents along feeder with increasing penetration of EMs

V. SENSITIVITY ANALYSIS

In reality many variations of networks - in which residents may be closer together or further apart, load models differ, and transformers may be more or less loaded - exist. Because of many assumptions regarding the simulation inputs a sensitivity analysis becomes useful when interpreting the results.

The following section will have a look at the sensitivity of the results to the following four variables; feeder properties, transformer size, EM load size and lastly the residential load model used. These were the simulation inputs that did not have data readily available and assumptions needed to be made.

A. Feeder Properties

Feeder properties refer to several characteristics including the network topology, distances between customer nodes and cable properties. For this analysis, the effect of the distance between the customer nodes was tested. For the base case-study the customer nodes were 30 m apart and violations occurred as shown in the first (grey) row of Table 1. The distance between the customer nodes was then adjusted to 45 m. The results are shown in the second row of the table.

When the distance between the nodes was increased, the factor limiting the uptake of EMs changed from transformer loading to voltage unbalance. Although when including risk, the limiting factor was still the transformer loading and the allowable penetration percentage did not decrease, the effect of the feeder property tested was significant. This is highlighted by the fact that when the distance between nodes increased from 30 m to 45 m, the percentage at which the minimum voltage level is violated drops from 111% to 34% and the percentage at which voltage unbalance exceeds the allowed value drops from 66% to 28%.

B. EM Load Model

The EMs were initially modelled as 3.5 kW loads when charging. To account for the uncertainty in the EM load model, the network was also tested with EMs modelled as both 2.1 kW and 4 kW loads, and the results compared to that of the initial (grey row in the table) 3.5 kW loads. Table 2 shows that when the EM load size is reduced to 2.1 kW, when including risk there are no violations to the minimum voltage level or voltage unbalance even when each customer is assigned the maximum number of EMs allowed in the simulation. It is also noticed that when the load size is increased, the penetration percentage at which violations occur decreases.

TABLE 1. HC SENSITIVITY TO FEEDER PROPERTIES

d (m)	Hosting Capacity based on Technical Variable							
	Voltage		***Unbalance***		***Trfmr Loading***		***Conductor Loading***	
	Excl. risk	*5% risk*	*Excl. risk*	*5% risk*	*Excl. risk*	*5% risk*	*Excl. risk*	*5% risk*
30	56	111	56	66	56	26	56	31
45	20	34	20	28	20	26	20	31

TABLE 2. HC SENSITIVITY TO EM LOAD MODEL

EM Load [kW]	Hosting Capacity based on Technical Variable						
	Voltage		***Unbalance***		***Trfmr Loading***	***Conductor Loading***	
	Excl. risk	*5% risk*	*Excl. risk*	*5% risk*		*Excl. risk*	*5% risk*
2.1	116	none	62	none	26	27	33
3.5	56	111	31	66	26	24	31
4	55	99	28	60	26	23	28

TABLE 3. HC SENSITIVITY TO RESIDENTIAL LOAD MODEL

Load Class	Hosting Capacity based on Technical Variable						
	Voltage		***Unbalance***		***Trfrmr Loading***	***Conductor Loading***	
	Excl. risk	*5% risk*	*Excl. risk*	*5% risk*		*Excl. risk*	*5% risk*
4	56	111	31	66	26	24	31
3	116	160	48	72	67	49	57

C. Transformer Size

The transformer used for the initial simulation was sized to operate at around 80% of its peak capacity under passive conditions (no dispersed ESS). As shown in the results section, this transformer became overloaded at an EM penetration percentage of 26%. If the transformer was sized to operate at 90% of its peak capacity under passive conditions, it would become overloaded at an EM penetration percentage of 11%. Increasing the size of the transformer would be effective at alleviating the transformer overloading problem. However, before significantly increasing the transformer size it is advised to look at the next most pressing issue limiting uptake so that the transformer is not unnecessarily oversized.

D. Load Model

The residential load model needs to be characterized by the consumer class behaviour. When the load used for the simulation was changed from class 4 (township area) to class 3 (informal settlement), the residential load beta PDF was given the following parameters: alpha = 0.248, beta = 1.008 and scaling factor C = 20. The ADMD of the load was then 0.91 kVA. Table 3 shows the results, the grey row showing the results of the initial simulation and the white row the results of the adjusted load. With the adjusted load model, the penetration percentage at which violations to minimum voltage, unbalance and cable loading occurred all increased.

When interpreting the results including risk the minimum voltage level drops below the allowed value at 160% while the voltage unbalance exceeds the supply standards at a penetration percentage of 72%. The cables become overloaded at a penetration percentage of about 57% and the transformer around 67%. With this smaller residential load, the cable overloading became the factor limiting the uptake of EMs.

VI. CONCLUSIONS

It is evident that even with the assumptions and simplifications made in the case study due to a lack of available information, EM charging will affect low voltage distribution networks especially if the uptake of EMs is significant and charging takes place at a residential level.

The simulation shows that the primary factor limiting the uptake of EMs is the transformer loading. A solution to this may be to increase the transformer size, while a second and cheaper way may be to control or disincentivize the charging of EMs during the peak demand period.

The voltage drop along the feeder length caused by mass simultaneous charging appears to be the least problematic issue. Violations occur at relatively high penetration percentages without allowing risk and over 100% when allowing a 5% risk margin and chance of violating the limit.

The simulation highlights some risks that policy makers and network planners need to at least be aware of, especially when embracing technology before its effect on the network is fully understood.

The sensitivity analysis calls attention to the importance of accurately modelling the simulation inputs as the effect of these inputs significantly affects the simulation results. Because these results inform policy makers and network planners, it is suggested that further research – ideally with more accurate data, network and load models if available - be done to see the full extent of the issues shown in this sample network simulation.

REFERENCES

[1] T. Klein, 'The Race to Transport Electrification: National Electric Vehicle Policies around the World', vol. 1072, no. June, 2019.

[2] 'Global EV Outlook 2019', Paris, France, 2019.

[3] 'E-motorbikes launched in Rwanda', Business Ghana, 2019. [Online]. Available: https://www.businessghana.com/site/news/technology/197745/E-motorbikes-launched-in-Rwanda. [Accessed: 08-Feb-2020].

[4] J. Bright, 'Rwanda to phase out gas motorcycle taxis for e-motos', Tech Crunch, 2019. [Online]. Available: https://techcrunch.com/2019/08/28/rwanda-to-phase-out-gas-motorcycle-taxis-for-e-motos/https://techcrunch.com/2019/08/28/rwanda-to-phase-out-gas-motorcycle-taxis-for-e-motos/. [Accessed: 08-Feb-2020].

[5] 'Motorcycles set to become main mode of transport in Africa', The East African, 26-Sep-2016.

[6] 'Advertisement', Ampersand. [Online]. Available: https://ampersand.solar/. [Accessed: 08-Feb-2020].

[7] A. Peters, 'This electric motorcycle startup is transforming the Rwandan taxi industry', Fast Company, 2020. [Online]. Available: https://www.fastcompany.com/90460273/this-electric-motorcycle-startup-is-transforming-the-rwandan-taxi-industry. [Accessed: 08-Feb-2020].

[8] Yanditswe, 'More electric motorcycles to hit Kigali streets, local manufacturers Ampersand announces', Rwanda Broadcasting Agency, 2019. [Online]. Available: https://www.rba.co.rw/post/More-electric-motorcycles-to-hit-Kigali-streets-local-manufacturers-Ampersand-announces. [Accessed: 08-Feb-2020].

[9] R. Elmendorpon, 'Rwanda government pushes electric cars, bikes', How We Made it in Africa, 2019. [Online]. Available: https://www.howwemadeitinafrica.com/rwanda-government-pushes-electric-cars-bikes/63853/. [Accessed: 08-Feb-2020].

[10] J. de la Croix Tabaro, 'New Electric Motorcycle Hits Rwandan Roads Next Month', KT Press, 08-Oct-2019.

[11] E. Hakizimana, 'Rwanda unveils EV charging station for electric motorcycles', The Inspirer, Oct-2019.

[12] H. Mugemana, 'Uncertainties about e-motorcycles untangled', The New Times, 2019. [Online]. Available: https://www.newtimes.co.rw/news/uncertainties-about-e-motorcycles-untangled. [Accessed: 19-Feb-2019].

[13] C. H. Tie, C. K. Gan, and K. A. Ibrahim, 'Probabilistic Impact Assessment of Electric Vehicle Charging on Malaysia Low-Voltage Distribution Networks', Indian J. Sci. Technol., vol. 8, no. 3, p. 199, Feb. 2015.

[14] A. Temiz and A. N. Guven, 'Assessment of impacts of Electric Vehicles on LV distribution networks in Turkey', in 2016 IEEE International Energy Conference, ENERGYCON 2016, 2016, pp. 1–6.

[15] J. Quirós-Tortós, L. F. Ochoa, A. Navarro-Espinosa, M. Gillie, and R. Hartshorn, 'Probabilistic Impact Assessment of Electric Vehicle Charging on Residential UK LV Networks', in 23rd International Conference on Electricity Distribution, 2015, pp. 15–18.

[16] A. Maitra, P. Richardson, A. Keane, J. Taylor, and M. Moran, 'Impact of electric vehicle charging on residential distribution networks: An Irish demonstration initiative', in 22nd International Conference on Electricity Distribution, no. 0674, pp. 1–4.

[17] C. R. Cherry, J. X. Weinert, and Y. Xinmiao, 'Comparative environmental impacts of electric bikes in China', Transp. Res. Part D Transp. Environ., vol. 14, no. 5, pp. 281–290, 2009.

[18] C. T. Gaunt, E. Namanya, and R. Herman, 'Voltage modelling of LV feeders with dispersed generation: Limits of penetration of randomly connected photovoltaic generation', Electr. Power Syst. Res., vol. 143, pp. 1–6, 2017.

[19] P. Chen, Z. Chen, and B. Bak-Jensen, 'Probabilistic load flow: A review', 3rd Int. Conf. Deregul. Restruct. Power Technol. DRPT 2008, no. July 2014, pp. 1586–1591, 2008.

[20] C. Su, 'Probabilistic Load-Flow Computation Using Point Estimate Method', vol. 20, no. 4, pp. 1843–1851, 2005.

[21] R. N. Allan, B. Borkowska, and C. H. Grigg, 'Probabilistic analysis of power flows', Proc. Inst. Electr. Eng., vol. 121, no. 12, p. 1551.

[22] M. J. Chihota and C. T. Gaunt, 'Transform for Probabilistic Voltage Computation on Distribution Feeders with Distributed Generation', in Power Systems Computation Conference (PSCC), 2018, pp. 1–7.

[23] NRS, 'NRS 034-1:2007 Electricity distribution — Guidelines for the provision of electricity distribution networks in residential areas Part 1 : Planning and design of distribution networks', 1999.

[24] N. Muzi, 'Only 5 percent of EV charging happens at public charging points', Transport & Environment, 2018. [Online]. Available: https://www.transportenvironment.org/press/only-5-percent-ev-charging-happens-public-charging-points. [Accessed: 20-Oct-2019].

[25] 'Charging at Home', Office of Energy Efficiency and Renewable Energy. [Online]. Available: https://www.energy.gov/eere/electricvehicles/charging-home. [Accessed: 20-Oct-2019].

[26] SABS, 'NRS 034-1 Electricity distribution - Guidelines for the provision of electricity distribution networks in residential areas Part 1: Planning and design of distribution networks'. National Standards South Africa, South Africa, 2007.

[27] 'Zero SR/F Technical Specifications', Zero Motorcycles. [Online]. Available: https://www.zeromotorcycles.com/zero-srf/. [Accessed: 17-Feb-2020].

[28] 'Harley Davidson LiveWire Detailed Specs', Harley Davidson. [Online]. Available: https://www.harley-davidson.com/us/en/motorcycles/livewire.html. [Accessed: 17-Feb-2020].

[29] A. Strange, 'Super SOCO TC Max Review', lexhaminsurance, 2019. [Online]. Available: https://www.lexhaminsurance.co.uk/blog/super-soco-tc-max-review/. [Accessed: 23-Feb-2020].

[30] O. Box, 'Governing Electricity Quality of Service in Rwanda', pp. 1–35, 2016.

[31] NERSA, ELECTRICITY SUPPLY — QUALITY OF SUPPLY Part 2 : Voltage characteristics , compatibility levels , limits and assessment methods. 2003.

[32] A. Bosovic, M. Music, and S. Sadovic, 'Analysis of the Impacts of Plug-in Electric Vehicle Charging on the Part of a Real Low Voltage Distribution Network', 2015 IEEE Eindhoven PowerTech, PowerTech 2015, pp. 3–7, 2015.