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Ebeneza Chaula
*Department of Electrical Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania*, ebenezachaula27@gmail.com

Ibrahim Mwammenywa
*Department of Electrical Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania*, a.m.ibra90@gmail.com

Santos Kihwele
*Department of Electrical Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania*, kihwele2002@yahoo.com

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*Regular Research Manuscript*

# Voltage Profile Enhancement in Iliceto Shield Wire Scheme for Rural Electrification: Case of Chalinze - Mbwewe Transmission Line in Tanzania

**Ebeneza Chaula, Ibrahim Mwammenywa† and Santos Kihwele**

Department of Electrical Engineering, University of Dar es Salaam, Dar es Salaam, Tanzania
†Corresponding Author: ibrahim.mwammenywa@udsm.ac.tz; ORCID: https://orcid.org/0000-0003-2735-643X

## ABSTRACT

*Rural electrification faces challenges due to significant voltage drops over long transmission distances, affecting reliability and power quality. While the Iliceto Shield Wire Scheme (ISWS) offers a modern, cost-effective solution, voltage stability remains a challenge. This study analyses voltage profile enhancement within ISWS, focusing on the Chalinze-Mbwewe section of the 132 kV transmission line, using LTSpice simulations. Due to LTSpice limitations, direct solar PV integration was mimicked by introducing a secondary voltage source at each load centre, producing 33 kV to match the original source voltage. This approach maintained an improved voltage profile from Msoga Village to Mbwewe over 80.9 Kilometers. Simulation results with the existing 50 mm² indicate that before solar PV integration, voltage drops averaged 17.8%, exceeding acceptable limits. Even after PV integration at all six village load centres, voltage drops remained above the ±5% threshold (ranging from ~7% to 19%), highlighting that PV alone cannot fully resolve voltage stability when using undersized conductors. In contrast, upgrading to a 100 mm² conductor combined with solar PV integration reduced voltage drops to within 5%, thereby meeting regulatory standards and improving system stability.*

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## HIGHLIGHTS:

- Investigated voltage profile improvement in the Iliceto Shield Wire Scheme.
- Simulated distributed solar PV support along the Chalinze–Mbwewe corridor.
- Solar PV integration reduced excessive voltage drops to acceptable levels.
- Conductor upgrading enhanced voltage regulation and network efficiency.
- Findings support sustainable and reliable rural electrification in Tanzania.

## INTRODUCTION

### Background

Access to affordable and reliable electricity is crucial for social and economic development. Globally, electricity is considered a fundamental necessity, enabling both domestic and industrial activities. It plays a vital role in modernizing rural communities, facilitating agriculture, business growth, healthcare improvements, and access to education. Studies confirm that electrification enhances productivity and income generation, enabling communities to access markets and financial services and ultimately reducing poverty. Furthermore, reliable electricity fosters educational advancements through digital learning and internet connectivity, narrowing the gap between urban and rural education (Tonini et al., 2022).

Despite progress in energy access, rural electrification remains a major global challenge. The International Energy Agency (IEA) reports that, although substantial strides have been made, as of 2023, around 750 million people, 10% of the global population, still lack electricity access, with over 80% residing in developing regions, particularly Sub-Saharan Africa and parts of Asia. Rural electrification is widely regarded as a key step toward poverty reduction and modernization, helping nations achieve economic resilience and sustainable development. (IEA, 2025).

Tanzania has made significant progress in expanding electricity access over the last decade. As of 2024, the country's total grid-installed capacity has reached 3,404.20 MW, with the following composition: 62.1% hydropower (primarily from the Julius Nyerere Hydropower Project), 35.1% natural gas, 2.5% fuel, and 0.3% biomass (World Bank, 2025). Electricity access has increased from 14.5% in 2013 to 48.9% in 2024, marking one of the fastest expansion rates in Sub-Saharan Africa (MacroTrends, 2024). Despite this, rural electrification remains a challenge. According to the Rural Energy Agency (REA) report (April 2024), 79.6% of urban areas

and 38.2% of rural areas are electrified, highlighting a gap in infrastructure and affordability constraints (REA, 2024).

Currently, several methods have been used globally to expand electricity access in rural areas. The key approaches include Single Wire Earth Return (Irechukwu & Mushi, 2021), Decentralized Microgrids (Mwakijale et al., 2023), Hybrid Systems (Seiyefa Aondo Vincent et al., 2024) and the innovative Iliceto Shield Wire Scheme (ISWS) (Acri et al., 2022).

**Iliceto Shield Wire Scheme**

ISWS, first proposed by Professor Francesco Iliceto in 1982, is a cost-effective modern approach to rural electrification. It repurposes shield wires on high-voltage (HV) transmission lines by insulating and energizing them at medium voltage (MV), typically 20 kV to 34.5 kV, from a nearby HV/MV station (Iliceto, 2016). Distribution transformers connect the shield wire to the ground, supplying electricity to rural communities as shown in Figure 1. This method significantly reduces infrastructure costs compared to conventional MV electrification, making it an effective solution for remote areas. ISWS has been successfully implemented in multiple countries, including Ghana, Brazil, Laos, Sierra Leone, Togo, Burkina Faso, and Ethiopia, demonstrating its ability to expand electricity access efficiently (Chaves & Tavares, 2018).

The ISWS method enables low-cost electricity supply to homes and industries near HV by utilizing shield wires, metal conductors that typically protect HV lines from lightning strikes, allowing power delivery to communities along the HV line without the need for new transformer stations or MV distribution infrastructure. This method significantly reduces electrification costs, with studies showing that ISWS can save up to 80% compared to conventional MV electrification while maintaining power quality standards (Falvo et al., 2019).

One example is the 132 kV Chalinze-Hale-Tanga transmission line as shown in Figure 2, in eastern Tanzania, which spans 235 km, connecting Chalinze and Tanga substations. Despite passing through 16 villages, many remain unelectrified, leaving around 81,402 residents with less than 10% electricity access. The line has two sections: Chalinze to Hale, transmitting 102.88 MW, and Hale to Tanga, transmitting 51.44 MW, both at a 0.9 power factor. Extending three-phase MV lines to these villages is economically unfeasible due to low demand and long distances. A study in Mpaji village found that ISWS leads to a 10.89% voltage drop but reduces investment costs by 49.4% compared to conventional MV electrification (Munisi & Kihwele, 2021).

Like conventional MV distribution systems, ISWS experiences voltage drop challenges over long distances, affecting reliability and power quality. Various voltage enhancement solutions have been studied, including tap setting adjustment, increasing transformer size, and using larger conductors, where implementation costs remain a barrier (Croce & Level, 2013). Studies on Guinness and Ikpoba Dam substations recommend service cables not exceeding 400 meters to maintain voltage stability (Okundamiya et al., 2009). Similarly, voltage regulation in Ghazni city showed drops exceeding IEC60204-1 limits, affecting power quality, with tap changer transformers proposed for improving voltage profiles in both ISWS and conventional MV networks (Mohammad Sarwari et al., 2022).

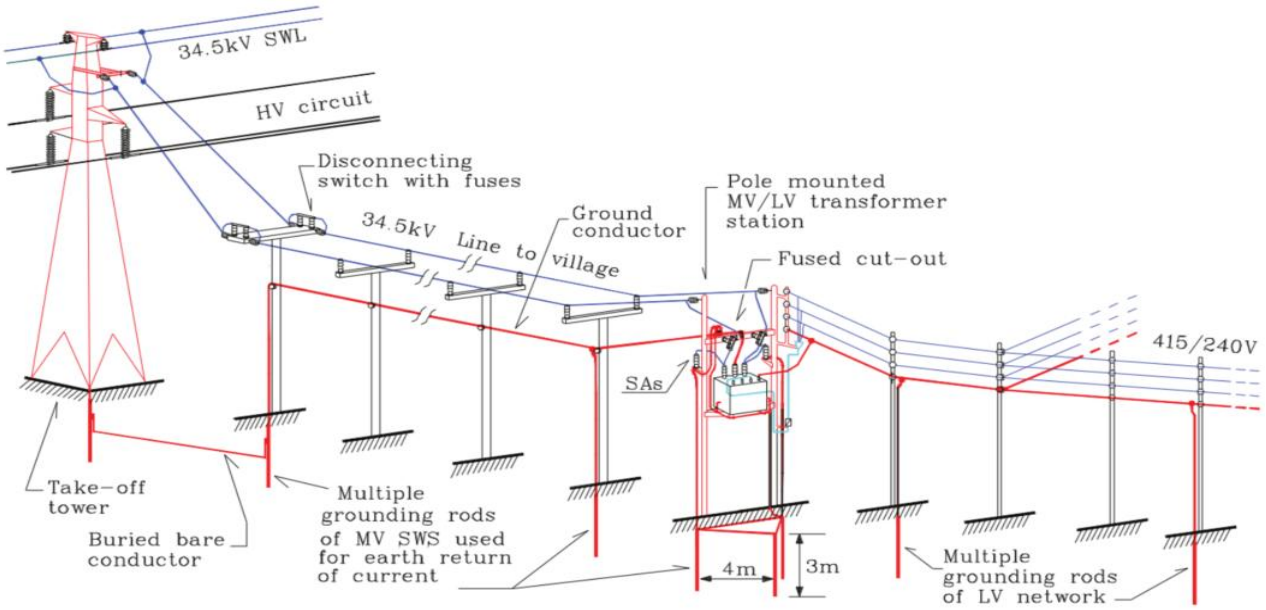


**Figure 1: The typical three-phase ISWS distribution network in a village (Iliceto, 2016).**

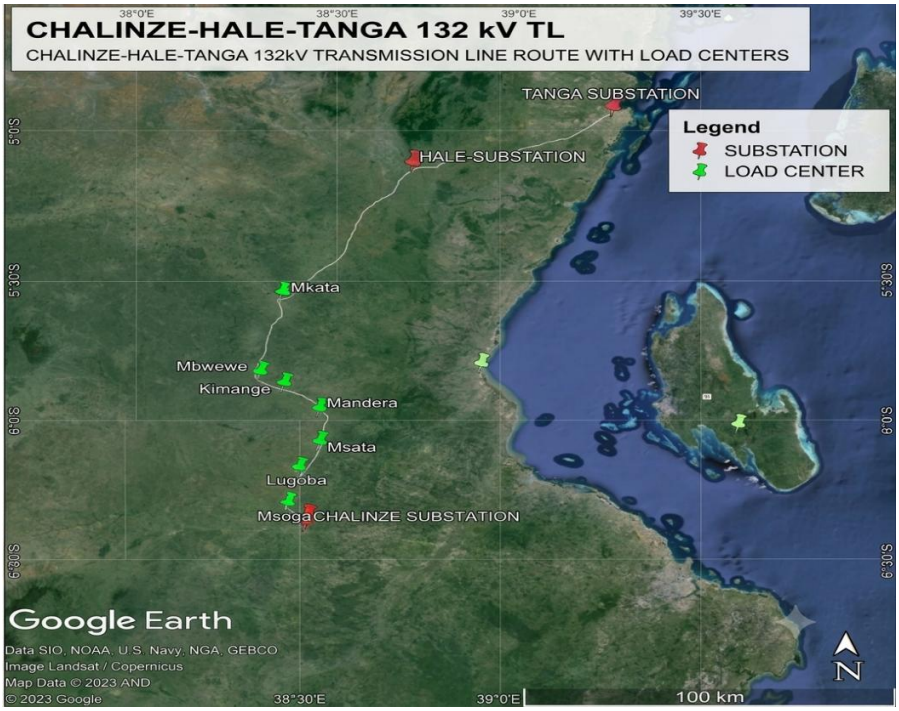


**Figure 2: Chalinze Hale Tanga Transmission line.**

Studies indicate that solar PV microgrids help stabilize voltage by providing localized power generation, reducing reliance on long-distance transmission (Nasir et al., 2020). Research on solar PV with battery storage highlights its role in regulating voltage fluctuations and improving reliability in rural distribution networks (Masenge & Mwasilu, 2020). Simulation-based studies further support decentralized solar integration for voltage stability (Narad & Khan, 2019). Hybrid solar PV-grid networks minimize transmission losses, enhancing voltage regulation (Uswarman et al., 2024). Given the voltage drop challenges in ISWS, integrating solar PV with existing ISWS infrastructure offers a viable solution for stable rural electrification. This paper models ISWS with solar PV integration for the Chalinze-Mbwewe section of the 132 kV transmission line using the LTSpice simulator to analyze voltage profile improvements before and after solar PV integration, also examining the impact of upgrading the 50 mm² conductor.

## RELATED WORKS

Several studies have examined voltage profile enhancement in HV/MV transmission networks through solar PV integration. Mouheb et al., (2012) demonstrated that solar PV compensation improves voltage drop in LV networks, enhancing stability and providing clean energy to rural communities. Mouheb et al., (2020) investigated solar integration for voltage correction in Algeria, showing that MV-connected PV systems regulate voltage effectively, while LV-connected mini-power plants offer localized stability.

Farkas et al., (2019) found that PV inverters actively support voltage stability by injecting reactive power in HV networks. Similarly, Singh (2019) showed that coordinated inverter control enhances voltage profiles in active distribution networks.

Kadi et al., (2021) explored PV-STATCOM technology, proving its effectiveness in mitigating voltage fluctuations in HV grids. Alghamdi and Alamri, (2015) highlighted that large-scale PV integration improves voltage regulation in transmission systems.

Together, these studies confirm that solar PV integration, combined with ISWS, is a viable approach for voltage profile enhancement, ensuring stable rural electrification and improved energy reliability. However, none of the prior work has jointly evaluated the ISWS with both distributed solar PV integration and conductor sizing optimization for the Chalinze–Mbwewe corridor in Tanzania. This gap is critical because ISWS alone cannot fully resolve voltage drops over long rural transmission distances, and PV integration effectiveness depends strongly on conductor size. By explicitly combining ISWS with distributed solar PV integration and conductor optimization, this paper provides new evidence for sustainable rural electrification strategies in Tanzania and offers insights applicable to similar contexts.

## MODELING AND SIMULATION

### Data Collection and Existing Solution

Data was gathered by surveying and observing the villages, as well as by conducting oral interviews with the rural households in the villages of Chalinze. The active and reactive power of each load centre was obtained from Tanzania Electric Supply Company (TANESCO), as shown in Table 1.

Equation 1 defines the per-unit voltage drop, calculated from the sending point to the tail end of the Chalinze Mbwewe section. Now, the differential equation form of Equation 1 is represented by Equation 2, and the resulting Euler equation for each increment in distance

per one km is represented by Equation 3 (Mohammad Sarwari et al., 2022).

**Table 1: Chalinze to Mbwewe load centers (Munisi, 2021)**

| Load Centers | Distance, d (km) | Active Power, P (kW) | Reactive Power, Q (kVAR) |
|---|---|---|---|
| **Chalinze** | 0.0 | 782.4 | 378.9 |
| **Msoga** | 15.7 | 569.1 | 275.6 |
| **Lugoba** | 22.4 | 424.6 | 205.7 |
| **Msata** | 39.9 | 331.9 | 160.8 |
| **Mandera** | 53.8 | 281.0 | 136.1 |
| **Kimange** | 67.3 | 93.9 | 45.5 |
| **Mbwewe** | 80.9 | 0.0 | 0.0 |

$$\Delta V_{p.u} = \frac{d(r_{SW}P + x_{SW}Q)}{{V_L}^2} \quad (1)$$

$$\frac{d(\Delta V)}{dd} = \frac{1}{V_L}(r_{SW}P - x_{SW}Q) \quad (2)$$

$$\Delta V_{n+1} = \Delta V_n + h.\frac{d(\Delta V)}{dd} = \Delta V_n + h.\frac{1}{V_L}(r_{SW}P - x_{SW}Q) \quad (3)$$

Where: $\Delta V_{p.u}$ is the per unit voltage drop , $r_{SW}$ is resistance of the shield wire (SW) per km, $x_{SW}$ is reactance of SW per km, $d$ is the length of the line, $V_L$ is the line voltage at distance d, $P$ is the active power and $Q$ is the reactive power, $\Delta V_n$ is Voltage drop at the current distance, $\Delta V_{n+1}$ is voltage drop at the next distance, $h$ is the step size (small increment in distance per one km) and $\frac{d(\Delta V)}{dd}$ is the derivative calculated from the formula.

The numerical method was applied to evaluate the voltage drop along transmission lines per Equations (1), (2) and (3). The resulting data were plotted using MATLAB software. Two distinct scenarios were analyzed without solar PV: one without any electrical loading and another with consistent loading of approximately 50 kW across the villages along the line, as shown in Figure 3.

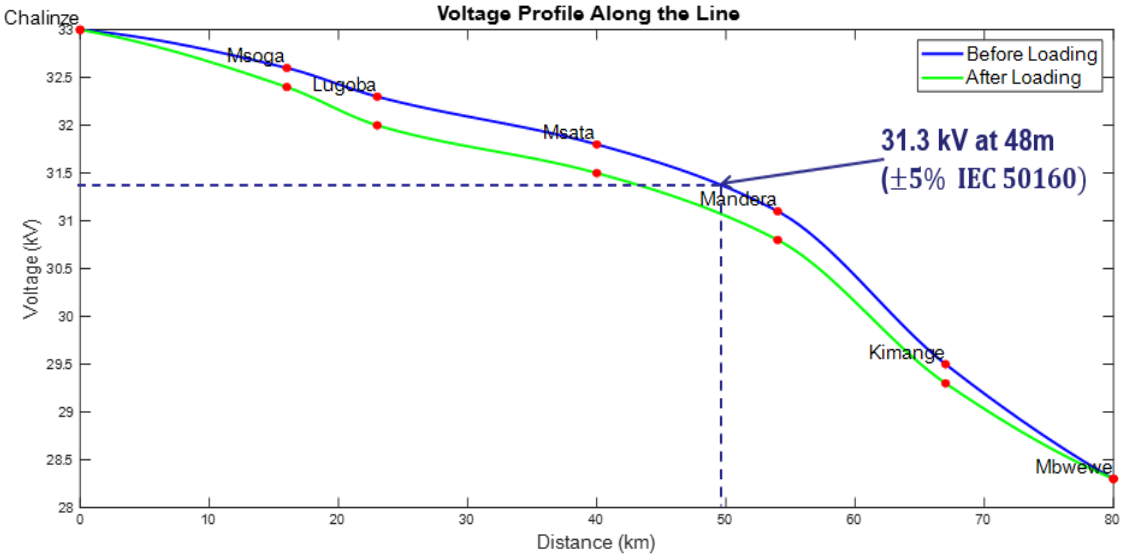


**Figure 3: Voltage Profile Along the Line Without Solar PV.**

## Proposed Solution

The proposed integration of a photovoltaic power plant (PVPP) into ISWS for modern rural electrification can follow two main approaches, as shown in Figure 4. The first approach, known as Direct Feed, involves connecting the PV plant directly to a busbar at an MV substation used for ISWS (Figure 4(a)), allowing power to be efficiently distributed through the MV network. The second approach, Indirect Feed, connects the PV plant at a load centre (Figure 4(b)), which is applicable only on the LV side, ensuring localized energy distribution. This method is particularly beneficial for rural areas where LV networks are more prevalent. To enhance rural electrification, this paper proposes connecting the PVPP to six load centres, optimizing energy distribution and reliability. Additionally, a schematic diagram in Figure 5 illustrates how ISWS will supply power to a village with integrated solar PV, further reinforcing the sustainability and efficiency of the electrification process.

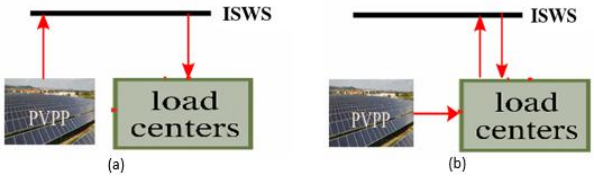


**Figure 4: Solar PV connection to ISWS**

## Load Modelling

The Chalinze-Mbwewe line section includes different small populations that require very light loads. For the easy analysis, the loads were concentrated near the nearby population centre to obtain six load centres (villages) to be supplied by SWLs. In this study, all loads were reported at medium voltage with a delta configuration.

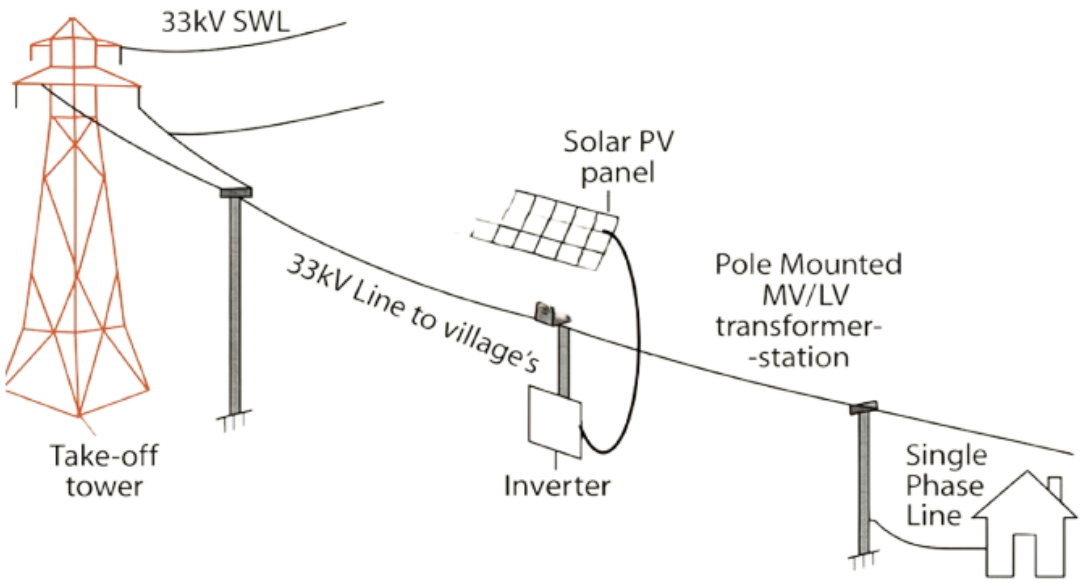


**Figure 5: Schematic diagram of Single phase ISWS village with solar PV connection.**

The constructed model on LTSpice of the MV load centres is shown in Figure 6, representing Lugoba load with its values of the resistance and the reactance.

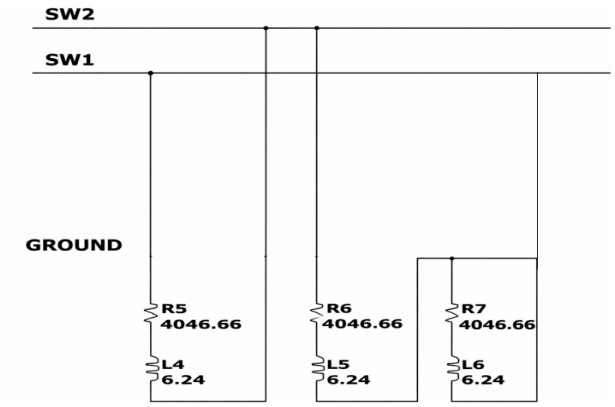


**Figure 6: LTSpice load model for Msoga-Lugoba section**

## Energizing of the SWs

The SWs are powered at rms voltage $V$=33 kV through an HV/MV stepdown transformer that serves as an ideal voltage generator in the star arrangement. The generator feeds the SW1, SW2 and ground at phase angles of 0, 120 and 240, respectively. According to Equation 4, the generator's input voltage, $V_{in}$, is of a sinusoidal nature with an amplitude of 26.9 kV. Since the study is solely focused on the supply of the two SWs, the presence of the HV line will be for the purpose of determining the impact it has on the SWLs. Figure 7 displays the LTSpice model for the SWs supply.

$$V_{in} = \frac{V\sqrt{2}}{\sqrt{3}} \tag{4}$$

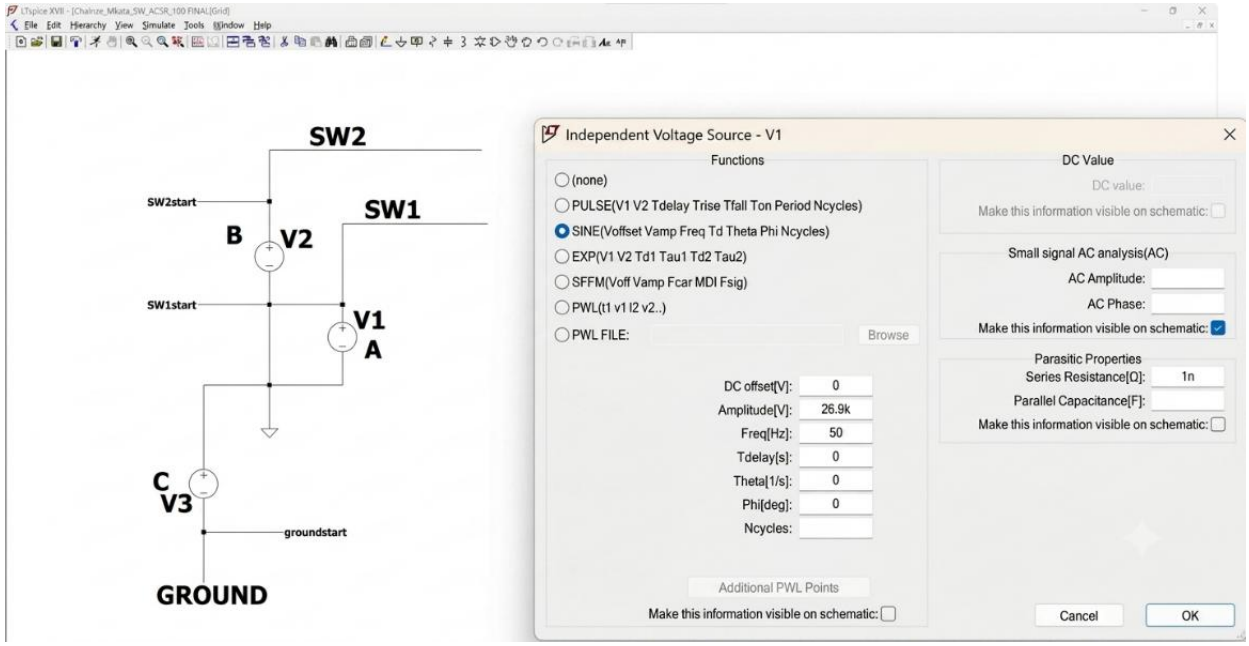


**Figure 7: LTSpice SW supply model**

### SWs Configuration

Since the loads are represented at MV, the line parameters can be referred to the pi scheme, which is the most suitable scheme due to the shortness of the line under study. The SWL was divided into six sections, and each section contains line constants in the pi scheme and the respective load. In case of the short line analysis, the longitudinal impedance $Z_\pi$ stays constant while the total admittance can be divided into two identical admittances $Y_{\pi,}$ as illustrated in Figure 8.

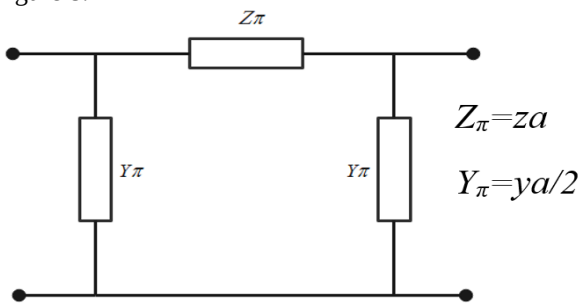


**Figure 8: pi scheme for short transmission line (Falvo et al., 2019)**

### Line Impedances

The impedance of the SWs depends on the selection of the cable type to be implemented in this study. Since the resistance and reactance are expressed in per unit length, therefore to get the actual values, each segment must be multiplied by its corresponding distance. Importantly, the ohmic resistance per unit length of the metallic conductor (ground phase) is determined by its material properties and operating frequency; it is therefore independent of soil resistivity. In this study, only the conductor resistance was considered, while soil-dependent ground return effects were not explicitly modeled. Finally, the line model was constructed in Spice as shown in Figure 9 which gives the Msoga-Lugoba segment and Figure 10 illustrates the depicts the capacitance evaluated per kilometre of the Chalinze-Msoga segment of the power line.

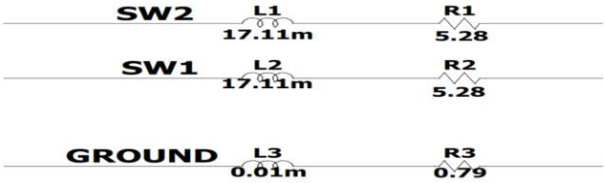


**Figure 9: LTspice line impedance for Msoga-Lugoba section**

During the simulation, a fixed time-step of 0.0001 s was used to ensure adequate resolution of the 50 Hz waveform (≈200 points per cycle), and analysis was conducted from $t_0 = 0.2$ s to $t_1 = 3$ s. The initial 0.2 s was excluded to avoid source startup transients, while the extended window to 3 s allowed observation of multiple cycles, confirming that the system reached steady-state conditions well within this interval. The parameters of the proposed model used in the simulation are listed in Table 2. Due to limitations in the LTSpice simulator, direct integration of solar PV could not be performed within the simulation environment. To overcome this constraint, the effect of solar PV was mimicked by introducing a secondary voltage source at each load centre.

Consequently, the analysis was categorized into two distinct cases: one without solar PV, where the system relied solely on the primary voltage source and another with solar PV, where the secondary voltage source acted as a local power injection, stabilizing voltage levels at specific load points. Furthermore, an additional scenario was introduced to examine the influence of conductor size on voltage profile enhancement, comparing 50 mm² and 100 mm² conductors.

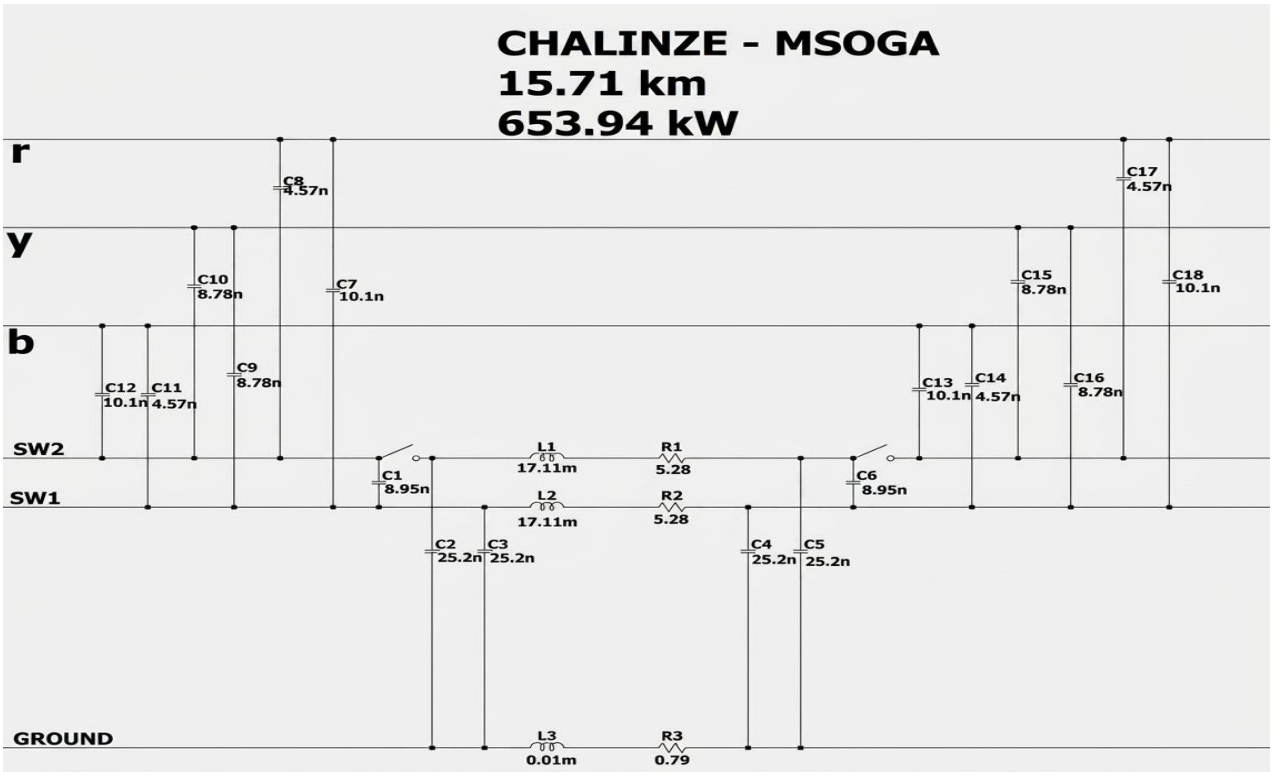


**Figure 10: LTSpice complete model for Chalinze-Msoga segment distribution line.**

**Table 2: Parameter of the proposed SWL**

| Parameter | Value | SI Unit |
|---|---|---|
| HV Nominal Voltage (rms) | 132 | kV |
| SW Nominal Voltage (rms) | 33 | kV |
| SW Resistance | 0.336 | Ω/km |
| SW Inductance | 1.089 | mH/km |
| Ground Resistance | 0.050 | Ω/km |
| Ground Inductance | 0.064 | mH/km |
| Capacitance between SWs | 1.139 | nF/km |
| Capacitance between SW and ground | 3.212 | nF/km |

## RESULTS AND DISCUSSION

### *Case 1:* Existing 50 mm² ACSR Conductor

Table 3 presents the average percentage voltage drop values obtained from simulations using the existing 50 mm² ACSR conductor, currently implemented in the Chalinze–Hale–Tanga transmission line, which serves as the baseline for assessing voltage drops in the ISWS technology for the Chalinze-Mbwewe section. Each column in Table 3 represents a separate LTSpice simulation run, in which the secondary voltage source (mimicking solar PV integration) was placed at a single village load centre, allowing comparison of voltage-drop improvements when PV is integrated at different points along the corridor. The simulation results, summarized in Table 3, reveal that voltage drops exceed 5% in multiple locations, particularly at Msata, Mandera, Kimange, and Mbwewe villages, which are situated at the farthest end of the transmission line.

Without solar PV integration, the percentage voltage drop increased significantly, reaching 23.58% at Mbwewe village, demonstrating the limitations of long-distance transmission with a small conductor size. Even after integrating solar PV, voltage drops remain above ±5% at all load centers, confirming that while distributed generation improves stability, the existing 50 mm² conductor is insufficient to fully mitigate transmission losses. Given that TANESCO and IEC 50160 set the permissible voltage drop limit at ± 5%, the results highlight the necessity of improving conductor size to reduce resistance, minimize transmission losses, and enhance voltage regulation across the network.

The analysis in Figure 11 highlights the percentage voltage drop trend along a transmission line, comparing cases with and without solar PV using a 50 mm² conductor. The findings show that voltage drop is most severe in the absence of solar PV, increasing progressively from Msoga to Mbwewe. Even with solar PV acting as a secondary voltage source at load centers, the voltage drop remains consistently above the 5% operational limit, particularly at locations farther from the main source.

Figure 12 illustrates the influence of solar PV integration on the voltage profile along a transmission line using the existing 50 mm² ACSR conductor. The voltage profiles indicate that as transmission distance increases, solar PV at Chalinze substation significantly enhances the voltage profile, minimizing voltage drop along the line. The integration ensures that five critical load centers maintain a stable and acceptable voltage supply within the recommended ±5% IEC 50160 standard, improving overall system performance and reliability.

### *Case 2:* Proposed 100 mm² ACSR Conductor

Table 4 presents the percentage voltage drop values obtained from simulations using the proposed 100 mm² ACSR conductor, evaluated as a solution to improve the ISWS technology for the Chalinze-Mbwewe section. This alternative conductor was introduced to address the excessive voltage drops observed with the existing 50 mm² ACSR conductor, as demonstrated in *Case 1*.

**Table 3: Comparison of percentage voltage drop values for ACSR 50 mm² conductor**

| Chalinze-Mbwewe ACSR 50 mm² | Distance from Chalinze [km] | Percentage Voltage Drop (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Without Solar PV | Remarks | With Solar PV at | | | | | | |
| | | | | Msoga | Lugoba | Msata | Mandera | Kimange | Mbwewe | Remarks |
| MSOGA | 15.7 | 11.80 | Exceeds standard | 0.00 | 8.19 | 8.42 | 8.62 | 8.79 | 8.98 | Exceeds standard |
| LUGOBA | 22.4 | 13.41 | Exceeds standard | 9.58 | 0.00 | 8.40 | 8.67 | 8.82 | 9.09 | Exceeds standard |
| MSATA | 39.9 | 16.95 | Exceeds standard | 12.29 | 11.71 | 0.00 | 8.50 | 8.92 | 9.16 | Exceeds standard |
| MANDERA | 53.8 | 19.45 | Exceeds standard | 14.91 | 14.40 | 10.74 | 0.00 | 8.57 | 9.35 | Exceeds standard |
| KIMANGE | 67.3 | 21.65 | Exceeds standard | 17.26 | 16.72 | 13.15 | 12.47 | 0.00 | 10.75 | Exceeds standard |
| MBWEWE | 80.9 | 23.58 | Exceeds standard | 19.23 | 18.76 | 15.25 | 10.61 | 7.19 | 0.00 | Exceeds standard |

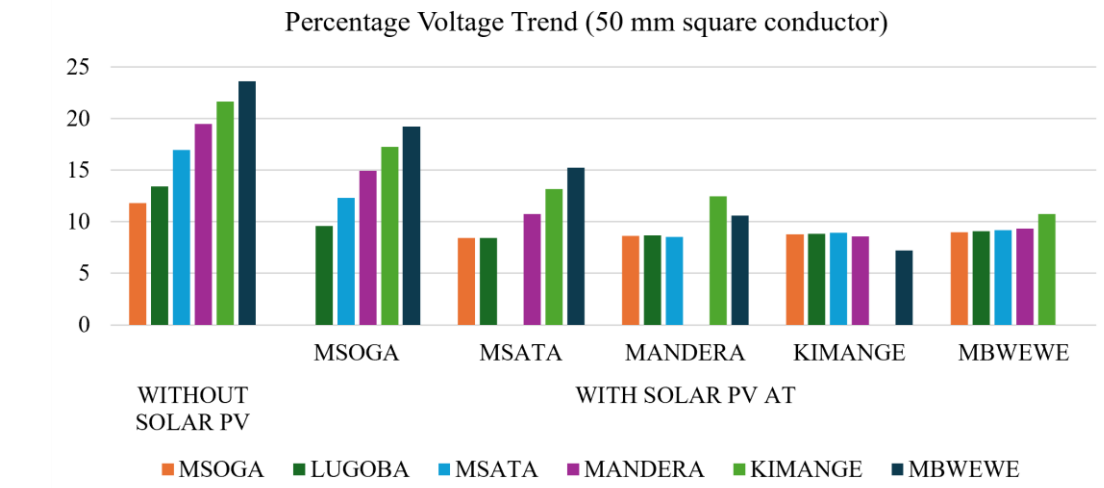


**Figure 11: Percentage Voltage Drop Trend for 50 mm$^2$ conductor.**

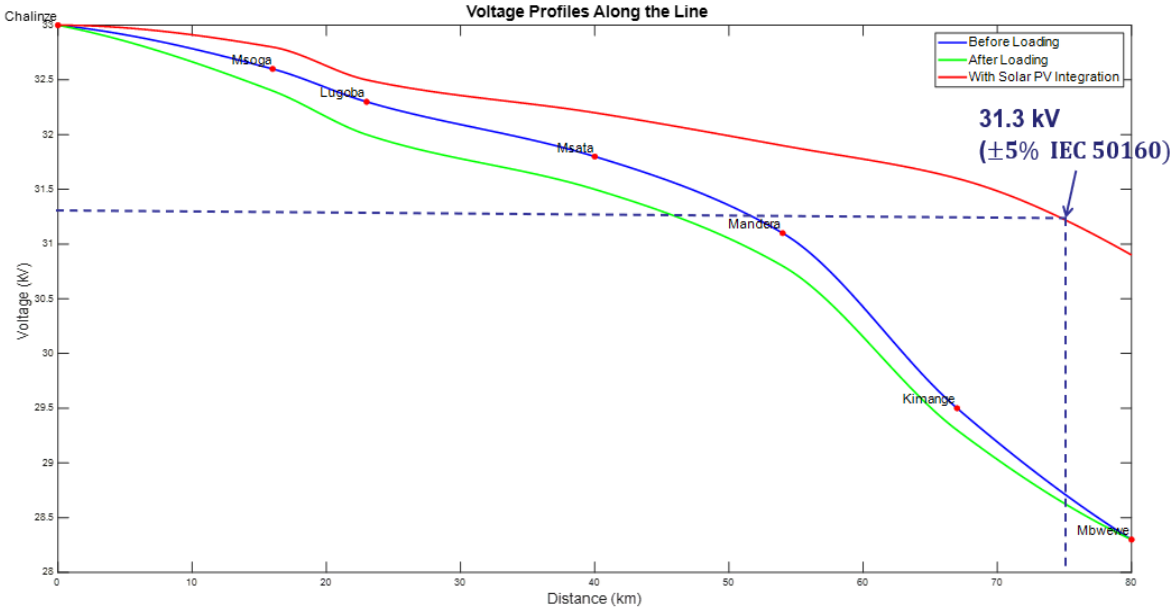


**Figure 12: Voltage Profile Along the Line with Solar PV for ACSR 50 mm² conductor.**

The simulation results indicate that upgrading to a 100 mm² conductor significantly improves voltage regulation across the network**.** Unlike the 50 mm² conductor**,** which exhibited considerable voltage losses, the larger conductor effectively minimizes transmission inefficiencies, ensuring voltage stability at all load centers. The most substantial improvements are observed at the farthest locations: Msata, Mandera, Kimange, and Mbwewe villages, where voltage drops are markedly reduced**.**

Even without solar PV, voltage losses are lower than those recorded for the 50 mm² conductor, with Mbwewe village seeing a notable improvement at 15.58% drop. However, integrating solar PV stabilizes voltage levels across the transmission line, ensuring consistent performance at distant load centers. The combination of optimized conductor sizing and distributed energy generation enhances ISWS reliability.

This analysis highlights the role of conductor selection in reducing transmission losses and maintaining voltage levels within standards.

The findings align with ISWS operational requirements, IEC 50160 standards, and TANESCO regulations, confirming the effectiveness of distributed generation and conductor optimization in improving voltage stability (Iliceto, 2016; TANESCO, 2012).

Figure 13 shows that voltage drops are highest in the system without solar PV, increasing progressively from Msoga to Mbwewe villages. However, integrating solar PV at key load centers significantly reduces these drops, keeping them within the acceptable 5% limit, especially at the farthest end load centers.

This trend reinforces that solar PV integration effectively mitigates voltage fluctuations and enhances stability across the network, with the greatest improvements seen in Mandera, Kimange, and Mbwewe villages, where voltage drops were previously excessive. The findings suggest that solar PV installations are most suitable at the farthest end load centers, where voltage instability is highest.

**Table 4: Comparison of percentage voltage drop values for ACSR 100 mm² conductor**

| Chalinze-Mbwewe ACSR 100 mm² | Distance from Chalinze [km] | Percentage Voltage Drop (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Without Solar PV | Remarks | With Solar PV at | | | | | | | |
| | | | | Msoga | Lugoba | Msata | Mandera | Kimange | Mbwewe | Remarks |
| MSOGA | 15.7 | 3.94 | Within standard | 0.00 | 0.17 | 0.42 | 0.62 | 0.77 | 0.94 | Within standard |
| LUGOBA | 22.4 | 5.41 | Within standard | 1.57 | 0.00 | 0.40 | 0.67 | 0.89 | 1.13 | Within standard |
| MSATA | 39.9 | 8.95 | Exceeds standard | 3.44 | 2.12 | 0.00 | 0.50 | 0.90 | 1.33 | Within standard |
| MANDERA | 53.8 | 11.45 | Exceeds standard | 5.29 | 3.76 | 2.74 | 0.00 | 0.57 | 1.15 | Within standard |
| KIMANGE | 67.3 | 13.65 | Exceeds standard | 6.40 | 5.40 | 5.15 | 2.49 | 0.00 | 0.75 | Within standard |
| MBWEWE | 80.9 | 15.58 | Exceeds standard | 7.21 | 6.73 | 5.25 | 3.65 | 2.19 | 0.00 | Within standard |

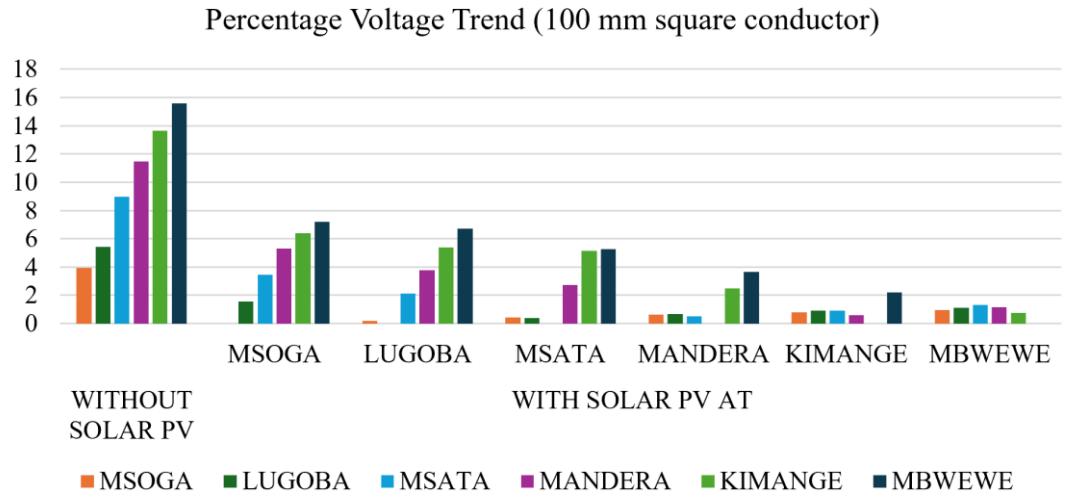


**Figure 13: Percentage Voltage Drop Trend for 100 mm² conductor.**

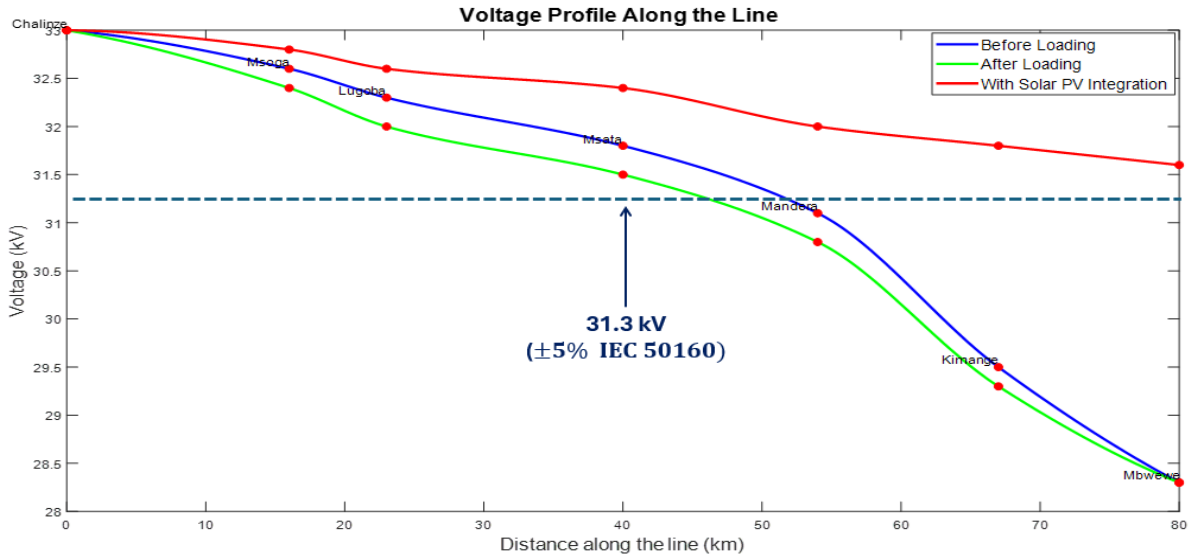


**Figure 14: Voltage Profile Along the Line with Solar PV for ACSR 100 mm² conductor.**

Figure 14 illustrates the influence of solar PV integration on voltage behaviour along a transmission line using the upgraded 100 mm² ACSR conductor. Compared to the previous 50 mm² configuration, the upgraded conductor

significantly enhances the voltage profile, reducing transmission losses and further minimizing voltage drop along the line. With solar PV at Chalinze substation, the upgraded system ensures that all six load centers receive a more stable and reliable voltage supply within the recommended ±5% IEC 50160 standard. This optimization enhances overall network efficiency, strengthens system reliability, and supports sustainable power distribution.

## CONCLUSION

The study successfully developed a model for supplying electricity to villages 80.9 km from the conventional MV distribution network, significantly enhancing the voltage profile in ISWS. Simulations using the existing 50 mm² conductor showed that, without solar PV, voltage drops averaged 17.8%, surpassing acceptable limits. However, integrating solar PV improved the voltage profile, reducing drops significantly (to ~7–19%), but still above the ±5% threshold. The findings confirm that transmission losses are strongly influenced by conductor size and system topology, demonstrating that a 50 mm² conductor alone is insufficient for maintaining the voltage profile, even with distributed generation support.

Further analysis revealed that upgrading to a 100 mm² conductor case, voltage drops without solar PV still exceed the ±5% limit at four of the six centres (Lugoba, Msata, Mandera, Kimange, and Mbwewe). However, when solar PV is integrated at certain load centres, particularly at Mbwewe, Kimange, or Mandera, the voltage profile improves across all six villages, bringing drops within the ±5% threshold. Therefore, the recommended configuration is a 100 mm² conductor combined with PV placement at the far-end villages (e.g., Mbwewe), which ensures compliance with IEC 50160 and TANESCO standards for reliable rural electrification.

The study concluded that, while solar PV integration enhances the voltage profile, its full effectiveness is realized when paired with conductor optimization. A combined approach incorporating optimized conductor sizing and solar PV proves essential for efficient rural electrification. The 100 mm² conductor meets IEC 50160 and TANESCO standards, delivering a cost-effective, sustainable solution for improving electricity access in Tanzania's remote regions. This is due to the energizing of ISWS cables using a free, clear and renewable energy – solar energy.

This study assumes the solar PV plant supplies power throughout the day. However, the PV generation is affected by the intermittent nature of solar energy (Mwammenywa & Hilleringmann, 2023). Further study is recommended in future works on the techno-economic model on the inclusion of the battery energy storage systems, inverter capabilities, controllers for electrical parameters, as well as the economic feasibility of this study.

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