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CONFERENCE PROCEEDINGS

INDUSTRIAL BASED RESEARCH: FOSTERING INNOVATION & SOCIO-ECONOMIC DEVELOPMENT

University of Dar es Salaam

Department of Mechanical and Industrial Engineering



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Feasibility Analysis of Using SWER for Homboza Village Electrification

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Abstract
The electrification level in Homboza village, one of the many rural areas in Tanzania, is very low. Out of the 5,565 Homboza dwellers, less than 10 percent access electrical energy. The major barriers to improved electrification rates in rural communities are high investment costs of extending the grid to rural areas, and the small, dispersed nature of electricity demand, arising from a population of low density and low-income levels. To overcome these, this paper proposes Single Wire Earth Return (SWER) electrification scheme. This is because SWER's installation costs are about one third of a three-phase system and a half of the single-phase system. This paper presents a Carson line model of SWER for Homboza village and is simulated in MATLAB/Simulink, and for comparison, a single-phase system is simulated too. The simulation results show that the earth potential between the ground electrodes is 18.15 V for the SWER. Further, SWER shows 10.07% voltage drop and 10.34% power loss over 20 km of distribution line, while single phase system shows 18.89% voltage drop and 19.58% power loss over the 20 km of distribution line. There is a possibility of supplying Homboza using SWER technology.

Keywords: electrification rates; single phase two wire system (SPTW); single wire earth return (SWER)

1 Introduction

Energy is required for sustainable development and economic growth. Providing electricity should be utmost priority for power utilities, despite the challenges faced. Up to the year 2018, only about 37% of the Tanzanian population had electricity access according to the International Energy Agency's (IEA, 2019).

These figures reveal that an alternative electrification technology for rural areas in Tanzania is required. The existing rural grid-connected electrification technique in Tanzania is Single Phase Two-Wire (SPTW) distribution system. Distribution systems supply industrial, commercial and residential loads with differing total demand ratios (Qian et al., 2011). SPTW can be used for small urban areas and unreasonable to apply for rural areas as they are not cost-effective.

Rural areas are considered residential loads characterized by (i) low population density, (ii) households of low-income levels, and (iii) remoteness from the main grid. Selection criteria for cost-effective efficient distribution network for rural areas must consider the characteristics of rural areas into consideration. Rural electrification technologies could use the conventional system or the Single Wire Earth Return network commonly known as SWER (Brooking et al., 1992).

SWER electrification scheme is a cheaper solution for electrical power extension to rural areas. SWER's installation costs are about half that of SPTW system. Single light-weight conductors, lighter poles, narrower right-of-way, small pole top assembly are some of the advantages of the SWER distribution system. An important aspect of the SWER system is earthing. Proper earthing for the safety of the rural inhabitants is required if SWER should be implemented. The maximum potential required across the ground electrodes is 25 V (Brooking et al., 1992). SWER can allow optimal selection of conductors, and (Fadhelbalndi et al., 2011) proposed a heuristic model that is able to predict when the conductors need an upgrade. This paper therefore seeks to solve the challenge of low rural electrification rate in Tanzania.

2. Methodology

The SWER line model is developed such that, the ground return path is assumed to be a conductor of infinite length, uniform resistivity, and parallel to the overhead conductor of length l carrying current I_b (Wolfs et al., 2007). Figure 1 shows the explained SWER line model with earth return known as Carson line model.

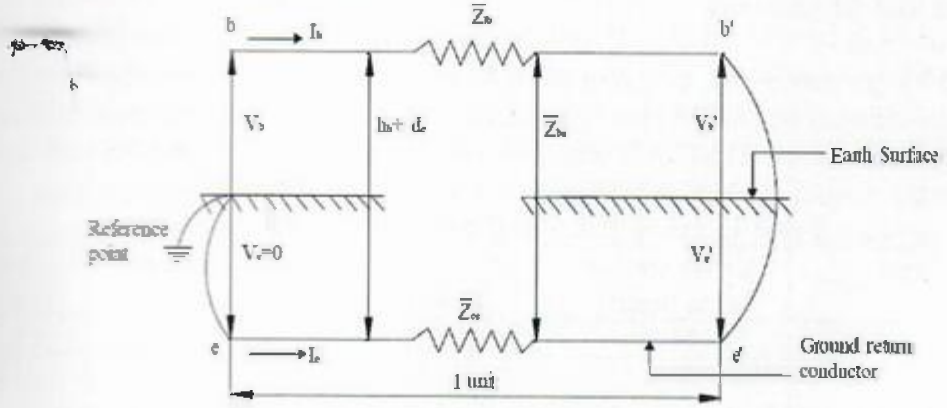


Figure 1. SWER/Carson line model with earth return (Irechukwu and Mushi, 2020)

The sending and receiving voltages of the earth return path and the overhead line can be calculated from Equation (1).

$$\begin{pmatrix} V_{bb'} \\ V_{ee'} \end{pmatrix} = \begin{pmatrix} V_b - V_{b'} \\ V_e - V_{e'} \end{pmatrix} = \begin{pmatrix} z_{bb} & z_{be} \\ z_{eb} & z_{ee} \end{pmatrix} \begin{pmatrix} I_b \\ -I_b \end{pmatrix} \quad (1)$$

Here, I_b is the current flowing in the SWER network overhead conductor, z_{ee} is the ground self-impedance, and z_{bb} is the line self-impedance. Impedance z_{be} is the mutual impedance between the overhead and the ground line, V_b is the overhead conductor's voltage, and V_e is the earth's surface voltage (Ciric et al., 2004). Difference in overhead voltage between the sending and receiving ends is $V_{bb'} = V_b - V_{b'}$. Difference in underground voltage between the sending and receiving ends is $V_{ee'} = V_e - V_{e'}$. Calculations from Equation (1) result into a reference earth's surface voltage V_e as 0. With a zero-earth voltage value, V_b can be calculated from Equation (2).

$$V_b = (z_b + z_{ee} - 2z_{be}) I_b = Z_{bb} I_b \quad (2)$$

In Equation (2), Z_{bb} is the total line impedance and is a result of $z_{bb} + z_{ee} - 2z_{be}$. Equation (3) gives the self-impedance, z_{bb} of the overhead conductor. Denote R_b as the SWER conductor

resistance, h_b as the conductor height above ground level, d_e as the depth of the ground return path from the earth surface, and r_b as the external radius of the conductor.

$$z_{bb}=R_b+j4\pi\times10^{-4}f\ln[\frac{2(h_b+d_e)}{r_b}] \quad (3)$$

Equation (4) determines the depth of the ground return path from the earth surface. Equation (5) gives the self-impedance of the ground conductor. Equation (6) calculates the mutual impedance between the overhead line and the ground return conductor. Using f as supply frequency,

$$d_e=\sqrt{\frac{\rho}{\omega\mu}} \quad (4)$$

$$z_{aa}=10^{-4}f\times[(\pi^2)-j(0.31\pi)+j4\pi\times\ln(356)] \quad (5)$$

$$z_{ba}=j2\pi\times10^{-4}\ln[\frac{(h_b)}{(\rho/f)^{0.5}}] \quad (6)$$

3. Results and Discussions

Simulation parameters

Table 1 shows properties of different SWER conductors. From this Table, aluminium conductor steel-reinforced (ACSR) is the conductor selected for its largest cross-sectional area and lowest unit resistance. MATLAB/Simulink is used to simulate the system and its setup is explained next.

Table 1: Properties of different SWER conductors

Conductor type	Cross section area [mm^2]	Resistance [Ω/km]	Overall diameter [mm]	Mass [kg/km]
ACSR	49.48	0.893	9	171
Aluminium-Steel clad	10.26	5.75	5.93	118
Galvanised Steel conductor	17.82	12.05	5.93	139

Simulation setup

Extension of the SWER line is from the grid to the distribution center. The distribution transformers are step-down transformers stepping down the voltage from 6.35 kV to 230 V. Figure 2 displays the MATLAB/Simulink simulation of the Homboza village proposed electrification scheme. The power lines from the three-phase source to the isolation transformer are shown. On getting to the isolation transformer, the neutral is grounded and the SWER overhead line is connected to the distribution transformer. This simulation can give out the voltage drop over the 20 km span of the SWER from the grid to the Homboza village load centre.

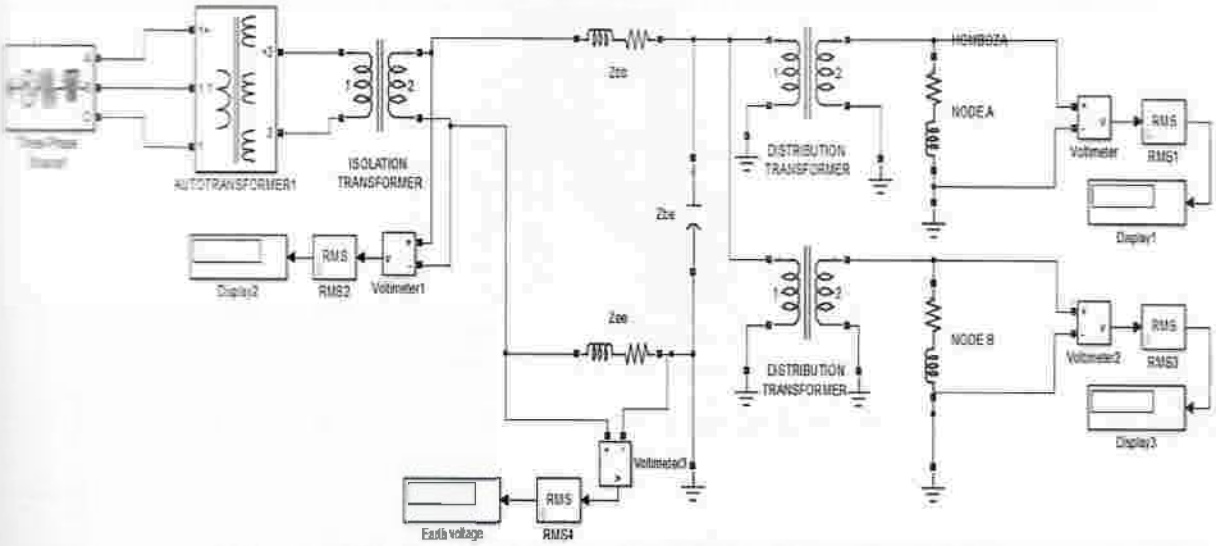


Figure 2. Simulation of SWER line in MATLAB/Simulink

Simulation results

The MATLAB/Simulink simulation model of the Homboza village SWER transmission system is shown by Figure 2. The parameters represented by Equations (3)-(6) are calculated with the help of data in Table 1. When the SWER line is fed by the auto-transformer, the earth potential measured by potentiometer through the impedance z_{ee} is 18.15 V, This is compared to the recommended magnitude of earth potential of 25 V, seems smaller for safe implementation of the SWER for electrifying Homboza village. The receiving end voltages are measured by the

4. *SPTW and SWER Comparison*

Voltage and Power Loss

Two basic factors that can be used to compare SPTW and SWER networks technically are voltage drop and power loss. Equation (7) and Equation (8) are the formulas for the voltage drop ΔV and power loss of the SPTW distribution network respectively. Equation (9) and Equations (10)-(11) are the formulas to compute voltage drop and power loss of the SWER distribution system respectively.

$$\Delta V = 2I(r\cos\alpha + x\sin\alpha) \tag{7}$$

$$\Delta P = 2I^2 rl \tag{8}$$

$$\Delta V = I[(r + r_e)\cos\alpha + x\sin\alpha] \tag{9}$$

$$\Delta P = I^2(r + r_e)l \tag{10}$$

$$\Delta P = \left(\frac{\Delta V}{2(r\cos\alpha + x\sin\alpha)}\right)^2 \left(\frac{(r+r_e)}{l}\right) \tag{11}$$

Voltage drop and power loss are calculated over 20 km length of distribution line for both SWER and SPTW. Figure 3 shows the voltage drop for SWER and SPTW. SWER has low voltage drop by about 8 per unit. Figure 4 shows power drop of SPTW and SWER. SWER has low power drop by about 9 per unit.

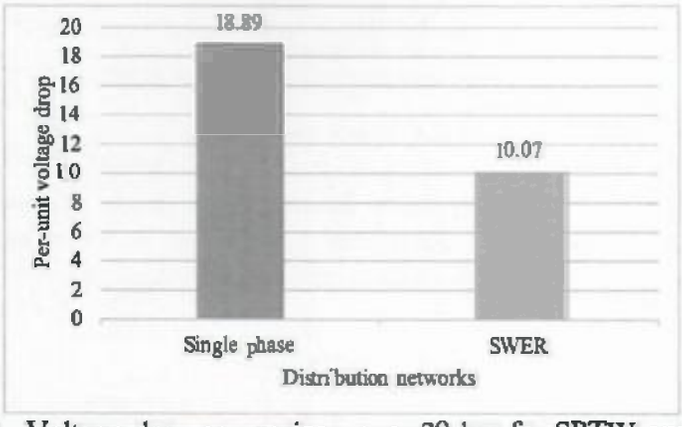


Figure 3. Voltage drop comparison over 20 km for SPTW and SWER

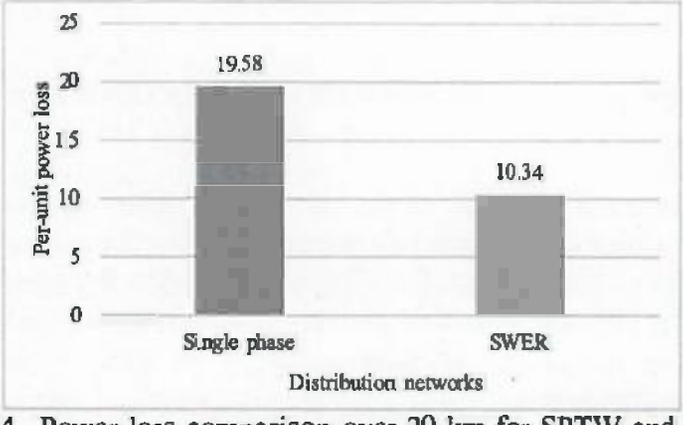


Figure 4. Power loss comparison over 20 km for SPTW and SWER

Benefit Cost Ratio

Power utilities use the marginal benefit-cost ratio to know if supplying an area with a certain distribution network would be beneficial. The benefit-cost ratio (B_C) can be calculated from Equation (12) as was presented by (IEA, 2019; Qian et al., 2011).

$$B_C = \frac{P_{VFS} K_S K_{val}}{D_I + D_{O,M} + (P_{VFL} L_{RMC} K_L)} \tag{12}$$

Here, D_I is the discounted value of investment stream, $D_{O,M}$ is the annual discounted value of operations and maintenance costs, K_S is the annual kWh sales, K_L is the annual kWh losses, P_{VFL} is the present value for losses, L_{RMC} is long range marginal cost for distribution, P_{VFS} is the present value for sales, K_{val} is the value of kWh used. The SWER and SPTW grid connection costs per rural household of a similar village to Homboza village are compared in Figure 5, where the SWER cost is half that of SPTW. Further, average annual connections for similar investment costs are shown in Figure 6 for SWER and SPTW. It has been argued in another paper (Irechukwu and Mushi, 2020) that this SWER system is economical than SPTW in sub-Saharan Africa, and has a higher potential to electrify rural areas. This has further been demonstrated in Australia and other parts of the world with great success (Da Silva and Negrao, 2018).

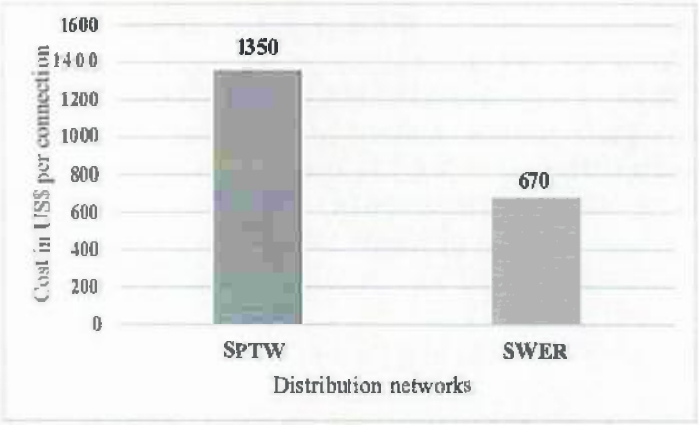


Figure 5. SWER and SPTW grid connection costs comparison per rural household

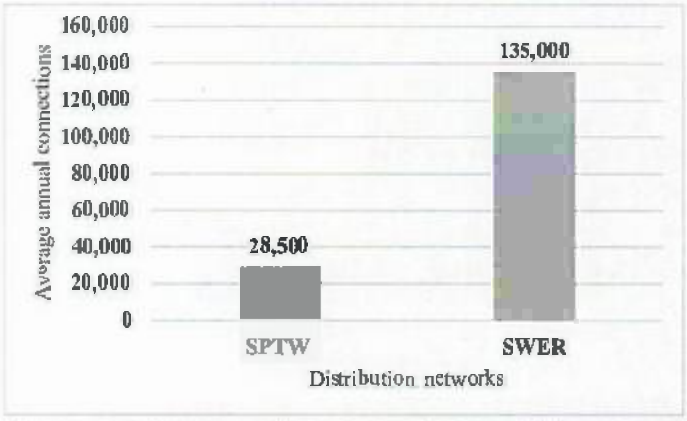


Figure 6. SWER and SPTW average annual connections comparison for similar investment cost

4. Conclusion

This paper has discussed the advantages of SWER network over SPTW for Homboza village electrification. SWER's voltage drop and power loss over 20 km of distribution line are 10.07 per unit and 10.34 per unit respectively. SPTW's voltage drop and power loss over 20 km of distribution line are 18.89 per unit and 19.58 per unit respectively. Added to that, the grid connection cost for a household using the SPTW network is $1350 while the SWER usage cost stands at $670. The simulation showed an earth potential of 18.15 V. Therefore, SWER is recommended for Homboza village electrification. Future study could include to build a demonstration to practically measure the power losses, and voltage drops for SWER system.

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