Feasibility Analysis of Using SWER for Homboza Village Electrification

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Abstract

The level of electrification in Homboza village, one of the many rural areas in Tanzania, is very low. Homboza village is the case study in this paper has a population of 5,565. Out of those less than 10 percent access of electricity energy. This study attributed these three major barriers to low electrification rate. The first barrier is the high investment costs which yield too high average costs of providing electricity services to rural areas. The second barrier is high costs of extending the grid to rural areas. The third barrier is the small and dispersed nature of electricity demand, arising from a population of low density and low income levels. To overcome these and extend the power distribution this village, this paper proposes Single Wire Earth Return (SWER) electrification scheme. This is because SWER's installation costs are about one third of equivalent three-phase three-wire system and one half of the single-phase systems. This paper presents a Carson line model of SWER for Homboza village and is simulated in MATLAB 2013b, and as a comparison, a single phase two-wire system is simulated too. The simulation results show that the earth potential between the ground electrodes is 18.15 V for the SWER. Further, the SWER shows 10.07% voltage drop and 10.34% power loss over 20 kilometers of distribution line. While single phase two-wire system shows 18.89% voltage drop and 19.58% power loss over the 20 kilometers of distribution line. There is a possibility of supplying Homboza using SWER technology.

Keywords: Power distribution networks, single phase two-wire system, 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. As at the year 2018, only about 37 percent 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 $25V$ (Brooking et al., 1992). SWER can allow optimal selection of conductors, and Bakkabulindi et al. (2011) proposed a heuristic model that is able to predict when the conductors need an upgrade.

2. SWER Line Model

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 b carrying

current I_b (Wolfs et al., 2007). Figure 1 shows the explained SWER line model with earth return known as Carson line model.

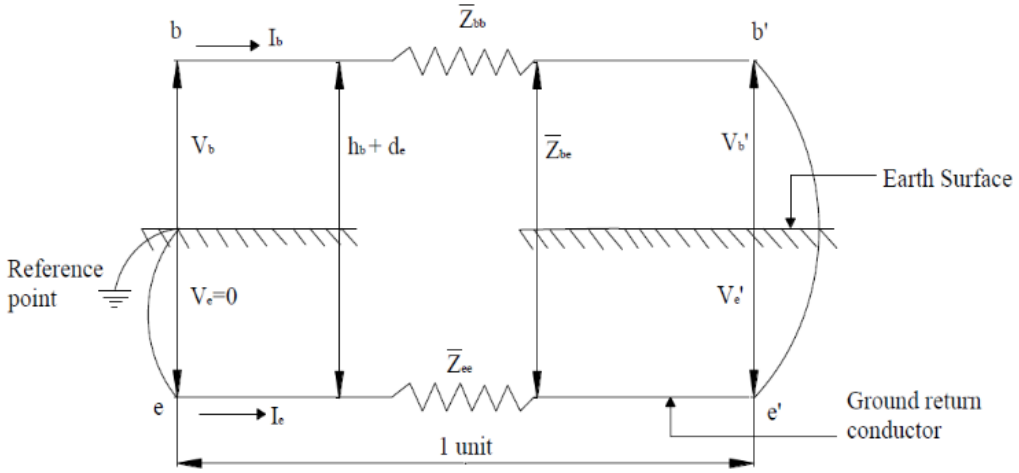


Fig. 1. SWER/Carson line model with earth return

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

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

where, I_b is the current flowing in the SWER network overhead conductor, z_{ee} is the ground self-impedance, z_{bb} is the line self-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, 2004). 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).

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

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

$$z_{bb} = R_b + j4\pi \times 10^{-4} f \ln[\frac{2(h_b + d_e)}{r_b}] \quad (3)$$

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.

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

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

$$z_{be} = j2\pi \times 10^{-4} \ln[\frac{(h_b)}{(\rho / f)^{0.5}}] \quad (6)$$

3. Simulation for Homboza Village

3.1. Simulation Parameters

Table 1 shows properties of different SWER conductors used in the simulation. From this table, Aluminium Conductor Steel-Reinforced (ACSR) is the SWER conductor selected for its largest cross-sectional area and lowest unit resistance. MATLAB/Simulink 2013b 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

3.2. 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 $6.35kV$ to $230V$. Figure 2 displays the MATLAB/Simulink 2013b simulation. 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.

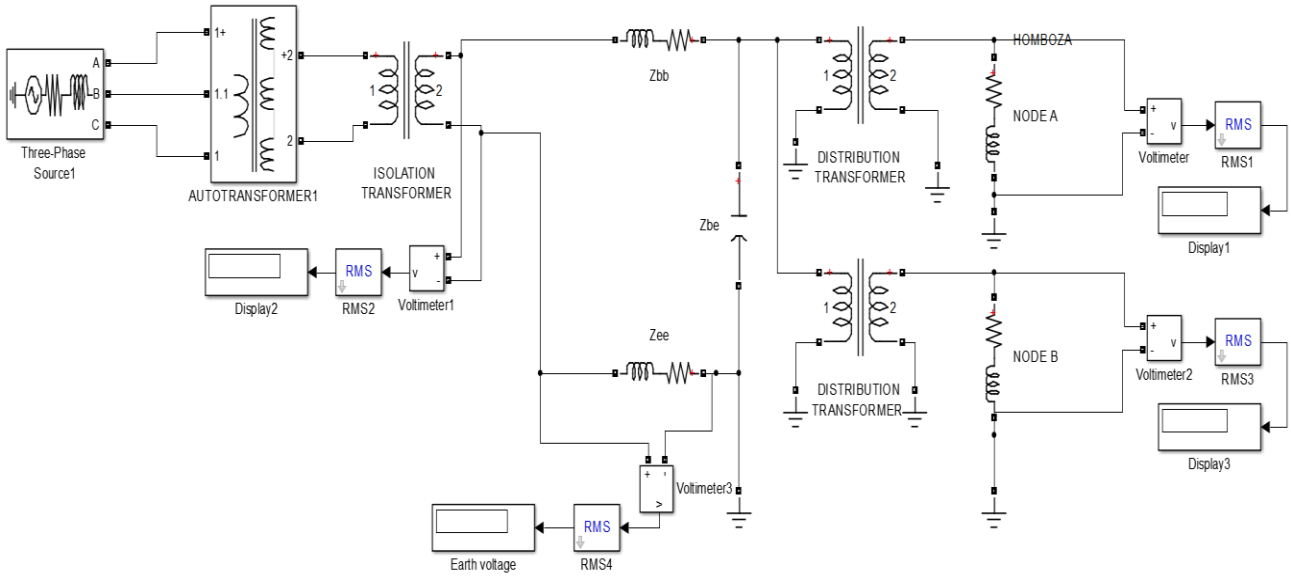


Fig. 2. Simulation of SWER line in MATLAB/Simulink 2013b

3.3. Simulation Results

The MATLAB/Simulink 2013b simulation gives the earth potential as $18.15V$, and comparing to the recommended magnitude of earth potential of $25V$, is way smaller for safe implementation of this SWER for electrifying Homboza village.

4. SPTW and SWER Comparison

4.1. 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 and power loss of the SPTW distribution network respectively. Equation (9) and Equation (10) are the formulas for the voltage drop and power loss of the SWER distribution system respectively.

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

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

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

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

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 (single phase). 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.

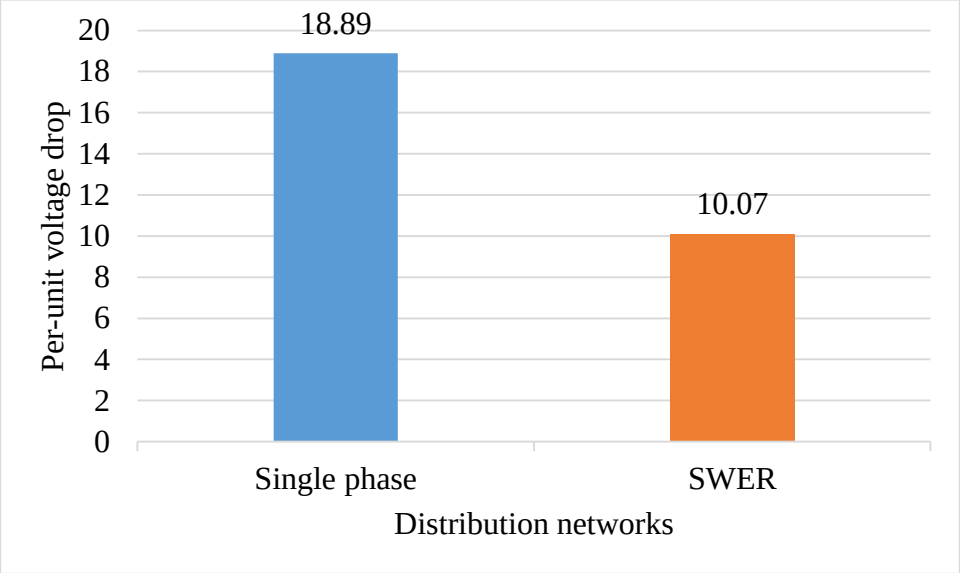


Fig. 3. Voltage drop over 20 km for SPTW and SWER

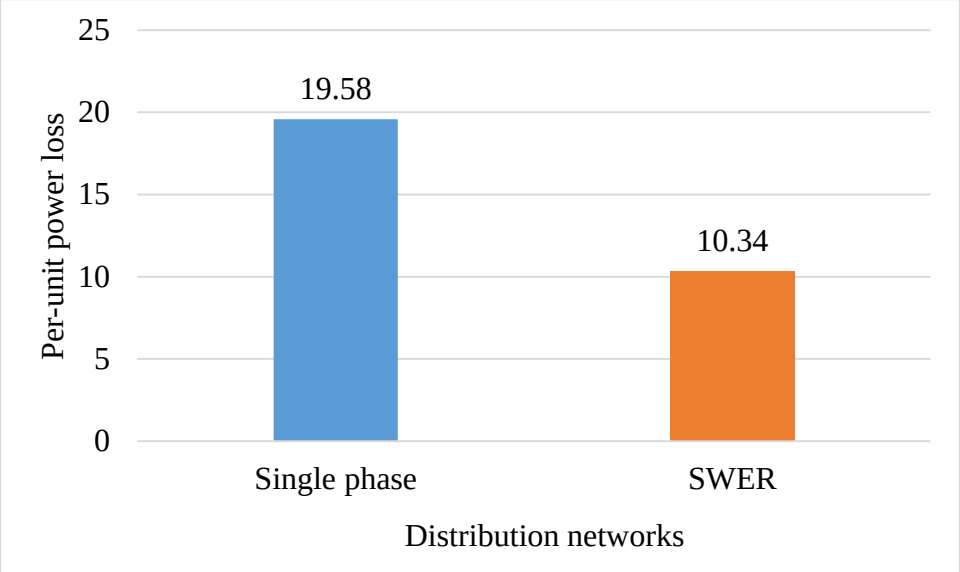


Fig. 4. Power loss over 20 km for SPTW and SWER

4.2. 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 (11).

$$B_C = \frac{P_{VFS} K_S K_{val}}{D_I + D_{O,M} + (P_{VFL} L_{RMC} K_L)} \tag{11}$$

Where, 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.

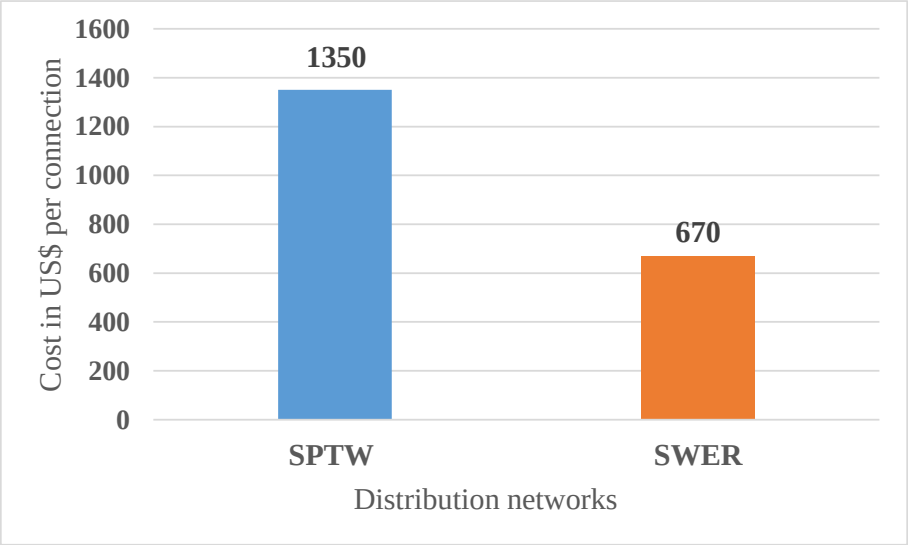


Fig. 5. SWER and SPTW grid connection costs per rural household

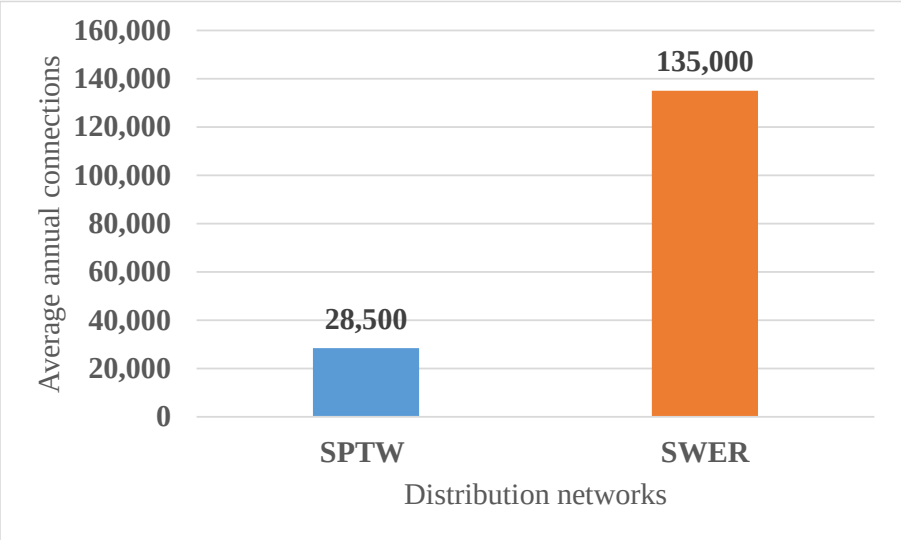


Fig. 6. SWER and SPTW average annual connections for similar investment cost

5. 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 $18.15V$. Therefore, SWER is recommended for Homboza village electrification.

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