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Rural Electrification Using Shield Wire Schemes

THE BOTTOM LINE

Shield wire systems running along existing high-voltage transmission lines can supply household electricity to communities located within 20 km of the high-voltage corridor. At a fraction of the cost of new substations or independent medium-voltage lines, shield wire systems are an attractive option for rural electrification, particularly in remote and sparsely populated areas that are costly to connect to the grid. Systems have operated successfully in Sub-Saharan Africa and elsewhere for more than a quarter-century. A new manual assists engineers in designing and building shield wire systems.

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Why is this issue important?

Shield wire schemes provide a cost-effective way to electrify villages located along high-voltage transmission lines

In Sub-Saharan Africa, high-voltage transmission lines cross remote rural communities that, despite their proximity to transmission lines, may be costly to connect if they are located far from existing high- and medium-voltage (HV/MV) substations. The high costs of connection, combined with the low levels of electricity consumed, often make such communities uneconomical to electrify using conventional technology. Even when financial resources are available to wire them, it can be hard to justify spending in such cases, with the result that many potentially reachable communities go unserved.

At the same time, people living along the transmission corridor have made land available for the towers that carry the lines, generally expecting to benefit through electrification of their communities. This reasonable expectation, combined with widespread vandalism of the towers and other equipment, makes it imperative that the people living along the corridor have an interest in helping the utility monitor the line.

Shield wire schemes (SWSs), invented in the 1980s by the late Francesco Iliceto of the University of Rome La Sapienza, provide a cost-effective way to do just that. SWS technology makes it possible to electrify communities located within 20 km of the transmission corridor. From the HV/MV substation, the SWS can be powered along a distance of 100 km with a load capacity of 3 to 5 MW.

SWS technology has been deployed in several countries in Sub-Saharan Africa (Burkina Faso, Ethiopia, Ghana, Sierra Leone, Togo), as well as Brazil and the Lao People's Democratic Republic. Over a period of more than 25 years, it has been used to electrify 200 communities and 350,000 customers living along 2,600 km of high-voltage transmission corridors. An improved version is being readied for service in West Africa.

How do shield wire schemes work?

Three types of schemes leverage existing equipment to provide electricity to households and other retail customers

In the mid-1700s, Benjamin Franklin suggested placing iron rods atop buildings to protect them from lightning strikes. The principle behind this practice is still applied to high-voltage lines through the use of shield wires to protect the lines. The shield wires are usually connected to the steel transmission towers to ground them.

To electrify communities located along a high-voltage transmission line, the shield wires are insulated from the towers and supplied with medium-voltage power (usually at 34.5 kV) from the nearest HV/MV substation. Insulation reduces losses from capacitive coupling and prevents electromagnetic induction of current from HV lines into the shield wires. Even when insulated, the shield wires continue to protect the high-voltage transmission line.

Each community is electrified through a lateral medium-voltage connection. The lateral connection from the shield wire may be aerial or underground, but where budgets are tight the aerial solution is

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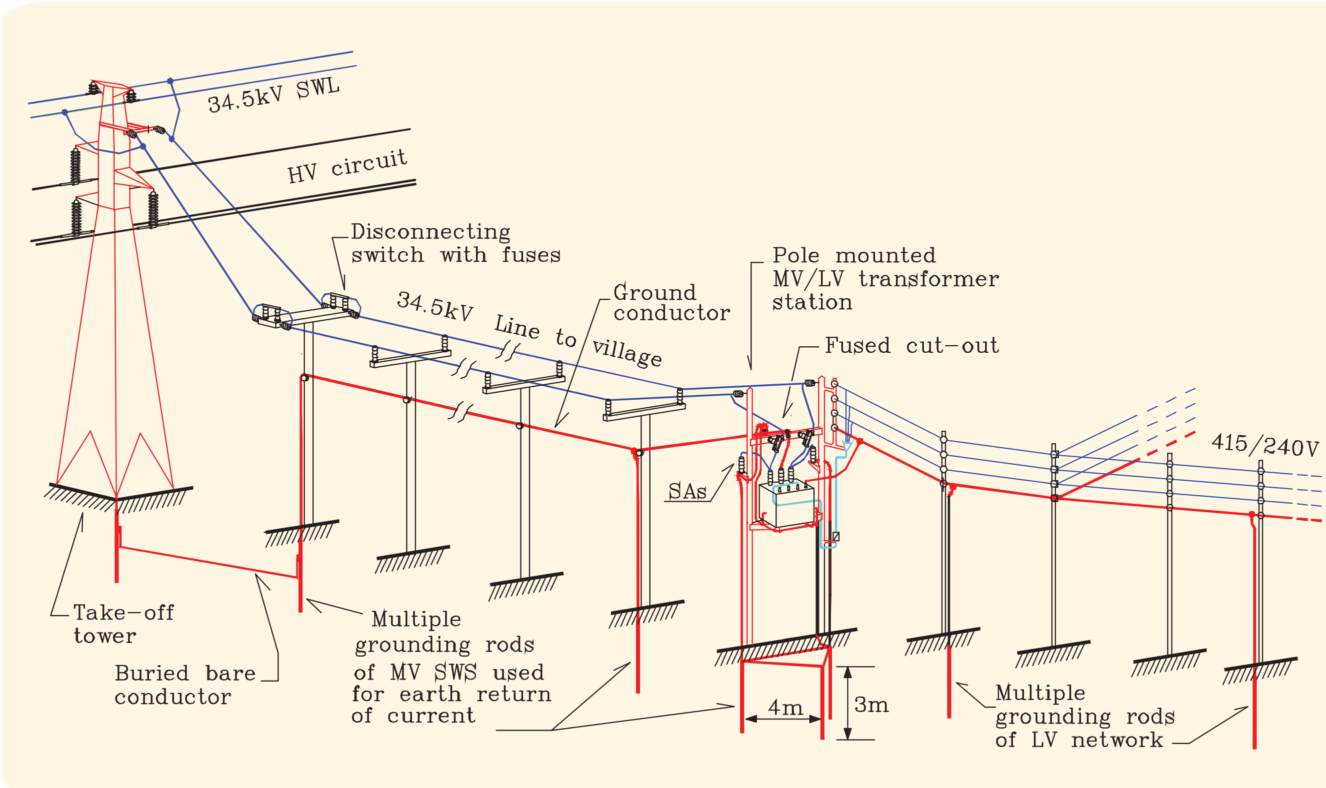
Figure 1. SWS with two shield wires with ground as the third phase conductor



Note: HV = high voltage; LV = low voltage; MV = medium voltage; SWL = shield wire line; SWS = shield wire scheme.

recommended. The lateral connection leads to one or more medium- and low-voltage transformers that provide low-voltage supply to consumers.

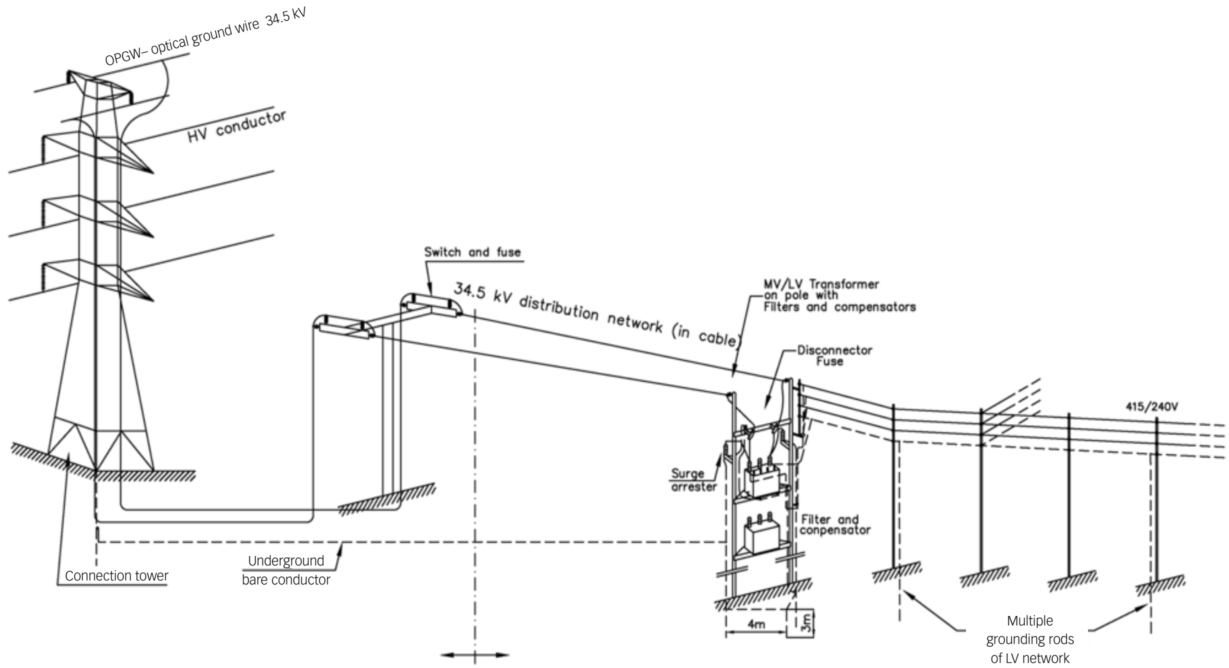
Three types of SWS are presently in operation:

- A single-phase scheme with one shield wire and earth-return of current
- A two-phase scheme with two shield wires
- A three-phase scheme with two shield wires and the ground as the third phase conductor.

Of these, the third is the most-used option, as it allows for the easy use of three-phase equipment at the customer level. Figure 1 shows a medium-voltage bypass, as well as the low-voltage power supply from an MV/LV transformer connected to the bypass.

A new three-phase version with two shield wires and a third phase conductor has also recently been designed and is currently being deployed in West Africa (figure 2). With the three-phase version, conventional equipment can be used to increase the reliability of the line and facilitate its operation.

Figure 2. New three-phase SWS with two shield wires and a third phase conductor



Note: HV = high voltage; LV = low voltage; MV = medium voltage.

The cost of making medium-voltage electricity available over a shield wire line along the route of a high-voltage transmission line is between 13 and 30 percent of the cost of an equivalent conventional medium-voltage line.

Some shield wires are equipped with optical fiber for communication purposes. Two such SWSs have been carrying communications signals for more than a decade in Burkina Faso and Togo. In some countries, such as Ghana, the SWS has been used to power a small water treatment station and a radio-television antenna.

Equipment failures have not been observed in SWSs that were properly designed and built, with good calibration of protective relays. This is the case in Ghana, where the technology has been in successful operation for more than 25 years; Brazil, where it has been operational since 1995; Lao PDR, where schemes were put into operation in 1996 and 2002; and Sierra Leone, where a scheme has been in operation since 2010. In Burkina Faso, Ethiopia, and Togo some equipment failures were caused by irregularities in acquisition or construction, primarily related to noncompliance with technical specifications.

How much do shield wire schemes cost, and what is their environmental impact?

Shield wire schemes provide medium-voltage electricity at a fraction of the cost of conventional medium-voltage lines, while minimizing environmental intrusion

The cost of insulating one or two shield wires for application of an SWS with earth-return of current involves only the procurement and transportation of insulators and fittings and their installation on existing shield wires. To estimate the additional costs of the three phase SWS (with the earth as a conductor), the following types of items should be taken into account:

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- On the transmission line: Insulators, fittings, the cost of additional shield wire and structural members, and the impact of these on the bearing capacity of towers
- At the supply bay for the shield wire line in the HV/MV station: Interposing transformer when needed, as an alternative to the tertiary winding of the HV/MV main transformer
- The cost of the resistance-inductance grounding circuit, the cost of the capacitor bank, and the supply bay of the SWS.

The total additional cost of a three-phase SWS with two aluminum-conductor, steel-reinforced (ACSR) shield wires having a cross-sectional area of 1 cm^2 and a length of 100 km is estimated at $3,390/km. For the new three-phase SWS with a third conductor, the estimated investment cost rises to $7,590/km. Both are far less than the estimate of $26,100/km for a 30 to 34.5 kV three-phase independent line with ACSR or all-aluminum-alloy conductors of the same area and an average span of about 230 meters.

In other words, the cost of making medium-voltage electricity available over a shield wire line of 100 km along the route of a high-voltage transmission line is between 13 and 30 percent of the cost of an equivalent conventional medium-voltage line.

Moreover, the installation of shield wire lines avoids the need to acquire an independent right-of-way, which would be necessary for an independent medium-voltage line. (Even if the new medium-voltage line were routed along the high-voltage line, the right-of-way would have to be widened.) Creating a new right-of-way or widening an existing one for an independent medium-voltage line could affect local agriculture and forestry and mar the landscape. In operation, the shield wire line does not require dedicated periodic bush clearing and patrolling, as these activities are already performed for the high-voltage line.

Summing up ...

Shield wire schemes are an attractive option for rural electrification

Shield wire schemes are based on a simple technology. They use conventional equipment to supply electricity with a load capacity of 3–5 MW to communities located within 20 km of a high-voltage transmission line, thus eliminating the need for additional substations. Depending on the desired specifications, schemes cost between 13 and 30 percent of an equivalent independent medium-voltage line, making them a very attractive option for rural electrification, particularly for remote and sparsely populated communities that might otherwise be too expensive to connect. SWSs have been operating successfully in and beyond Sub-Saharan Africa for more than a quarter-century, providing access to electricity to 135,000 previously unserved customers.

When designed and installed to appropriate specifications, the technology has proven very safe in operation, with a nearly nonexistent environmental and social footprint. All of these factors, combined with the ongoing development of refinements, mean that SWS technology is becoming increasingly popular with energy actors around the world, and particularly in Sub-Saharan Africa.

Reference

Iliceto, Francesco. 2016. *Rural Electrification with the Shield Wire Scheme in Low-Income Countries: Design, Construction, and Operation*. ESMAP Technical Report 010/16. Washington, DC: World Bank Group. http://documents.worldbank.org/curated/en/500631493652099113/pdf/114697-REVISED-JUNE12-FINAL-ESMAP-SWS-Manual-TR010-16-web-opt-REV2.pdf.

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