Iliceto Shield Wire Scheme (ISWS): A Leap-Frog Technique For Low-Cost Rural Electrification, Micro-Grids Connection and RES Promotion in Developing Countries. A Precious Legacy from Professor Francesco Iliceto.

M.C. Falvo, S. Maccario, F. Santi, A. Iliceto
Access to electricity in Africa

- Let us comment together some figures of African Energy Outlook 2019
- 55% of people in Sub-Saharan African lack the access to electricity (in 13 Countries, 3/4)
- Increasing share of the population without access to modern electricity (almost 70% in 2018)
Electricity Access in Sub-Saharan Africa

- Dramatic electricity access progress in East Africa from 2013
- Still, about half of the population without electricity in Sub-Saharan Africa live in 5 Countries
To reach the goal of universal access to electricity in SSA within 2030 is a challenge without precedents in the human history.

IEA «Stated Policies» Scenario 2040: > 90% of the world population without electricity will live in Africa (now 70%)
To develop a modern, adequate, reliable and resilient power system is a big challenge focusing on:

- Outages / Power Quality
- T&D losses
- Use of back-up generators
Electricity Access Solutions in Tanzania and SSA

Despite the low access rate (37%) today, the grid represents more than half of new connections by 2030 in the AC given its existing and planned coverage.

In the AC, around one-third of the remaining population, mainly located in sparsely populated areas far from the grid, would be best reached by stand-alone systems.

- Decentralised solutions seems to be the least-cost option for about 370 million people in SSA by 2030
- In Tanzania, grid >50% of new connections by 2030, 1/3 of the population best reached by mini-grids and stand-alone systems

Access in urban areas will largely be via grid connections, while decentralised solutions are the least-cost option for about 370 million people in rural areas to reach full access.

Sources: IEA analysis; KTH-dESA.
Communities That Live «Under The Grid»

**SPOTLIGHT**

What approaches can help communities that live “under-the-grid” but without electricity?

More than half of the urban population in African countries lives in informal settlements often lacking access to formal electrification services (Tusting et al., 2019). Furthermore, at least 110 million of Africa’s 600 million people without electricity access live in informal urban settlements close to or directly under a grid (GTM Research, 2017). A 2017 World Bank study on infrastructure in Africa discovered that connection rates for populations living under-the-grid is lower than 50% in most countries in sub-Saharan Africa, with a few exceptions such as South Africa, Nigeria, Gabon and Cameroon. Depending on the data source, estimates for under-the-grid populations without access to legal electricity in other African countries range from 61% to 78% (World Bank, 2017a).

prices are frequently unaffordable. Before the Last Mile Connectivity Project, the price of a connection in Kenya was around $400 per household (Lee, Miguel and Wolfram, 2016), nearly one-third the annual average per capita income and over three-times the mean of the willingness to pay of surveyed Kenyans. In Nigeria, 62% of under-the-grid households cite high connection costs as the major reason for not being connected to the grid (GTM, 2017). The Centre for Global Development estimates that there may be up to 95 million people living in under-the-grid areas in Nigeria, Kenya, Tanzania, Ghana and Liberia.

There is an urgent need for innovative approaches to provide affordable legal electricity to those living under-the-grid in African countries. A look at promising practices for

- >110 million of Africa’s 600 million people without electricity access live close or directly under a grid
- >50% of populations living under the grid in SSA lack a legal access to electricity
- Up to 95 million people living under-the-grid in Nigeria, Kenya, Tanzania, Ghana and Liberia
What is ISWS

Purpose of ISWS

- Minimisation of the cost power supply
- Innovative rural electrification solution

- It is proposed to replace the conventional connection to the grid
- It is compatible with the long distances involved and the small power required

Concept of ISWS

The use of shield wire lines for MV power supply + the use of the earth return current path =

- Insulating the SWs for MV operation (20-34.5 kV) from the towers of HV TL
- Energizing the SWs at MV from the HV/MV transformer station at one end of the HV TL
- Using the earth return of current as a MV distribution conductor
- Supplying loads by means of MV/LV distribution transformers branched between the SWs and the ground
Shield Wires of High Voltage Transmission Lines

High Voltage Transmission Line (HV TL) with 2 Shield Wires (SW)

High Voltage Transmission Line with 1 Shield Wire
ISWS Main Features

1) INSULATION OF THE SW(s)

COSTS ARE MINIMISED → 2 CASES:
- 1- HV TL already in operation
- 2- HV TL in construction (less expensive case)

ONLY COSTS OF THE ADDITIONAL MV INSULATORS AND ARCHING HORNs → They are incurred for most of the line length

Sharp cost increase: insulators have to be attached retroactively (on TL in operation already present, involving live line working).

2) MV SUPPLY OF THE SW(s)

FROM WHERE? It is typically derived from an intermediate point of the HV TL

MV VALUE? 20~34.5 kV depending on the MV used in the country

PURPOSE? Using the physical infrastructure of the HV TLs, the MV power can be transported over long distances at minimal costs

BENEFIT? Rural areas where the load demand is very low and which are far away (more than 100 km) from the HV/MV transformer station, can be economically supplied by ISWSs (rather than MV conventional system)

3) CONFIGURATIONS OF ISWS

3.1) With a single i-SW and earth return, providing a single-phase MV

3.2) With two i-SWs, providing a two wire single-phase MV

3.3) With two i-SWs and earth return, providing a three-phase MV
Single-Phase ISWS

It is applicable in HV TLs protected by one SW for single-phase MV distribution with earth return of current:

- if the HV/MV transformer station of origin of the SWL has a MV winding with the neutral solidly grounded, or if the neutral is grounded via a grounding transformer of low homopolar reactance, or via a reactor of low impedance, the SWL can be directly supplied from one terminal of the MV winding.

- if the neutral is high-impedance grounded or it has a rated voltage unsuitable for the long SWLs (too low), the SWL is supplied by an interposing transformer IT.
Three-Phase ISWS

- 3-phase more suitable for industrial / important loads
Main Benefits of ISWS Technique

**WHY IT IS WORTH USING ISWS?**

- **Low Cost** → investment cost to make the electricity available at MV with ISWS to rural areas «under the grid» is only **10~15%** of the investment cost of conventional solution (that uses long independent MV lines of the same rated voltage)

- **Reduced Voltage Drop and Power Losses** → Larger cross section of the SWs, lower losses, lower voltage drop, larger power flow

- **Low Environmental Impact** → ISWS does not increase the impact of the HV TLs, shorter MV line

- **Deterrent to Vandalism and Theft of HV Lines** → communities along the line must protect them to ensure power supply to themselves («under the grid»)

- **Upgradability** → large increase of load can be served adding new HV/MV transformer station at intermediate point (the construction of them is justified)
<table>
<thead>
<tr>
<th>Location</th>
<th>SWs</th>
<th>Starting year</th>
<th>Length</th>
<th>HV - frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghana</td>
<td>Three-phase SWs</td>
<td>1980s</td>
<td>1000 km</td>
<td>161 kV – 50 Hz</td>
</tr>
<tr>
<td>Brazil</td>
<td>Three-phase SWs 34.5 kV</td>
<td>1995</td>
<td></td>
<td>230 kV – 60 Hz</td>
</tr>
<tr>
<td>Laos</td>
<td>Single-phase SWs</td>
<td>1996</td>
<td>190 km</td>
<td>115 kV – 50 Hz</td>
</tr>
<tr>
<td></td>
<td>Three-phase SWs 34.5 kV</td>
<td>2002-2003</td>
<td>335 km</td>
<td>115 kV – 50 Hz</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>Three-phase SWs 34.5kV</td>
<td>2010</td>
<td></td>
<td>161 kV – 50 Hz</td>
</tr>
<tr>
<td>Togo</td>
<td>Three-phase SWs 34.5kV</td>
<td>-</td>
<td>265 km</td>
<td>161 kV – 50 Hz</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>Three-phase SWs 34.5kV</td>
<td>-</td>
<td>330 km</td>
<td>225 kV – 50 Hz</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Single-phase SWs</td>
<td>1990s</td>
<td>200 km</td>
<td>132 kV – 50 Hz</td>
</tr>
</tbody>
</table>

ESMAP-World Bank published ISWS Technical Manual, available on the website [esmap.org/node/57786](http://esmap.org/node/57786)
ISWS Application in Tanzania

- **2019** MoU TANESCO / UDSM / «Francesco Iliceto» Association
- **2019** M.Sc. Thesis Degree Energy Engineering: pre-feasibility study - ISWS application in Shinyanga rural areas
- **2019** Feasibility Study - ISWS Application in Tanga area (rural and industrial loads)
- **2020/2021** Tanga Demo Project implementation: engineering design, request for funding, construction
- **Post Demo Project:** if the low-cost will be effectively demonstrated, extension to the Country
- **Next Steps:** bidirectional approach to integrate local renewables / micro-grids in the grid
- **Capacity building:** «Francesco Iliceto» Association already financed two scholarships within this initiative University Sapienza will support capacity building activity and assign a M.Sc. Electrical Engineering scholarship to a UDSM graduate
  Professors Kihwele (UDSM) and Kyaruzi (UDSM; president of TANESCO) have been involved and already been in Italy to work on it – Advanced level courses at UDSM are foreseen
Survey of UDSM and Sapienza Graduates in Shinyanga Rural Area

Figure 4 – «Lusu» Substation Public HV/MV step down transformer station; on the left the oil transformer 132 kV/33kV HV/MV, on the centre the control monitor for the transformer, on the left the two Potential Transformers at HV side.

Figure 5 – Primary school in Ng’wamkanga village

Figure 6 – Chairperson’s office; surveying team

Figure 7 – High-Voltage Transmission Line Route 132 kV
### Shinyanga ISWS Pre-Feasibility Study Assumptions

**HIGH-VOLTAGE TRANSMISSION LINE:**
- **(S) Starting SS:** SHINYANGA SS  
- **(I) Internal SS:** LUSU SS  
- **(T) Terminal SS:** TABORA SS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ur</td>
<td>132 kV</td>
</tr>
</tbody>
</table>
| Length            | 203 km (S) To (T)  
|                   | 60 km (S) To (I)   |
| Type              | Single-circuit (S/C)  
|                   | Two SWs Steel 50 mm² |
| Tower             | 587 HV horizontal S/C |
| Conductor         | Single; Wolf, 150 mm² ACSR |

**HV/MV SS VISITED:**
- **LUSU SS**  
  - 132kV/33kV; 15 MVA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Public (Tanesco)</td>
</tr>
<tr>
<td>Estimated Power to be Transmitted</td>
<td>12 MW</td>
</tr>
<tr>
<td>Total Current Maximum Demand</td>
<td>1.240 MW</td>
</tr>
<tr>
<td>Current Maximum Demand for each feeder</td>
<td></td>
</tr>
<tr>
<td>1*Nzega</td>
<td>0.59 MW</td>
</tr>
<tr>
<td>2*Igunga</td>
<td>0.65 MW</td>
</tr>
<tr>
<td>3* Resolute</td>
<td>6 kW</td>
</tr>
<tr>
<td>Direction</td>
<td>Monodirectional</td>
</tr>
</tbody>
</table>

**LOADS TO BE SUPPLIED: 3 Villages**

<table>
<thead>
<tr>
<th>Section</th>
<th>Distance km</th>
</tr>
</thead>
<tbody>
<tr>
<td>LUSU-NG’WAMGANGA</td>
<td>15.58</td>
</tr>
<tr>
<td>LUSU-NDALAs</td>
<td>70</td>
</tr>
<tr>
<td>NG’WAMGANGA – HV TL route</td>
<td>1</td>
</tr>
<tr>
<td>NDALAs-HV TL route</td>
<td>2</td>
</tr>
</tbody>
</table>

**LOADS TO BE SUPPLIED: 3 Villages**

<table>
<thead>
<tr>
<th>Ng’wamganga</th>
<th>Family growth</th>
<th>523 to 540</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pd</td>
<td>0 to 2 MW</td>
<td></td>
</tr>
<tr>
<td>Ndala (x2)</td>
<td>Pd</td>
<td>0 to 2 MW</td>
</tr>
</tbody>
</table>

[Map of Shinyanga ISWS Pre-Feasibility Study Assumptions]
# Shinyanga ISWS vs. Conventional Tech. Cost Comparison

## CASE STUDY COST COMPARISON

<table>
<thead>
<tr>
<th>Implementation of a “Three-phase” ISWS to supply the unelectrified villages (4MW in tot.) with:</th>
<th>Implementation of a 30-34.5 kV three-phase independent line of 15.58 km + 70 km length to supply the unelectrified villages (4MW in tot.) with:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ACSR SWs of 100 mm² and length 15.58 + 70 km</td>
<td>I. all aluminium alloy conductor of about the same cross-section (95 mm²) supported by galvanized steel lattice poles and isolators</td>
</tr>
<tr>
<td>2. to be supplied by the tertiary winding of the HV/MV main transformer (6MVA)</td>
<td>II. including the capacitor bank</td>
</tr>
<tr>
<td>3. including the R-L circuit</td>
<td>III. including the MV supply bay</td>
</tr>
<tr>
<td>4. including the capacitor bank</td>
<td>IV. INCLUDING 10 MV/LV POLE MOUNTED TRAFOS (630 KVA)</td>
</tr>
<tr>
<td>5. INCLUDING MV SUPPLY BAY</td>
<td></td>
</tr>
<tr>
<td>6. INCLUDING 10 MV/LV POLE MOUNTED TRAFOS (630 KVA)</td>
<td></td>
</tr>
<tr>
<td>7. INCLUDING THE ADDITION OF 3 KM OF MV SPUR LINES</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>(0.3 + 0.6 + 0.25)€/m x 85.58 x 10³ M = 98,417 €</td>
<td>18.505 €/m x 102 x 10³ M = 1,583,658 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>37,500 €</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>13,400 €</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>10,000 €</td>
<td>II</td>
<td>8,400 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>45,000 €</td>
<td>III</td>
<td>30,000 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>11,937 € x 10= 119,370 €</td>
<td>IV</td>
<td>11,937 € x 10= 119,370 €</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>15,664 €/m x 3 x 10³ M = 31,328 €</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>370,679 €</strong></td>
<td><strong>1,622,057 €</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **23%**
- **100%**

### List of Sized Technical Components

- **MV convetional line**
  - Overhead conductors
  - Support/Poles
  - Insulated supports
- **MV/LV pole mounted trafo**
- **MV supply bay (involving SAs, CBs, Isolators, etc)**
- Capacitor Bank
Tanga ISWS Demo Project – Survey of Sapienza, UDSM, Tanesco
Chalinze – Hale – Tanga 132 kV (overloaded) Transmission Line

Very Low Expected Load in Shinyanga Region: TANESCO suggests a different demo project

Needs of power supply in Tanga Region (rural areas, industries, mining sites, hotels) along the route of the old 132 kV HV TL Chalinze-Hale-Tanga

Joint Survey of Tanesco, UDSM (prof. Kihwele) and Sapienza (prof. Santi): ensured pre-feasibility
Conclusions and Perspectives

- **ISWS is a precious legacy from Professor Francesco Iliceto**, a giant in power system studies
  - He did not register any patent
  - He left a fund to promote power system studies in developing countries (capacity building) and to support poor electrical engineering students (*Francesco Iliceto Association*).

- **ISWS is the cheapest technology** to electrify the rural communities «*under the grid*» (along HV TLs, in a strip of about 100km around the line). The investment cost of ISWS is **10%-15%** of the conventional MV electrification techniques.

- Compared to the conventional methods ISWS ensures:
  - the same **power quality**,
  - the same **safety**,
  - a reduced **environmental impact**,
  - a reduction in electrical **losses**,
  - a reduction in **voltage drop**.

- For developing countries / rural areas with low-density population (i.e. Sub-Saharan Africa) ISWS can be an important enabling factor of microgrids and renewables, a «*leap-frog*» towards a sustainable power system (SDG n.7).
«Lusu» substation - Day 11° of July - Prof. Santos Kiwhele with the 3 graduate students Ester (CoET-UDSM), Sara (Sapienza) and Heavenlight (CoET-UDSM)