HV Line Supports Alternatives Comparison in Remote African Areas: A Specific Example In Zambia for the Lufubu Cascade Link to the National Grid

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***Abstract*—The overhead transmission line design is one of the main services provided by SP. These transmission lines often cross areas situated far from the main centres of population. The Lufubu Cascade project in Zambia includes several overhead transmission lines (132 and 330kV). In this case, where preventing vandalism and unauthorised access is essential, the Design Pylon provides a superior alternative to the traditional lattice tower. During Lufubu transmission system design, SP has assessed the possibility of maximizing benefits of Pylons taking advantage from BYSTRUP's design by a "pros&cons" analysis with the specific purpose of minimizing vandalism acts to the line and O&M impact to investment costs.**

Keywords—Africa, Zambia, overhead transmission line, high voltage, pylons, availability, vandalism

I. INTRODUCTION

Most of the power generating plants (existing and planned) in Zambia are in the south meaning that substantial energy to be transferred over long distances to the centre and north where more than 70% of the entire load demand is located.

In 2013, the founder of the first independent power producer in Zambia, the Lunsemfwa Hydro Power Company (LHPC), with ancestral ties to this part of the country, came up with the idea of exploring the possibility of exploiting the Lufubu River for hydropower purposes, in the northern province. This is a predominantly rural province, with agriculture being fundamental for the population's livelihood, which has lagged behind in terms of development due to poor and inadequate growth-enhancing infrastructure and access to social services that have posed a challenge for development.

The Lufubu Cascade project finds ground on the planned strategy of the Zambian government, who is progressively carrying into effect the hydropower potential of the country, opening to the IPP and implementing the transmission system strengthening on vast scale looking at the neighbouring countries for energy exchange and trade purposes.

The Zambian electricity supply industry consists of three major market players namely ZESCO (Zambia Electricity Supply Corporation Limited), CEC (Copperbelt Energy Corp.) and the LHPC involved in generation, transmission, distribution and supply. System operation is coordinated by ZESCO's national control centre in conjunction with the various subsidiary control centres.

The grid is operated as part of an interconnected power system under the Southern African Power Pool (SAAP) linking South Africa and Zimbabwe to the south via 330 kV lines, and the Democratic Republic of Congo (DRC) and Tanzania to the north and east at 220 kV and 66 kV voltage respectively.

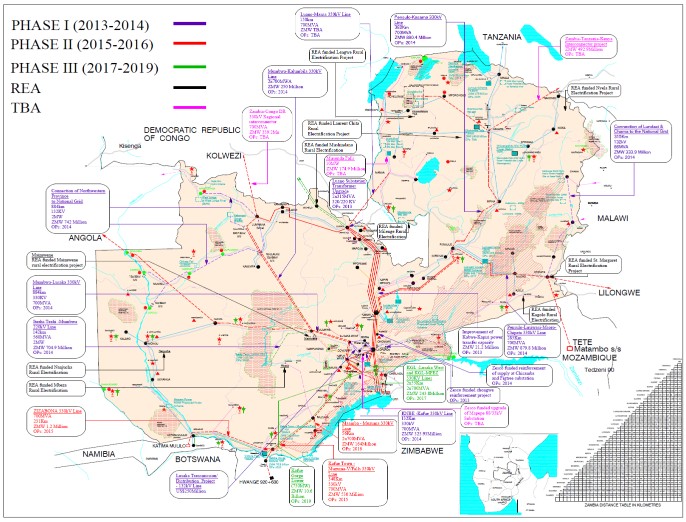

Figure 1 – Lufubu Cascade project location

Presently, the system is operated with heavy load shedding schedules due to insufficient generating capability to cover the increasing load demand, as per the expected growth in the next few years between 150 to 200 MW per annum, with a severe and immediate shortfall in supply. In the north, the Lufubu Cascade (as marked by the red circle in the next figure) will fill a geographical gap, providing a substantial input of about 330 MW to the grid, boosting by 13% the present installed capacity targeting the planned 7,350MW in 2030.

II. PROJECT TRANSMISSION SCHEME

The three plants of the cascade will be linked each other by 132 kV overhead lines (OHLs) and from the terminal substation at Lufubu 1 a 330 kV OHTL will interconnect the cascade with the national grid in the 330 kV substation at Kasama. A 330 kV single circuit overhead line linking Lufubu 1 to Kasama (201 km), rated 700 MVA is equipped with twin bundle ACSR "Bison".

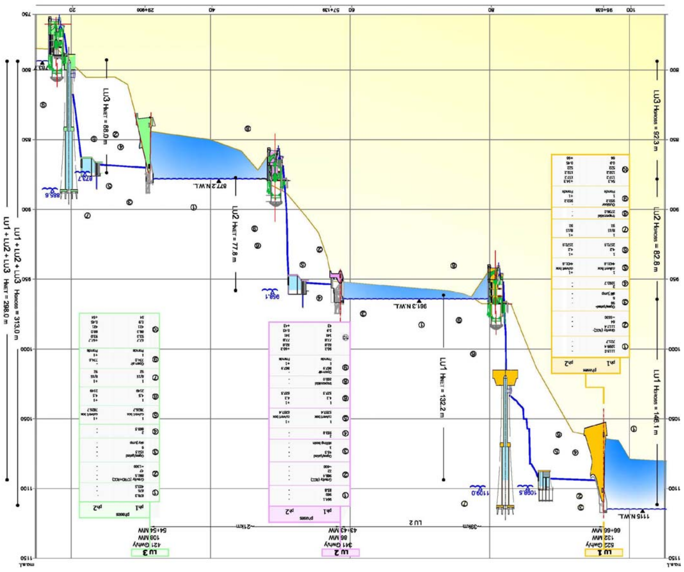

Figure 2 – Lufubu Cascade HPP, design scheme drawing

III. NEED FOR AN IMPROOVED AVAILABILITY RATE OF THE 330KV TRANSMISSION LINE

Besides feeding considerable energy production contribution into the grid, the project will support the interconnected grid with several valuable services such as voltage, reactive power, primary frequency and secondary power-frequency control (by automatic remote control of some generating units) and tertiary power-frequency control (manual by operators). It will also boost power export capability towards neighbouring countries.

Considering these features, it is worthwhile mentioning the high reliability requested to the new 330kV link feeding the national grid.

The Lufubu project area could reportedly be subject to vandalism acts to the line structures.

In view of this, possible alternatives were evaluated at the design stage for further improving safety and reliability of the project's lines.

For what the 132kV lines are concerned, the selected supporting structure is a polygonal steel pole. This option features some pros, among the others:

- difficult to climb due to unsuitable configuration offered to the intentional access
- quasi nihil absence of bolted elements to unscrew, as the pole is made of only few parts compared to the innumerable ones of a lattice tower

For what the 330kV overhead line is concerned, to accommodate the challenges in Zambia, SP collaborated with an architecture and design company, whose mission is to develop new power pylons, tailored for each client's individual need. The company already had successfully installed new design towers in Denmark, a design that could prove valuable in a Zambian context as well.

The Danish firm behind the Design Pylon was requested to assess the viability of any alternative solution.

The main pros of the "unconventional" design are:

- reduced items offered to vandalism acts, such as bolted connections and steel elements
- impossibility to climb the pole
- longer lifespan (more than 80 years compared to the 50 to 60 years of the traditional structure)
- simplicity in installation, being the foundation made by a large steel pile driven into the ground by using a hydro hammer
- time saving during erection works, as the working time for foundation piling is approximately half a day per pile, grouting included, against almost three weeks per tower foundation of the traditional design
- easiness in pole erection (less than one day per pole)
- environmental impact improvement, due to an higher integration of the pole structure with the surrounding ambient and minor visual impact
- maintenance reduced to almost zero (no routine maintenance)
- maintenance on live conductors is easier and becomes possible from a mobile elevated platform or crane with less possibility of dangerous shocks due to the reduced structures exposed

Figure 3 – 400kV line pylon installed in Denmark

Figure 4 – 400kV line pylon foundation, Denmark

Among the "contras", investment costs of the poles is more than twice the equivalent cost of a traditional lattice structure.

IV. Design Criteria and Concept

The Design Pylon has proven its remarkable benefits by being successfully installed and energized for the last ten years on a 27km line in Denmark[1]. The Pylon in Denmark is designed for a single circuit 400kV line but it is feasible for 330 kV and 132 kV in even smaller versions according to the relevant loads and specifications.

The pylon design uses a robust, tubular shaft for the first 15-20 meters above ground, making it impossible to climb and/or access for non-maintenance personnel.

Finally, the reduced size pylon means it requires a smaller corridor, is easier to transport, and leaves a smaller footprint compared to the lattice tower structure.

Using new materials, the pylon is built to last for 80 years, requiring no routine maintenance or surface treatment. A feature that can save the operator significant expenses.

The pylon can be produced anywhere in the world, providing an opportunity to keep the investment local. This is an important feature for many operators wanting to keep the large investment within national boundaries.

V. Application Background of the Design Pylons

In March 2001, Energinet.dk (the Danish transmission system operator) received a license to construct a new117km 400 kV connection between the cities of Aarhus and Aalborg.

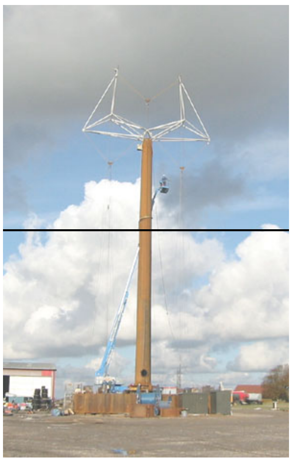

Figure 5 – Bystruo 400kV pole Prototype

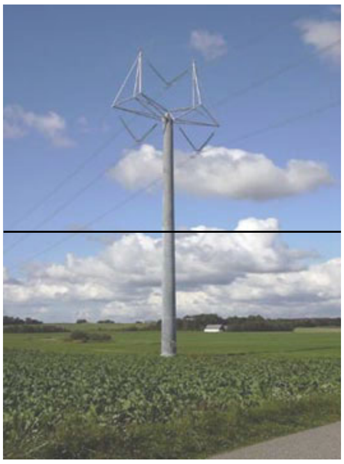

Figure 6 – V- string, insulator arrangement

Figure 7 – Angle tower @ BYSTRUP

A. Construction work and technical experiences

The line was erected during 2003. The main part of the foundation work was made in April-August, towers erection took place in June-August and conductors stringing in July-September.

Figure 8 – Steel pile

Figure 9 – Connection

Figure 10 – ready for pole @BYSTRUP

B. Foundations

The foundation is a large steel pile, driven into the ground by using a hydro hammer. This method was suitable for soil with the occurrence of sand and clay on this line. The working time for this operation is approximately 30 minutes per pile.

C. Erection of towers

The new concept for the design of the shaft and foundation was very advantageous for the erection of tower systems.

The whole operation is done in a few hours.

Figure 11 – Erection of shaft

Figure 12 – Conductors Stringing

Figure 13 – Lifting lattice top

D. Advances since 2003

Since the Design Pylon was installed in Denmark in 2003, significant progress within power pylon design, production and installation processes etc. has been made. These advances mean the pylons can be made even more cost-efficiently, for instance, instead of applying steel, poles could be produced using concrete meeting durable solution. Moreover, the poles can be directly embedded into the ground, a minimally invasive, effective method that has proven its worth in the US for years. Installation of poles can now also be done via helicopter, with up to 8 pylons installation per day, in all kinds of landscapes.

Finally, increased competition between suppliers for new pylons could lower the total cost.

VI. Economic Considerations

Before you begin to in view of setting up a comparison in between the two alternatives, namely the "traditional one" and the unconventional option, the following assumptions have been made:

- investment cost of the two options differs in supports (towers and steel pylons) supply and installation only, being almost equivalent the other items (conductors, fittings, transport, insurance, etc.)
- the traditional design incurs in O&M costs and loss of revenues, namely:
    - O&M cost in terms of 0,2% of the lattice towers supply and 0,6% of the remaining cost, per year, which gives 9,2kUSD/km every 10 years, thus about 7kUSD/km actualized cost @8% interest rate

- replacement of 3,5% (i.e. 10 pieces) of the number of towers and relevant foundations, after 50 years
- no.10 events of outage due to vandalism over 75 years lifespan (one every 10 years, the first at the beginning of the line operation), each lasting 20 days; these events result in a revenue loss of 8MUSD each (20 days x 3,7GWh/day @10,7cUSD/kWh), say 14MUSD actualized cost @8%

COMPARISON STD DESIGN - UNCONVENTIONAL DESIGN Supply and inst costs			
		STANDARD DESIGN	UNCONVENTIONAL DESIGN
Line specific cost	kUSD/km	290	366
Line length	km	201	201
Cinv'_supply	kUSD/km	172	253
Supports supply	kUSD/km	75	183
Foundations supply	kUSD/km	47	21
Conductors+GSW supply	kUSD/km	46	46
Insulators and fittings supply	kUSD/km	4	4
O&M	USD/km*y	0,92	0,30
Towers/pylons maintenance	USD/km*y	0,34	0,00
Other maintenance 0,6%	USD/km*y	0,58	0,30
Line lifespan	yrs	75	75
Interest rate		8%	8%
O&M, act, 75yrs	kUSD/km	7,9	2,5
O&M, act, 75yrs for 201km	kUSD	**1594**	**512**
Vand act loss	kUSD	**14096**	**0**
line refurbis after 50 yrs. 10 tower and foundation replacement	kUSD	526	0
line refurbis. after 50 yrs, act	kUSD	**11,2**	**0**
line installation cost	kUSD/km	61	56,2
line indirect costs	kUSD/km	57	56
Cinv per km	kUSD/km	290	366
Total installation cost, 201km	kUSD	**58314**	**73486**
Actualized investment cost	MUSD	74,0	74,0

Figure 14 – Comparison data of standard and unconventional design

The "unconventional design" incurs in the following O&M costs: no maintenance costs for steel pylons; O&M costs in terms of 0,6% of the remaining cost per year, which gives 3kUSD/km every 10 years, thus about 2,5kUSD/km actualized cost @8%.

To be noted that the pole design foundations are predominantly built by machineries instead of workmanship.

As anticipated above, the break-even point, i.e. the energy tariff that gives the economic equivalence of the two alternatives is 10,7cUSD/kWh.

In conclusion, we point out how the added value of the benefit of alleged avoided operation interruption needs to be considered with the drawback of a higher investment cost (+26%) and the uncertainty of vandalism acts occurrence (here assumed once every 10 years with a 20 days outage).

VII. Conclusions

The assessment performed jointly by SP and BYSTRUP revealed the following findings:

- undoubted advantages of the pylon design against potential vandalism and ransacking of the traditional lattice structures in Zambia
- a prevalently sandy terrain favors the pylon foundation installation
- an increase in the energy tariff above 11cUSD/kWh could tips the scale in favor of the unconventional design, as shown by the break-even analysis
- progress in innovation since 2003 increases the benefits of installing the new design in Zambia

References

[1] Oebro, H., Bystrup, E., Krogh, K., Foder, M.H. (2004) "New type of Tower for Overhead Lines", Preferential Subject PS 3 For Study Committee B2.