HVDC Opportunities for Achieving SDG7 for East Africa Region

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Abstract

Globally, and especially in developing countries, the demand for electrical power is rising. Along with climate change concerns, the increase in demand has led to rapid expansion in generation especially from renewable energy sources. Consequently the existing energy infrastructure has been left struggling to cope with power transfer levels above their initial limits. The sub-Saharan region, including South Africa, has been highly affected by the critical challenges of load-shedding, which impedes economic growth and aggravates unemployment. One obvious solution to transmission congestion is to construct additional HVAC lines as seen across the region. However, apart from the capital costs, new rights of way require environmental impact and engineering assessments, a long list of licenses, agreements, authorizations and compulsory land purchases. Thus, power transmission companies need to look for alternative technologies that can enhance power transmission and integrate renewables while maximizing existing rights of way.

In a world consumed by cost-cutting yet obliged to improve environmental impact, HVDC is the answer to this challenge faced by energy companies: move more power, more efficiently, with the lowest losses possible. As envisioned by SDG7: access to reliable, affordable and clean energy to all. The paper using a case study of East Africa argues the Africa energy sector to consider converting existing HVAC to HVDC as opposed to developing new HVAC lines especially for interconnectors across neighboring countries. The paper highlights how this will increase the capacity thus ensuring that countries are able to share cheap RE, reduces power losses and improve reliability.

Keywords: HVDC, HVAC, SDG7, Power transmission, Grid Connection, interconnector.

1) Introduction

East Africa and Africa at large is characterized by dispersed loads and generation sources spanning hundreds and in some case thousands of kilometers. With electricity demand growing daily as experienced across the continent, there is urgent need for energy sector to plan and work around the clock on moving more power to the load centers. This will play a key role in attainment of Africa climate summit 2023 resolution of Increasing Africa's renewable generation capacity from 56 GW in 2022 to at least 300 GW by 2030, both to address energy poverty and to bolster the global supply of cost-effective clean energy for industry [1]. Bulk power transmission from generation stations to the load centers is transferred using high voltage network. High voltage alternating current (HVAC) has dominated the transmission of bulk power for a long time. Despite HVAC having a number of advantages some of its pitfalls which include; high power losses, relatively lower power transfer capacity and prone to stability challenges. Therefore, to urgently address the aforementioned challenges associated with HVAC, most energy sectors are opting to use HVDC lines in this era of green energy, which are site specific, and for attainment of SDG7. HVDC power lines possess many advantages over HVAC lines in economics, high power transfer capacity, system stability, reliability, control, low short circuit current levels, structural simplicity, and low line power losses [2].

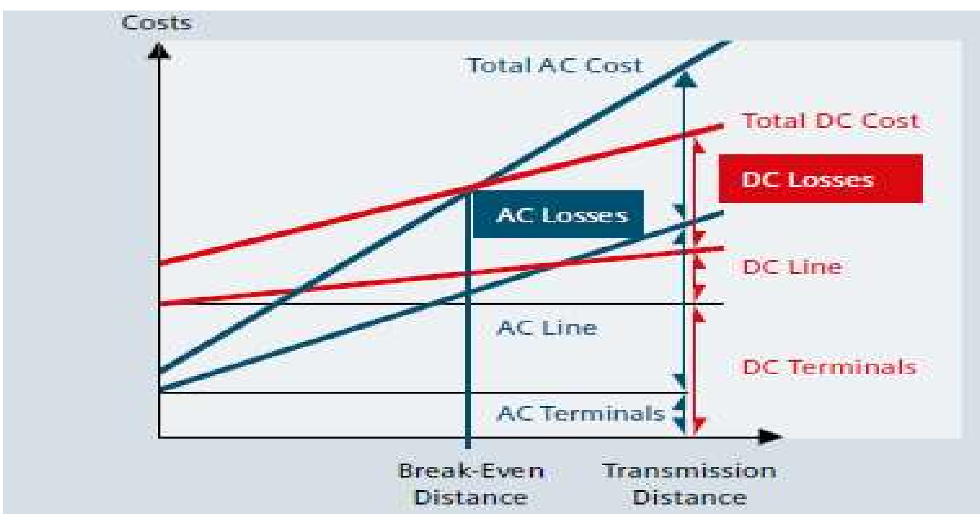

Fig.1. Comparison of Cost vs Distance between HVAC and HVDC [3].

A number of studies have shown that conversion of HVAC lines to HVDC lines increases the power transmission capability [2]. This fact lets the conversion HVAC to HVDC as an interesting alternative for the Transmission Expansion Planning, TEP, even more if restrictions to build new lines are more demanding. With East African countries struggling with the transfer of more power on the aging transmission infrastructure, HVDC offers a solution to the highlighted challenges. A DC transmission line has a lower visual profile than an equivalent AC line and so Contributes to a lower environmental impact. There are other environmental advantages to a DC transmission line through the electric and magnetic fields being DC instead of AC.

Different lay-outs can be applied for the considered HVDC link, such as a monopolar or bipolar system with ground return or metallic return. A bipolar system with ground return is chosen as it offers increased redundancy and allows some flexibility for future tappings/extensions. The increased redundancy is achieved because the system can still operate at 50% of its nominal rating in case of an outage of one converter or line. HVDC links not only decouple both HVAC systems such that faults in one system do not propagate to the other system, they can also provide grid support after an incident takes place. One of such support mechanism, which would be of interest, is to provide frequency control to the EAPP system. Countries with substantial amount of inertia and primary reserve can be offered to the systems by modifying the power controllers.

The paper proposes to the African energy sector to consider conversion of the existing HVAC to HVDC as opposed to developing new HVAC lines especially for interconnectors across neighboring countries. The paper highlights how this will increase the capacity thus ensuring that countries are able to share cheap RE, reduces power losses and improve reliability as they work towards attainment of SGD7 and Vision 2030/2063.

2) Conversion of HVAC to HVDC Transmission Lines.

The conversion of HVAC lines to HVDC is an interesting alternative recently analyzed and currently has very few cases implemented globally. Several feasibility studies for conversion of lines describe the main aspects to take into account to increase the transmission capability. Two types of line's conversion are proposed [2]:

Table 1: proposed line conversion methods

Type A:	**Type B:**
Minor modifications in the structure that can be performed by changing the allowable height of the conductors with respect to ground during the conversion process.	Major modifications of structures that do not allow conductors can be located at a suitable distance from ground during the conversion process.

Type A conversion could consider hot-line work to reduce the downtime of the line. This can be a key factor to reduce the impact on the reliability of the transmission system during the conversion process. Conversion Type B may require that the line remain out of service for extended periods, thus having a greater impact on the reliability of the system. However, the increase in transmission capacity can be higher than Type A conversion.

Table 2: shows the results of expected capacity on conversion type to be used [4, 5].

HVAC AC double circuit	Rated MW	HVDC Bipolar Topology Technology	Mw Expected	Percentage Increment	Conversion Type
145kV	110	$\pm 290kV$	390	255%	Type B
245kV	380	$\pm 490kV$	1,330	250%	Type B
520kV	990	$\pm 840kV$	3,430	246%	Type B
420kV	1,200	$\pm 400kV$	2,200	83%	Type A
287kV	560	$\pm 240kV$	863	54%	Type A
287kV	560	$\pm 245kV$	1,762	215	Type A

The conversion of HVAC lines to HVDC reduces both the cost of investment and the Break Even Distance (BED). Conversion of lines extends the distance range in which the HVDC is less expensive than HVAC for transmission lines.

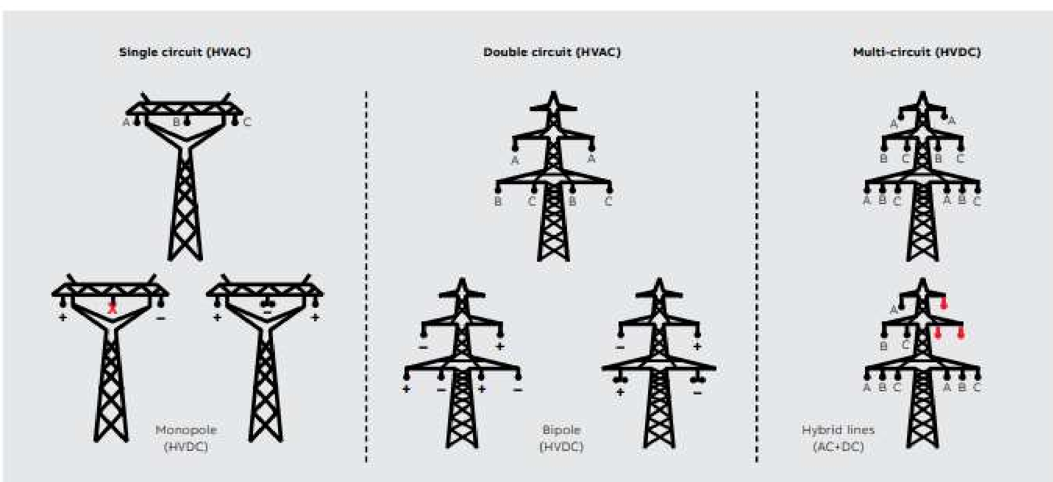

Fig2. Converting HVAC to HVDC towers

3) Methodology

In this study, two options were considered with the focus area on Lake Turkana Wind Power Plant (LTWP) to Suswa transmission corridor. The paper assumed that LTWP to Suswa is energized and operated at 400kV AC as designed. The methodology used two stages in each of the analyzed options: The computation of power losses from the transmitted power and the assessment of maximum transfer capacity of the transmission lines. The transfer capacities in both options were computed by carrying out the PV analysis and power losses were approximated by running load flow simulations. Modeling and simulations were done on Power System Simulator for Engineering (PSS/E) version 33 (see Fig. 3 and 4).

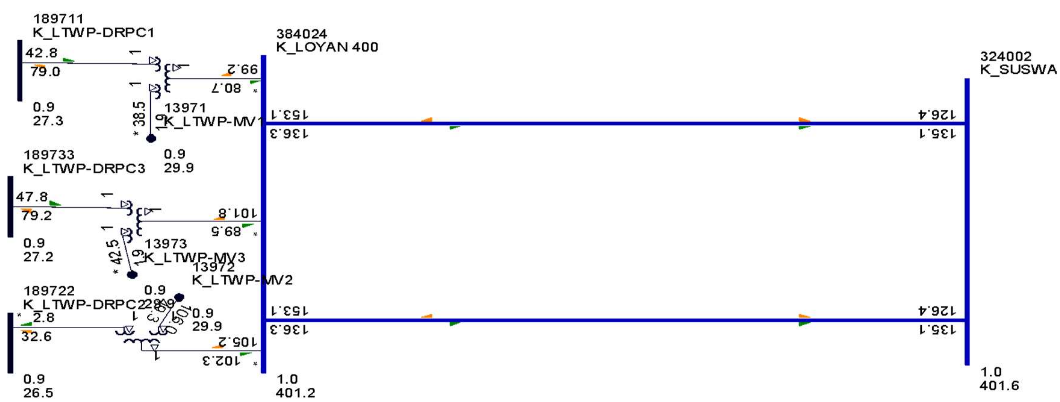

Fig. 3: HVAC for LTWP-Suswa 400kV

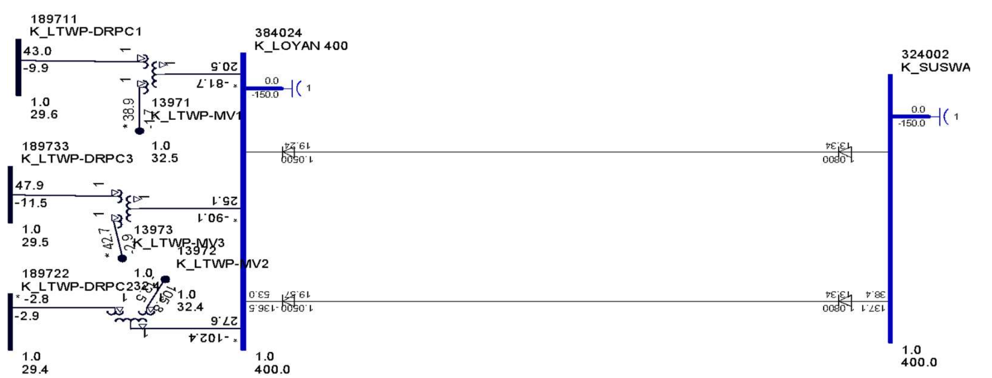

Fig. 4: HVDC for LTWP-Suswa 500kV

4) Results and Discussions

The load flow and maximum transfer capacities calculated for HVAC and HVDC systems are as shown in Table3. Fig.3 indicates that maximum transfer capacity calculated for LTWP-Suswa 400kV HVAC lines was 2360MW with the rated capacity of 3275.6MVA whereas the transfer capacity for the simulated LTWP-Suswa 500kV

HVDC was 3000MW equivalent to the rated capacity of the lines of 3000MVA. The difference in the power carrying capabilities between HVAC and HVDC arises because the transmission capacity of HVAC operates based on its operational security (voltages at the notes) and reactive power, whereas HVDC is only limited by the thermal constraints associated with the conductor. Therefore, it can that deduced that conversion of a transmission line from HVAC to HVDC might provide improved transmission capacity and reduced transmission losses.

Table 3: shows the results of capacity increase on conversion type A to be used.

HVAC AC double circuit	**Rated MW**	**HVDC Bipolar Topology Technology**	**Mw Expected**	**Percentage Increment**	**Conversion Type**
400kV	2360	$\pm 500kV$	3000	127.11%	Type A

Cost Analysis

A first basic cost estimation of the presented HVAC and HVDC options are presented for a direct connection between LTWP and Suswa. This paper considered investment calculation costs. Furthermore, the cost of the AC substations, which have to be built for all studied options, are not included. Therefore, the costs as given are merely to compare the different options and give not a good estimate of the final cost.

Table 4: cost comparison for HVAC VS HVDC

HVAC line (400 kV)	**HVDC line (VSC - 1GW – without intermediate tapping)**
Lines + compensation (400 kV double circuit)= 1.5×430 km×0.40 M$ = 258 M$ (Additional substations used for voltage control (2): 64.4 M$) Approximate total cost of double circuit =USD 322.4M	Converter stations = 2*144 M$ = 288 M$ Bipolar Lines = 430 km*0.29 M$ = 362.5 M$ Approximate total cost for bipolar converter station =USD 387.0M

Thus;

Annual cost of the power Losses

Difference in the losses between HVAC and HVDC

=4.08MW-1.1MW

=2.98MW

It is possible to establish a relationship between peak demand on a system and the average technical losses through consideration of load factors and loss load factors. Load factor (LF) is the ratio of the average demand over a period to the maximum demand within that period for the particular network and loss load factor (LLF) is the as average power losses over a period to the losses at the time of peak demand.

The formula adopted is:

$$LLF = (0.3 \times LF)+(0.7\times LF\times LF) \quad \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

As the basis for loss calculations, because the network considered is mainly transmission. Using the LLF formula stated and an assumed load factor of 0.693;

Thus:

$LLF = 0.3 \times LF + 0.7 \times LF^2$

$LLF = 0.3 \times 0.694 + 0.7 \times 0.694^2$

$LLF = \underline{0.545}$

Annual energy losses (kWh)

$$\text{Power Losses (kW)} \times LLF \times 8760\text{hrs} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Thus: $=2980\times0.545\times8760$

$\cong 14{,}227{,}116\text{kWh}$

Using data from EPRA which indicates that the average energy cost (excluding the capacity costs) in April 2022 was 10.36kshs/kWh [6], therefore, the cost benefit on the power losses gained by implementing HVDC is:

Cost on energy losses saved $= 14{,}227{,}116\text{kWh}\times10.36\text{kshs/kWh}$

$\cong$Ksh. 147.392M

From the analysis, it's clear that HVDC offers high power transfer capacity and lower power losses compared to HVAC even though the HVDC has high investment costs. However, the high investment cost is offset by the cost saved on the high-energy losses likely to be experienced with HVAC.

5) Conclusion

Based on the result of this paper with other preceding papers, the utilities within EAPP should consider the implementation of hybrid HVAC/HVDC system. By doing so, the utility company will save on cost, increase transmission efficiency and reduce socio-economic problem emanating from resettlement programs. Therefore, we recommend the use of HVDC transmission lines in evacuation of power form the isolated wind and solar generation plant which are oftentimes site specific, this will ensure reduced losses as these plants are normally far away from load center thus optimization of the green energy transition and attainment of SDG7.

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