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Analysis of power transmission using cross-linked polyethylene cables for offshore oil and gas fields

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Abstract : *The offshore oil and gas industry requires power for the subsea loads and the operations of facilities. This paper analysis uses MATLAB simulations for the modular subsea direct current system (MSDC) model to analyse the voltage drop in the transmission cable for the Akpo field with a power source of 100MW and Agbara field with a power source of 5MW located at 200km and 30km respectively from shore using the cross-linked polyethylene (XLPE) cable. Using the 132kv XLPE cable for the Akpo field analysis, a voltage drop of 0.00044% was observed for no load condition and a voltage drop of 0.00314% was observed under loading condition. For the Agbara field, it was observed that about 0.001127% voltage drop was recorded under no load condition and about 0.0047% was recorded under loading condition. The results for both fields showed a voltage drop less than 1% which validates the National Electrical code: 210-19(a), (FPN 4) and 215-2(b) which recommends a 5% voltage drop for feeder circuit. Comparing the XLPE cable with the high density poly-ethylene HDPE cable shows that results obtained from the XLPE gave a better voltage drop.*

Keywords:*Cross-linked polyethylene (XLPE), High-density- poly-ethylene (HDPE), MATLAB, National Electric code, Voltage-drop.*

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I. INTRODUCTION

Due to the power demand in oil and gas industry, and taking into consideration emission on our environment resulting from the conventional offshore platforms, an alternative power generation via a model which can be compared with clean energy power source like tidal, wind turbine etc is modelled and simulated. This is done so as to help reduce emission and cost of offshore power generations and transmission to subsea loads. Prediction is that by 2035 the production of oil and gas in deep-water is expected to reach about ten million barrels per day, equivalent to 10% of the global production [1]. Reports show that 11.5% of global emission comes from the production, storage and transportation of hydrocarbons. Also, it has been stated that the offshore oil and gas industry uses 30% more energy than strictly needed [2].

Det Norske Veritas and Germanischer Lloyd (DNV GL) ([3]) has shown the expected trend of subsea development as compared to the growth of other aspects of oil and gas development at the Norwegian continental shelf (NCS) (see Fig 1.1).

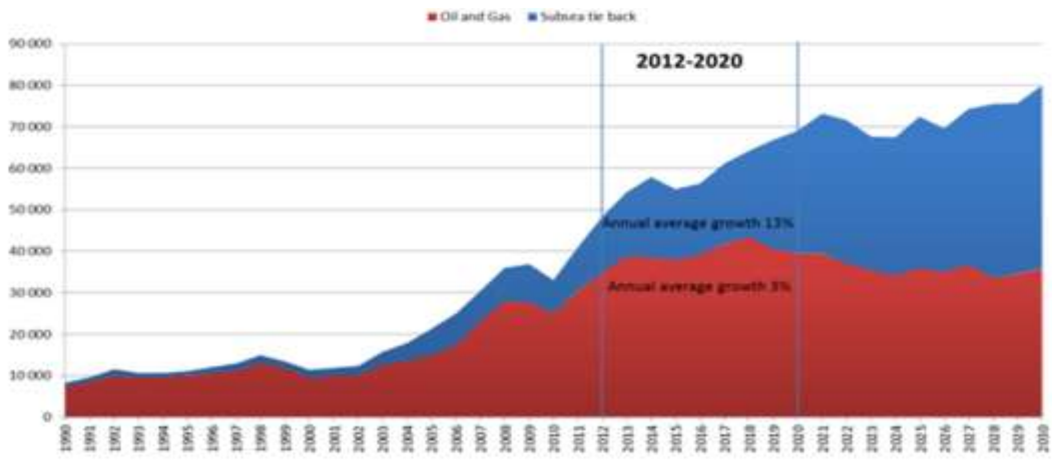


Figure 1.1: Subsea grows faster than general oil and gas at NCS (Based on figures from Rystad Energy) Source: [3].

Having seen the trend in the figure above, the focus now should be the subsea loads which consume the power. These loads include subsea pumps, compressors, subsea trees etc. The trend in the industry shows that technology improvement on subsea production has been rapid and such installations has been advantageous in cost reduction [4].

Considering the analysis made by [5], which noted that all electric subsea trees consumes lower power as compared to the electro-hydraulic subsea trees. An All-electric subsea process has been analysed but there is no wide application in the world. Analysis available like the module for the BP forties platform did not consider the supply of generated power to subsea loads [6]. Finally going by the focus of this paper of using all subsea process system on the seabed which will thereby reduce the size and weight of offshore platforms, a MATLAB simulation was done using the modular subsea direct current system (MSDC) model to ascertain losses resulting from increased stepout distances for two oil fields, namely Agbara and Akpo fields.

II. METHODOLOGY

MATLAB Simulink was used on the MSDC system which was earlier modelled using PSCAD by [7]. The simulation concept is shown in Fig 2.1.

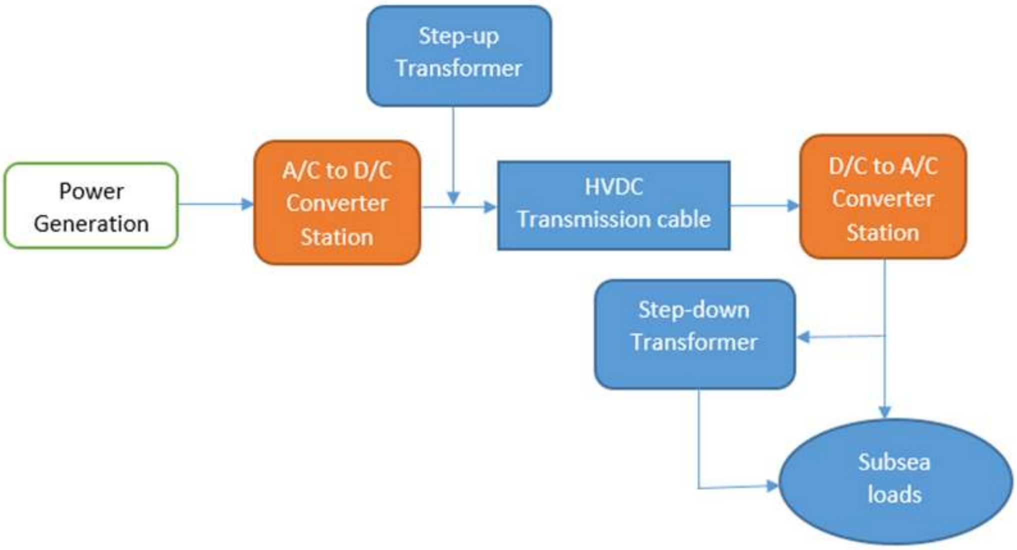


Figure 2.1: the modular subsea direct current system concept (source: [8]).

The Power source, converter station, high voltage direct current cable (HVDC), transformers and subsea loads are shown as modelled in the MATLAB Simulink. A Power of 100mw and 5mw were modelled for the Akpo and Agbara field respectively.

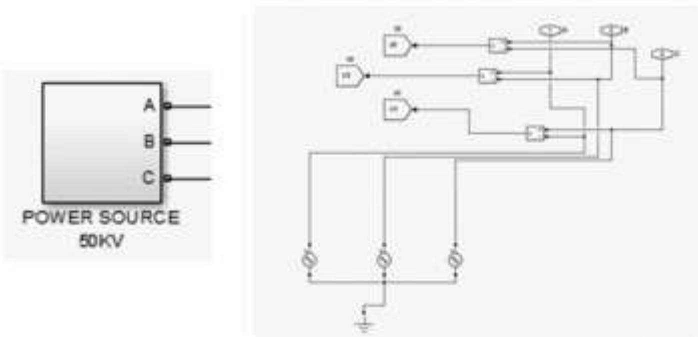


Figure 2.2: power source model from matlab simulink model

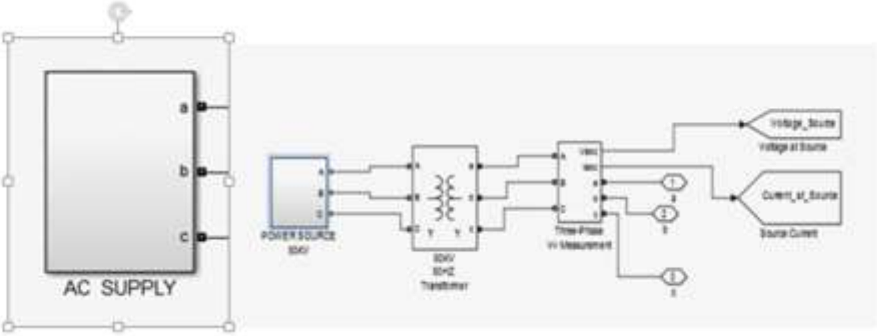


Figure 2.3: ac power supply block from matlab simulink model

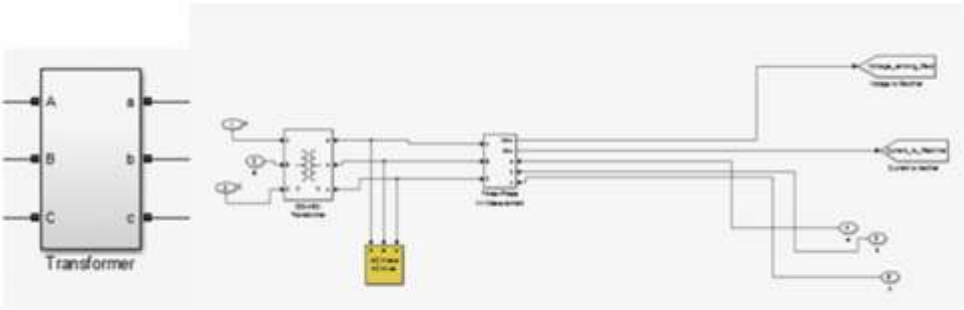
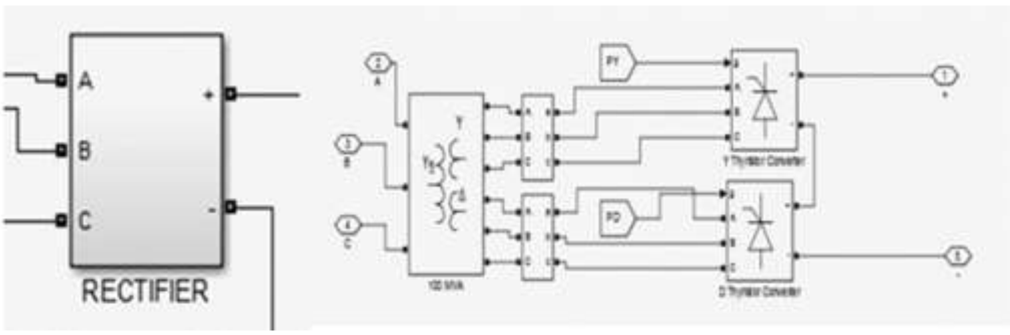


Figure 2.4: step up transformer block from matlab simulink model



. **Figure 2.5:** the rectifier block from matlab simulink model

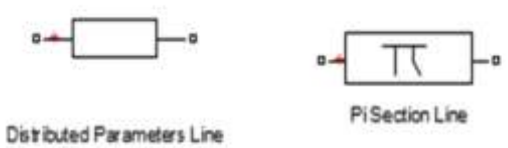


Figure 2.6: parameter and pi section line

The cable used for the simulation was modelled with the cross-linked polyethylene (XLPE) cable which is mostly preferred when using converter stations. Some major characteristics and advantages of the XLPE cable include: excellent physical and electrical properties, capability of carrying large currents. Also, it has excellent thermal deformation resistance and excellent aging property. The XLPE cables have the ability to convey current under normal condition at (90°C), Emergency condition at (130°C) and short-circuit at (250°C). Other advantages include: ease of installation, free from high height limitation and maintenance, no metallic sheath required [9].

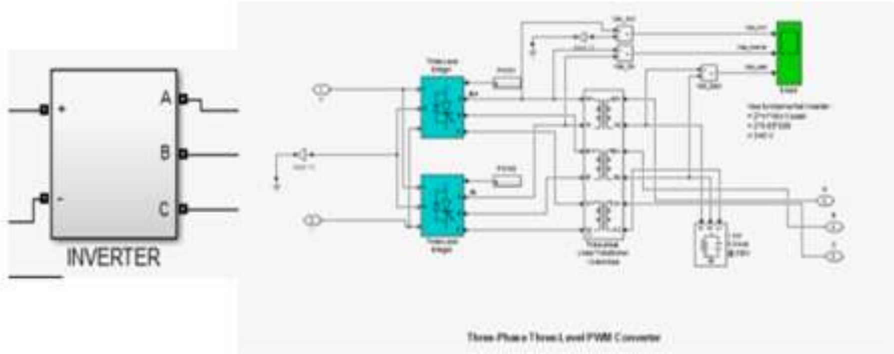


Figure 2.7: the inverter block from matlab simulink model

Fig 2.2, 2.3. 2.4, 2.5, 2.6 and 2.7 show the various stage from the power generation to the inverter section. Firstly power is generated with assumption that the power is from a grid source. The power is then sent through ac power supply source to a step-up transformer before it goes into the rectifier which converts the alternating current to DC current. Subsequently, the power is transmitted via the high voltage direct current cable to the inverter that converts the power back to AC, which is used by the subsea loads. The subsea loads were modelled using induction machines as shown in Fig 2.8. The model run under loading and no-load conditions.

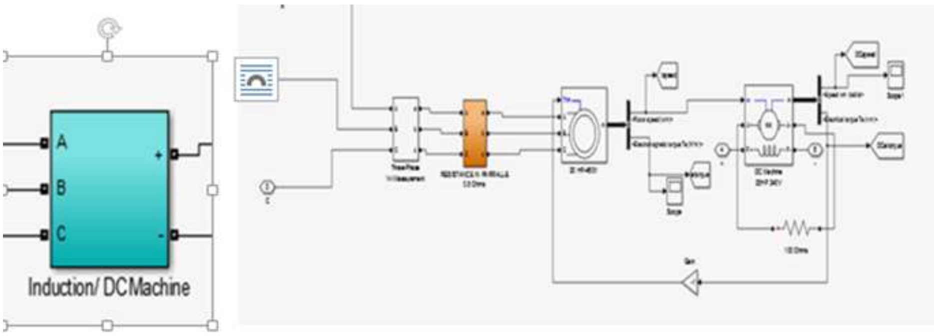


Figure 2.8: Induction/dc machine

III. RESULTS AND DISCUSSION

Results obtained from the MATLAB simulations without load and under load condition are shown in Fig 3.1 and Fig 3.2.

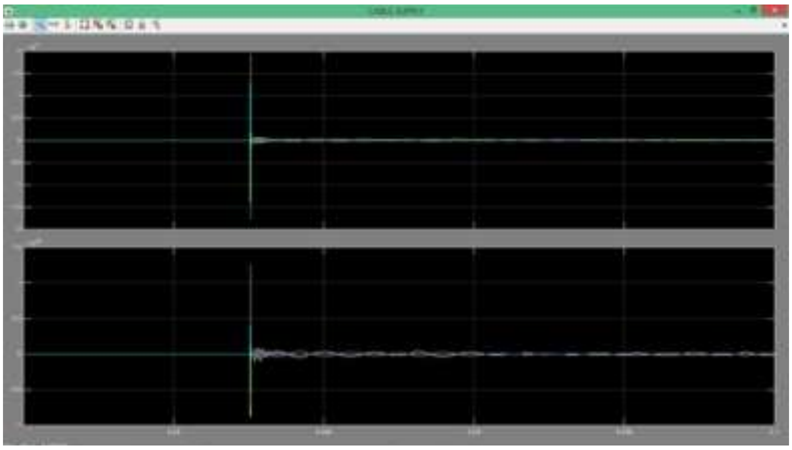


Figure 3.1: voltage and current supply to the transmission cables without load

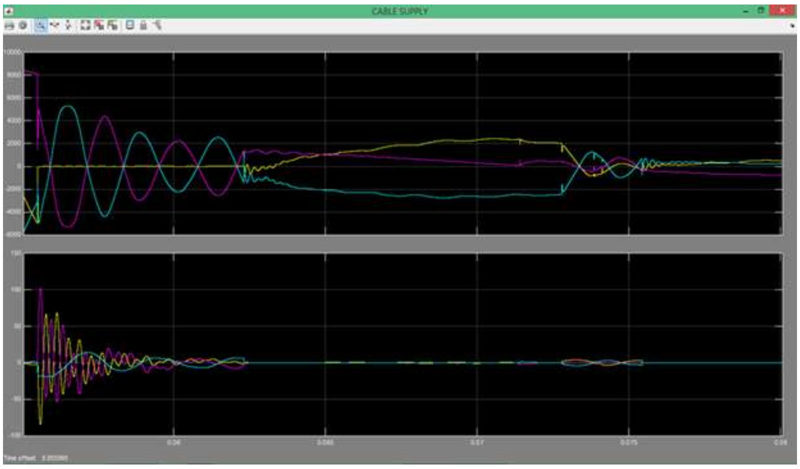


Figure 3.2: voltage and current supply to the transmission cables with load

From Fig 3.1 and 3.2 it was observed that the signal wave form increased and became bigger under loading condition in Fig 3.2 as compared to no-load condition in Fig 3.1. As shown in Fig 3.1, the wave form does not indicate any sign of power consumption by the subsea loads. Due to the fact that the Agbara and Akpo field were run for both load and no-load conditions, the signal form appeared to be similar for both cases. Losses and voltage drop were observed for both fields and the results were plotted accordingly as shown in Fig 3.3 and 3.4 for the Agbara field, while Figs 3.5 and 3.6 for Akpo field.

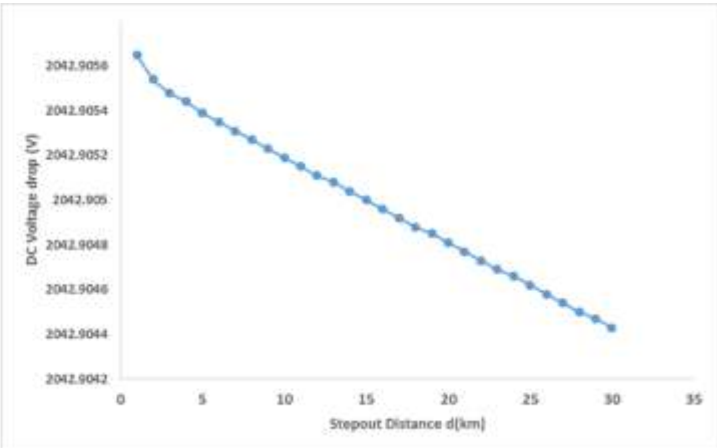


Figure 3.3: total dc voltage drop for 30km step-out distance for agbara field under load condition

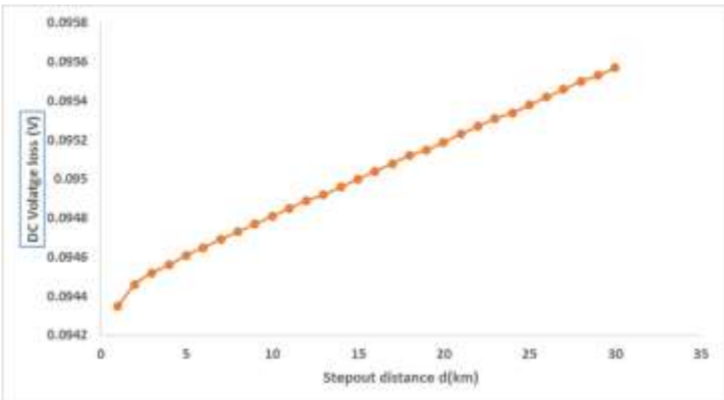


Figure 3.4: total dc voltage loss for 30km step-out distance for agbara field under load condition

From Fig 3.3 and Fig 3.4, it was observed that using a 400kv XLPE cable for the simulations, the losses increased with Voltage drop which shows that voltage drops as distance is increased. Considering the total percentage voltage drop the cable encountered on the Agbara field, it was observed that about 0.001127% voltage drop was recorded under no load condition and about 0.0047% was recorded under loading condition.

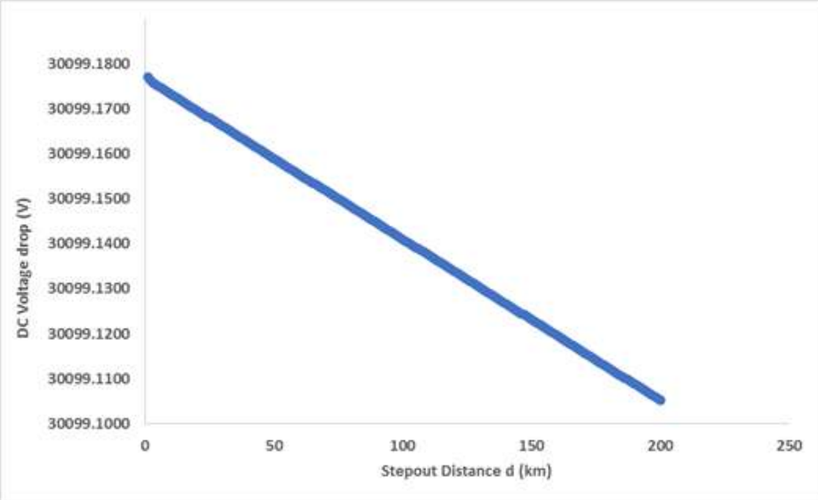


Figure 3.5: dc voltage drop for 1km to 200km under load condition for akpo field.

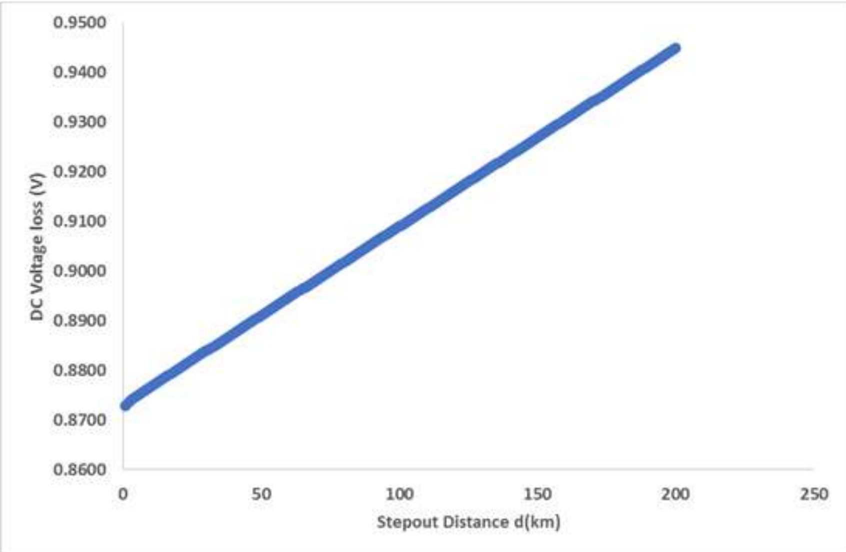


Figure 3.6: dc voltage loss for 1km to 200km under load condition for akpo field.

Similar to the Agbara field, the Akpo field simulation was done using a 132kv XLPE cable. When load and no-load conditions were compared,voltage drop of 0.00044% and 0.00314% were for no load and load conditions. Comparing this result with the National Electrical code: National Electrical code: 210-19(a), (FPN 4) and 215-2(b), shows that the voltage drop for both cases fall within the recommended percentage drop, which is five percent voltage drop for feeder circuit. Hence having a value less than 1% voltage drops for both fields shows that the simulation results were good and adhered to industry standard.

Berven in [10] carried out similar simulation for a 10.44MW power source using a high density poly-ethylene (HDPE) cable. A range 0km and 30km was covered and the results show voltage drops of 3000 volts and 2988.015039 volts respectively. Calculating the voltage drop over a 30km stepout distance gives a 0.4% voltage drop, which is similar to the values obtained for Agbara field in this study. Though, the values of voltage drop for Agbara field over a 30km stepout under a loaded condition shows that the Agbara field has a lower voltage drop over the investigated stepout distance. In relation to the Akpo field with a power of 100MW over the 200km stepout distance, the voltage drop is also less as compared to [10] results. This can be attributed to the cable selection parameters like the conductor cross sectional area which is $1000mm^2$ for the Akpo and Agbara field but $400mm^2$ for [10]. Fig 3.7 shows that plot for berven simulation over a 30km stepout distance. Similarly a Table 3.1 show comparing cable parameters for the agbara field simulation and the berven simulation parameters.

Table 3.1: Comparing cable parameters between berven parameters and Agbara parameters

Selected Cable Parameter	Berven values	Agbara values
Cable type	HDPE Cable	XLPE Cable
Cross sectional area	400 mm^2	1000 $\mathbf{mm^2}$
Cable Resistance	0.862 ohms	0.0176 ohms/km
voltage	3000 Volts	2048 volts
length per cable	20km	30km
Max. Temperature	20 degrees Celsius	20 degrees Celsius
Current	3480.278A	900 A

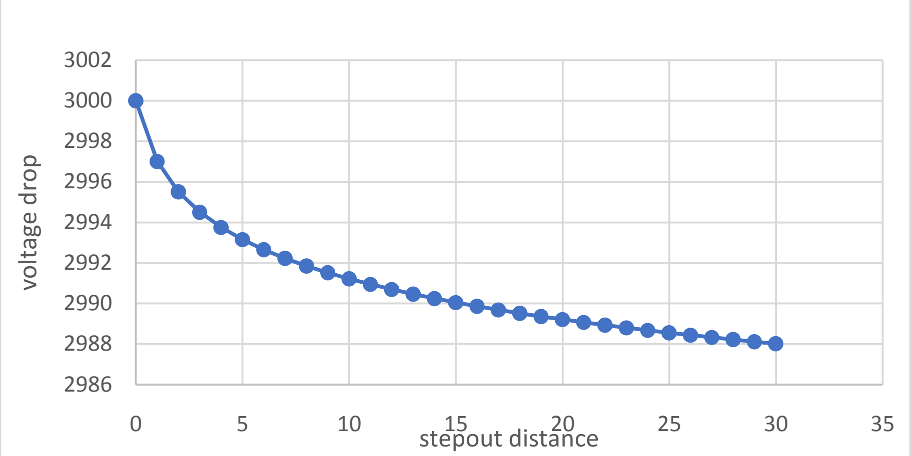


Fig 3.7: dc voltage drop for berven over a 30km stepout distance.

IV. CONCLUSION

From the analysis, it was observed that the modular subsea direct current (MSDC) system as modelled in this analysis using MATLAB, run effectively and generated results in line with industry requirement. Using 400 KV XLPE and 132kv XLPE cables for Agbara and Akpo field, the simulation results showed a voltage drop less than 1% for both cases in both loading and no-load condition which also implies that the choice of cable is good over the step-out distances. Since the losses arelow, the issue of offshore power generation where an excess of 30% of power is generated on platforms in the offshore industry can be resolved by using the MSDC system which will give the advantage of flexibility in power generation source and cable selection type. Also, based on distance, this will help reduce cost for offshore power generation and transmission to subsea loads. Finally, comparing the results of voltage drop obtained in this study with that of Berven, shows that the MATLAB simulation results presented in this study is better based on the cable parameters selected.

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