DESIGN AND MODELLING OF HVDC LINE FROM BAHIR DAR (ETHIOPIA) TO ASWAN (EGYPT)

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***Abstract:** This paper presents the design of HVDC transmission system and shows why it is preferred over HVAC transmission for power transmission over long distances. The HVDC transmission design presented here originates from Bahir Dar substation in Ethiopia and terminate at Aswan in Egypt. The total length of the transmission line is approximately 2313km. The design involved choice of the most feasible routing. The entire route was subdivided into these sections. A bipolar dc link configuration was chosen with a standard transmission voltage of +/- 800kV to transfer 2000MW power. The most economical solution for the conductor type from the design was ACSR Finch type, four conductors per pole. The conductor size was 846.6 mm^2 cross-sectional area and 32.84 mm diameter. The proper size of the smoothing reactor 200 mH was selected. Moreover, the other basic considerations in HVDC like design of line parameters, converter transformer, and harmonic filters were conducted. The designed and modelled transmission line required two converter stations; one at Bahir Dar in Ethiopia and another at Aswan in Egypt. Furthermore, during the conversion of AC to DC or vice versa harmonic contents were generated because of nonlinear loads like rectifiers, but these contents were mitigated by using harmonic filters and smoothing reactors coordinately. This paper also gives the feasibility of converting a double circuit AC line into composite AC-DC transmission line given with the advantage of stability improvement, damping oscillation and reactive power compensation for AC weak buses. Simulation and experimental studies using MATLAB 2015a Simulink model were carried out for the coordinated control as well as independent control of AC and DC power transmissions.*

***Keywords:** HVDC, HVAC, Converter transformer, Harmonics, Smoothing reactor, Filter.*

I. INTRODUCTION

Electric power transmission system play the role of transporting energy for a wide range of distances ranging from few kilometer up to hundreds even thousands km. Now a days large blocks of power are needed to be transmitted. There arises some technical problems of transmitting power to such a long distance using ac. Thus, in the view of the draw backs of ac the HVDC transmission has come into picture. Beginning with a brief historical perspective on the development of High Voltage Direct Current (HVDC) transmission systems, this paper presents an overview of the status of HVDC systems in the world today. It then reviews the underlying technology of HVDC systems, and discusses the HVDC systems from a design and modelling points of view. It has been widely documented in the history of the electricity industry, that the first commercial electricity generated (by Thomas Alva Edison) was direct current (DC) electrical power. The first electricity transmission systems were also direct current systems. However, DC power at low voltage could not be transmitted over long distances, thus giving rise to high voltage alternating current (HVAC) electrical systems. Nevertheless, with the development of high voltage valves, it was possible to once again transmit DC power at high voltages and over long distances, giving rise to HVDC transmission systems.

The development of power semiconductors, especially IGBT's has led to the small power HVDC transmission based on Voltage Source Converters (VSCs). The VSC based HVDC installations has several advantages compared to conventional HVDC such as, independent control of active and reactive power, dynamic voltage support at the converter bus for enhancing stability possibility to feed to weak AC systems or even passive loads, reversal of power without changing the polarity of dc voltage (advantageous in multi terminal dc systems) and no requirement of fast communication between the two converter stations. HVDC technology has characteristics which makes it especially attractive for certain transmission applications. HVDC transmission is widely recognized as being advantageous for long-distance, bulk power delivery, asynchronous interconnections and long submarine cable crossings. New converter designs have broadened the potential range of HVDC transmission to include applications for underground, offshore, economic replacement of reliability-must-run generation, and voltage stabilization. HVDC techniques are used in the power grid in cases where high voltage alternating current (HVAC) techniques simply cannot be used or have large disadvantages. If long distances have to be bridged, HVAC cables can no longer be used due to the high capacitive currents. From a certain length of cable on, the capacitive current is so large compared to the current that has to be transmitted, that it is no longer feasible to use AC voltage. This break-even point depends on many factors, but at present lies around 30 km for submarine cables and around 500 km for overhead lines [1].

Actually, HVDC transmission is a means for transmitting electric power over long distances.Unlike ac transmission networks, which face numerous stability problems over long distances and require extensive reactive power compensation and voltage support along the transmission line, HVDC systems require no reactive compensation, except at the two converter ends, and eliminate stability issues inherent in ac systems.Rapid controllability of HVDC links has made them ideal for connecting large ac systems in a stable manner [2].

One of the first HVDC systems similar to the ones existing now a days was implemented using mercury arc valves. In 1941 [3] a 60MW, ±200kV, 115km buried-cable link was designed for the city of Berlin (Elbe-Project); however due to the collapse of the German government in 1945 the project was never completed. The main motivation for the project was that during war time a buried cable would be less conspicuous as a bombing target and hence offered higher reliability service. The equipment was removed to the Soviet Union and was put into service there. The mercury arc valves introduced to commercial service in 1954 marked the beginning of the modern era of HVDC transmission. They were common in systems designed up to 1975 but since then HVDC systems only use solid-state devices. A significant improvement in HVDC technology came around 1970 when thyristor valves were introduced to replace mercury arc valves. This reduced the size and complexity of HVDC converter stations significantly.

1.1. Statement of the Problem

As Ethiopia possesses many huge rivers which can generate green energy at affordable cost, EEPCo is currently striving to be a power hub of east Africa by selling power to neighborhood countries like Kenya, Djibouti, Sudan, and South Sudan through long power transmission lines with in lower electrical losses and less costs. It is well known that electric power can be transmitted using either direct current or alternating current transmission systems, but several design specifications are followed in order to come up with the most feasible and reliable system. Therefore, for such kind of long distance power transmission HVDC systems are preferred over HVAC systems to satisfy the requirements of the country in an economical way. Thus, the power from Bahir Dar (Ethiopia) to Aswan (Egypt) should be transmitted with in minimal electrical losses and costs through HVDC link.

1.2. Objectives

1.2.1. General Objective

The main goal of this project is to design and model HVDC transmission line from Bahir Dar (Ethiopia) to Aswan (Egypt).

1.2.2. Specific Objectives

This paper work includes the following specific objectives:

- Study and analysis of the designed HVDC system.
- Modelling and design of main components of an HVDC transmission system.
- Show the results in MATLAB simulink model.

II. METHODOLOGY

The design methodology is based on the concept whereby a transmission line is designed.

2.1. Design of the main components of HVDC

Design of system components of the bipolar HVDC transmission system is made to fulfill the N-1 contingency criteria. And the smoothing reactor is selected based on IEEE standard general requirements. The harmonic filters are designed to fulfill the standards set by ABB group which is the worldwide HVDC equipment supplier.

2.2. Modelling of HVDC

The power circuit model consists of convertor model which is 12 pulse thyristor, convertor transformer, transmission line model, smoothing reactor model and harmonic filter model.

2.3. Design procedure

Past project regarding HVDC transmission and conversion were referred for general ideas on the components required for successful closed-loop operation. The rectifier and inverter are the three level of VSC that use the thyristor module available in the MATLAB/Simulink/ Simpower system.MATLAB software, particularly Simulink, MATLAB's graphical interface is an Environment for designing and modelling systems, was used to model various aspects of the proposed power generation and transmission system. MATLAB version 2015a, equipped with the Sim PowerSystems block set, is the software used.

2.4. Comparison of HVDC and HVAC:

Comparison of the two transmission line option is carried out based on these basic criteria's, like investment cost, power transmission capability per conductor, RoW, and corona lossses.

2.5. Choice of Transmission voltage

The line voltage determines to a great extent the cost and performance of a transmission line.

In practice it is possible to determine the economic optimum voltage for lines more than 30km long using the following empirical formula [4].

$$V = 5.5 * \sqrt{\left\{\left(L/1.6\right) + \left(3P/150\right)\right\}} \quad \text{, where, } V = \text{Line voltage in kilovolts} \qquad (1)$$

L = Transmission distance in kilometers.

P = Power transmitted in kilowatts

The HVDC line designed was to have a capacity of 2000MW. A bipolar scheme was adopted for the line with each conductor having to accommodate 1000MW.

$$V = 5.5 * \sqrt{\left\{\left(2313/1.6\right) + \left(3 * 1000000/150\right)\right\}} = 805.44KV$$

Thus, standard voltage of 800KV is chosen.

2.6. Conductor type and size

The HVDC line design included the economic optimization of the conductors, considering applicable international standards. The +/-800 kV, 2313km long Bipolar HVDC Line from Bahir Dar to Aswan was designed. The conductors are used to satisfy:

- Transfer of a maximum design power of 2000 MW at +/- 800 kV nominal voltages on the bipolar line.
- Transfer continuously the specified maximum continuous overload for the pole operation over ground return, assumed 1500 MW.
- Provide safety of the line, considering the mechanical loads from wind.
- Provide satisfactory radio interference (RI), audible noise (AN) and corona loss performances.

The optimal conductor selection process was complex with the choice of suitable conductor (and sub-conductors) depending on the operating voltage, the power to be transmitted and the acceptable voltage drop and losses in the conductor. Thereafter, radio interference, audible noise and corona losses needed to be evaluated to find the optimum conductor bundle.

2.7. Voltage drop considerations

For a single conductor configuration, maximum power to be transferred assuming a certain percentage drop restriction voltage is given by [5]:

$$P(\max) = V^2 / \left(\%V(drop) * R_{dc} * L\right) \qquad (2)$$

Where, V =Sending end voltage, pole to ground, in our case 800 kV.

$\%V(drop)$ =Percentage drop in voltage.

R_{dc} = DC resistance of the conductor in Ω / km.

L =Distance in km.

Thus, to transfer 1500 MW per one pole, with maximum 10% drop voltage, the pole resistance needed to be less than:

$$R_{dc} = 800^2 \big/ (10 * 1500 * 2313) = 0.018446\,\Omega \big/ Km$$

Assuming four conductors per bundle (per pole), then the resistance of a single strand used to make the four-bundled conductor was obtained by multiplying the overall calculated resistance of the bundled conductor by four which gives:

$$R_s = 0.018446 * 4 = 0.073784\,\Omega \big/ Km$$

Accordingly, conductors with electrical resistances lower than 0.073784Ω could be used in this project. The conductors with this property are: Finch, Bunting, Grackle, Bittern, Pheasant, Dipper, Martin, Bobolink, Plover, Nuthatch, Lapwing, Falcon, Chukar– ACSR types and ASTER 851 – AAAC type [6].

2.8. Radio Interference (RI), Audible Noise (AN) and corona loss performances

This involved determining the RI, AN, and corona loss performances of the conductors. These qualities depend on the surface voltage gradients of the candidate conductors. This process was done taking into account different bundle arrangements. The basis for this comparison was to get a conductor type with a surface voltage gradient lower than the acceptable surface voltage gradient for a long transmission line which is 22kV/cm [6].

2.9. Current carrying capacity consideration

This was the next step involved in determining conductor size for this project. The required current carrying capacity of the designed line is given by:

$$\mathrm{I}_L = 1500MW \big/ 800\mathrm{KV} = 1.875\mathrm{KA}$$

For the four bundled conductor line chosen, each conductor was to carry a current given by:

$$\mathrm{I}_s = 1500MW \big/ (4 * 800KV) \approx 469\mathrm{A}$$

2.10. Conductor type considerations:

- Resistance/km ≤ 0.073784Ω/km
- Surface voltage gradient ≤ 22KV/cm (IEC standard).
- Power carrying capacity ≈1500MW.
- Current carrying capacity ≈469A.
- Minimum cost.

Thus, from the above considerations a 4-Finch conductor type of ACSR is chosen. Moreover, this conductor has 1.293in=3.284cm=32.84mm diameter [7].

2.11. Line parameters design

The parameters of a transmission lines per KM per poles are obtained as follows:

The resistance of the conductor is:

$$R_{dc} = \left(\frac{0.0155\Omega}{1000\,ft}\right) = \left(\frac{0.0155\Omega}{0.3048\mathrm{K}M}\right) = 0.05086\,\Omega/\mathrm{KM} \qquad (3)$$

The inductance and capacitance of each poles are also given by the empirical formula [8] as shown below:

$$L = 0.2 * \ln\left(D_m \big/ D_s^b\right) \mathrm{mH} \big/ \mathrm{KM} \qquad (4)$$

$$C = 0.0556 \big/ \left(\ln\left(D_m / r\right)\right) \mu F \big/ \mathrm{KM} \qquad (5)$$

Where, D_m = Geometric mean distance.

$D_s^{\,b}$ = Geometric mean radius.

$$r = \frac{3.284 * 10^{-2}}{2} = 1.642 * 10^{-2}\,m \text{ is the radius of the conductor.} \qquad (6)$$

As we have assumed four bundled of conductors per pole as shown below, the geometric mean radius of the conductor is found as follows:

Figure 1: (a) Four conductor per phase and (b) Bundle of conductor's configurations

Considering the two poles separated by 15m, the values of L and C will be calculated as given below.

First, the geometric distance $D_m = 15\text{m}$ and the geometric mean distance from figure 1 (b) D_s^b is:

$$D_s{}^b = \sqrt[m^2]{\left(\left(D_{11}D_{12}\ldots D_{1m}\right)\ldots\left(D_{m1}D_{m2}\ldots D_{mm}\right)\right)} \qquad (7)$$

Where, $m =$ number of bundle of conductors and $D_{1m} =$ the assumed distance between the conductors 1 and m etc.

$$D_s{}^b = 1.091\sqrt[4]{\left(D_s * d^3\right)}, \qquad (8)$$

Where, $D_s = 0.7788 * r$

$d = 1.293in = 2.54 * 1.923 = 3.284 * 10^{-2}\, m$ (i.e. the diameter of the single conductor).

So, $D_s{}^b = 1.091\sqrt[4]{\left(\left(\frac{0.7788 * 3.284 * 10^{-2}}{2}\right) * \left(3.284 * 10^{-2}\right)^3\right)} = 2.8303 * 10^{-2}\, m$

Thus, $L = 0.2 * \ln\left(\frac{15}{2.8303 * 10^{-2}}\right) = 0.12546\, \text{mH}/\text{KM}$

And $C = 0.0556 \Big/ \left(\ln\left(\frac{15}{1.642 * 10^{-2}}\right)\right) = 0.00856\,\mu F/\text{KM}$

2.12. LCC converter design

Overall 12-pulse converter models

The basic configuration of HVDC uses a three phase bridge rectifier or six pulse bridges, containing six electronic thyristors (switches), each connecting to one of the three phases power supply.

DC voltage rating: 800KV directly from the converter transformer.

System frequency: 50Hz

Source AC voltage: 400kV

Rated DC current = Rated DC power/Rated DC voltage

$$= 2000\, MW/800\text{KV} = 2.5\text{KA}$$

To fulfill N-1 contingency criteria, the converters should have a continuous and a short term overloading capability in the range of 10% to 30% [9].

The 12- pulse converter is constructed using two 6- pulse converter connected in series and phase shifted by 30 degree through star / star and star / delta transformers. The two three-phase star-delta and star-star transformer sources set the supply for 6-pulse bridges phase displaced by 30 degrees.

2.13. Commutation reactance of the rectifier and inverter

Since a too small value of the extinction angle γ will make the converter too vulnerable for commutation failures, it should never decrease below a certain minimum value γ_m (≈ 17).Values between $15°$ to $25°$ are typically used. In normal operation, the overlap angle is less than 60 ; typically full-load values are in the range of $15°$ to $25°$ [9].

2.14. Rectifier commutating reactance

The DC voltage output depends on the type of rectifier. The no load direct voltage, V_n can be obtained by: $V_d = V_n\left(\frac{\cos(\alpha) + \cos(\delta)}{2}\right)$

(9)

$\delta = \alpha + \mu$, For $\alpha = 15°$ and $\mu = 15°$

$$800 = V_n\left(\frac{\cos(15°) + \cos(30°)}{2}\right)$$

$$V_n = 873.386\text{K}V$$

$$V_d = V_n \cos\alpha - \Delta V_d \qquad (10)$$

Thus, $\Delta V_d = V_n \cos\alpha - V_d = 43.626\text{K}V$

$$\Delta V_d = R_c \text{I}_d \qquad (11)$$

The single line current of the HVDC line I_d can be obtained by:

i.e. $\text{I}_d = 1000MW/800\text{K}V = 1.25\text{KA}$

Therefor $R_c = \Delta V_d / \text{I}_d = 43.626/1.25 = 34.9\Omega$

$$\mathrm{X}_c = {\Pi R_c}/{3} \qquad (12)$$

$$\mathrm{X}_c = \frac{\Pi * 34.9}{3} = 36.5287 \,\Omega/_{Phase}$$

2.15. Inverter commutating reactance

$$V_d = V_n \left(\frac{\cos(\gamma) + \cos(\gamma + \mu)}{2} \right) \qquad (13)$$

For $\gamma = 17°$ and $\mu = 15°$ (to have a small commutating voltage drop).

$$800 = V_n \left(\frac{\cos(17°) + \cos(32°)}{2} \right)$$

$$V_n = 886.918\mathrm{K}V$$

$$V_d = V_n \cos\gamma - \Delta V_d$$

$$\Delta V_d = V_n \cos\gamma - V_d = 48.164\mathrm{K}V$$

Now, $R_c = {\Delta V_d}/{\mathrm{I}_d} = {48.164}/{1.25} = 38.5312\Omega$

And $\mathrm{X}_c = \dfrac{\Pi * 38.5312}{3} = 40.3293 \,\Omega/_{Phase}$

The bipolar line has a capacity of 2000 MW so that each pole is rated to 1000 MW. Each pole is composed of 12 pulse converters on each side of the transmission line. Pole to ground voltage rating of the 12-pulse converter is 800 kV and it is rated at 1.25 kA.

2.16. Converter transformer design

The HVDC transformer configuration of an individual project is unique to the project and determined by the sheer size of transformers in relation to the limitations in the transport infrastructure between the place of manufacture and the HVDC converter station. Here, a star ground/ Wye grounded/delta transformer is used to permit the optimal voltage transformation. It also functions to block triple harmonics produced by the converter from the receiving end.

The main driver behind size of the converter transformer is the rated power, which is a direct consequence of HVDC-transmission power capability and the transformer topology. The 12-pulse converter requires two 3-phase systems which are spaced apart from each other by 30 or 150 electrical degrees. The converter transformers are equipped with on-load tap-changers in order to provide the correct valve voltage. Hence, its rating is calculated by [10]:

$$S = \sqrt{2} * \mathrm{I}_d V_d \quad , \qquad (14)$$

Where, V_d =800KV and $\mathrm{I}_d = {\mathrm{P}}/{V_d} = {2000MW}/{800KV} = 2.5\mathrm{KA}$

Thus, $S = \sqrt{2} * 2.5\mathrm{KA} * 800\mathrm{K}V \approx 2828MVA$

2.17. Harmonic filters design

Here, in this thesis we are going to design passive filter (that is made only from passive elements – in contrast to an active filter, it does not require an external power source) because of its lower cost, reliable, easy to design and has high efficiency than active filters.

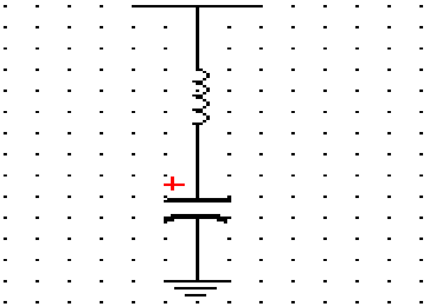

Figure 2: Single tuned filter

Now applying the empirical formula [11]:

$$\omega = \left({1}/{\sqrt{LC}} \right) \qquad (15)$$

Where, $\omega = 2\prod f$ is the angular tuned frequency in rad/s.

f is tuned frequency in Hz.

Thus, if we select the value of tuned frequency 150Hz with an inductance of 10mH.

The value of capacitance will be founded from the above equation as follows:

$$C = \left(\frac{1}{L*\omega^2}\right) = \left(\frac{1}{L*(2\prod f)^2}\right) \tag{16}$$

$$C = \left(\frac{1}{10*10^{-3}*(2*3.14*150)^2}\right) \approx 110\mu F$$

2.18. Control design of dc transmission

The current flowing in the dc transmission is determined by the dc voltage difference between the two converter stations.

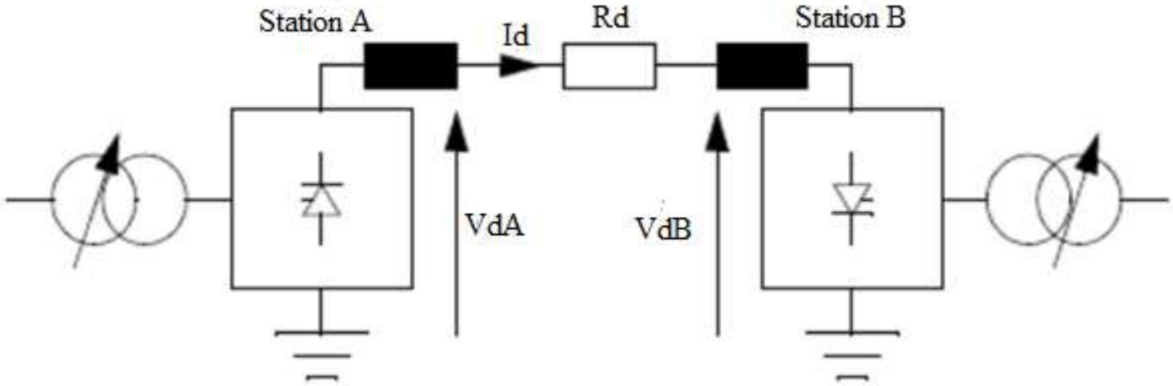

Figure 3: Control design of DC transmission [12]

Using the notation shown in figure 3 above, where Rd represents the total resistance of the line, and we get for the DC current

$$\text{Id} = \left(\frac{VdA - VdB}{Rd}\right) \tag{17}$$

Where, $VdA =$ dc voltage at station A.

$VdB =$ dc voltage at station B.

And the power transmitted into station B is

$$\text{Pd} = VdB * \text{Id} = VdB * \left(\frac{VdA - VdB}{Rd}\right) \tag{18}$$

III. RESULTS AND DISCUSSION

Here, the results of the design and modelling of HVDC transmission system is presented, and discussion about the findings will be done for selecting the best scenario among the simulation results shall be made.

As HVDC is composed of converters like rectifier and inverter which causes to produce current and voltage harmonics, filters and smoothing reactors are the applicable solutions to filter out these harmonic contents. So the effects of harmonics with and without these solutions are presented below.

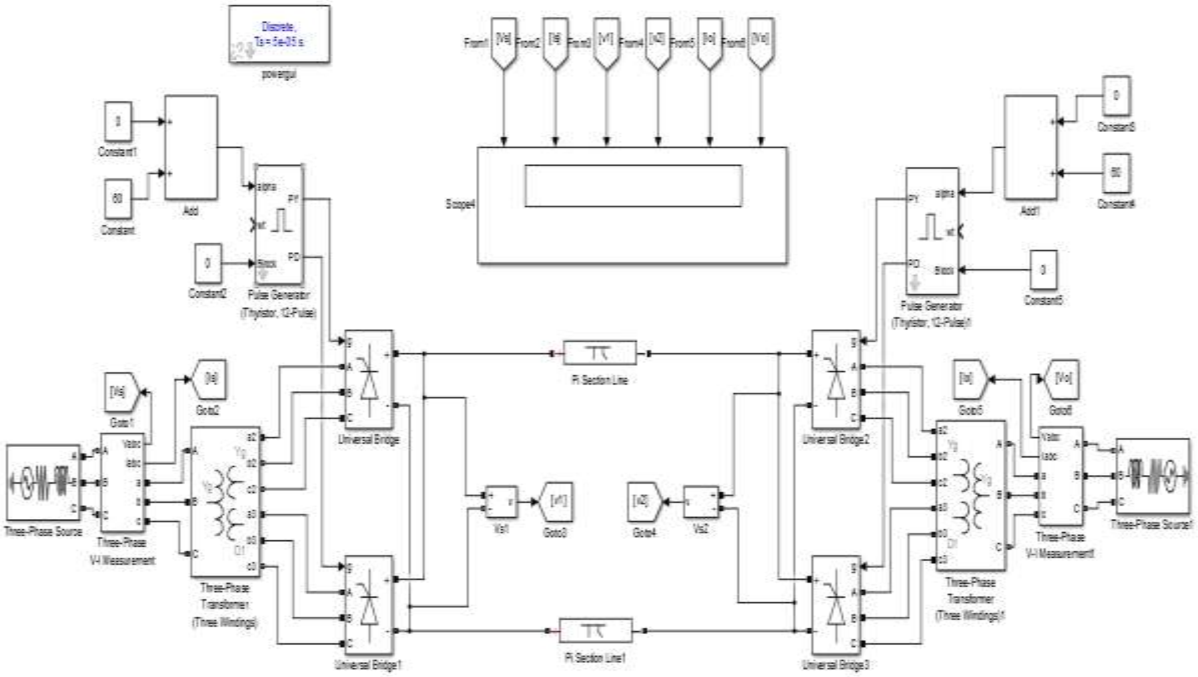

Figure 4: Block diagram of HVDC without smoothing reactors and filters

As we can see from the above diagram the components of HVDC like smoothing reactors and filters are ignored, so the effects of the absence of these components on modelling of HVDC seems as follows:

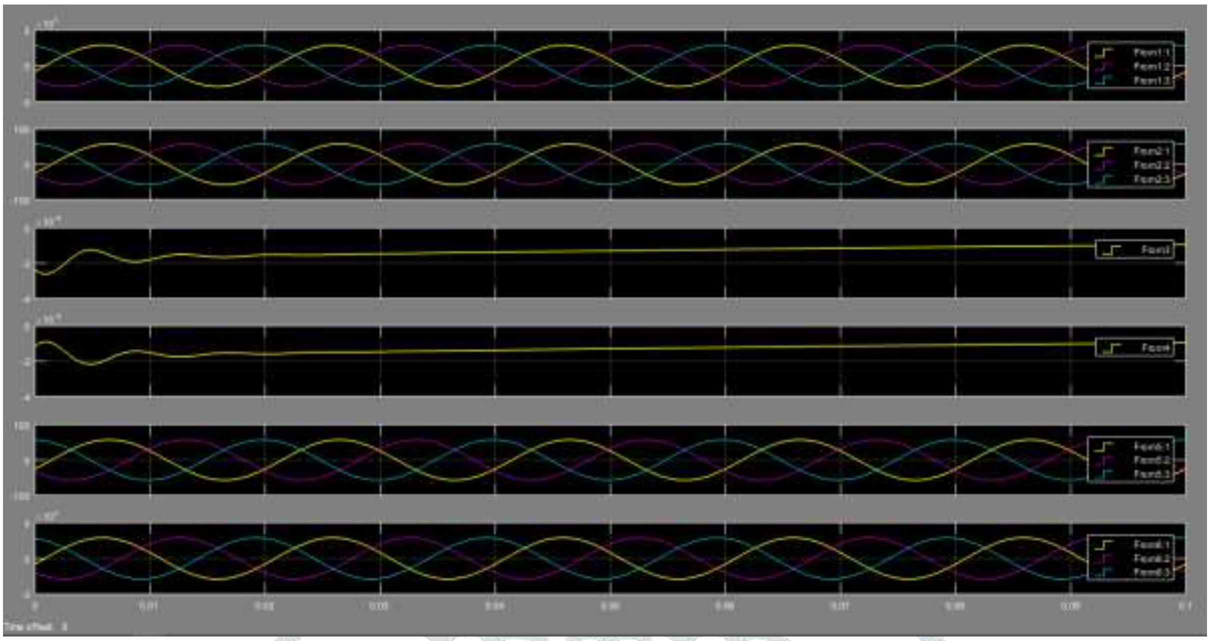

Figure 5: Simulated form of HVDC without filters and smoothing reactors

As shown in the above simulation due to the absence of filters and smoothing reactors, uncharacteristic harmonics, which are the most severe harmonics, exist. Moreover, the figure below shows HVDC system with harmonics due to the absence of filters but they are characteristic harmonics in which they will be filtered out by DC filters.

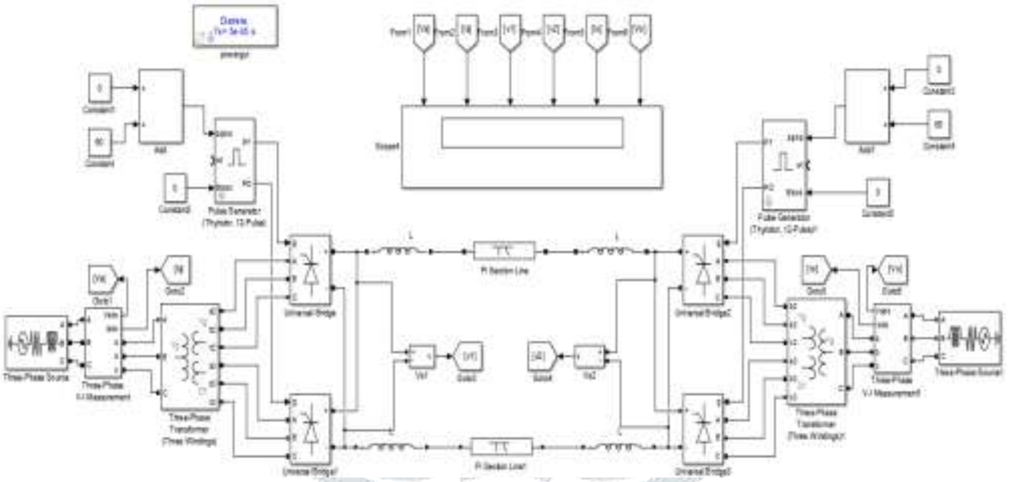

Figure 6: Block diagram of HVDC without filters but with smoothing reactors.

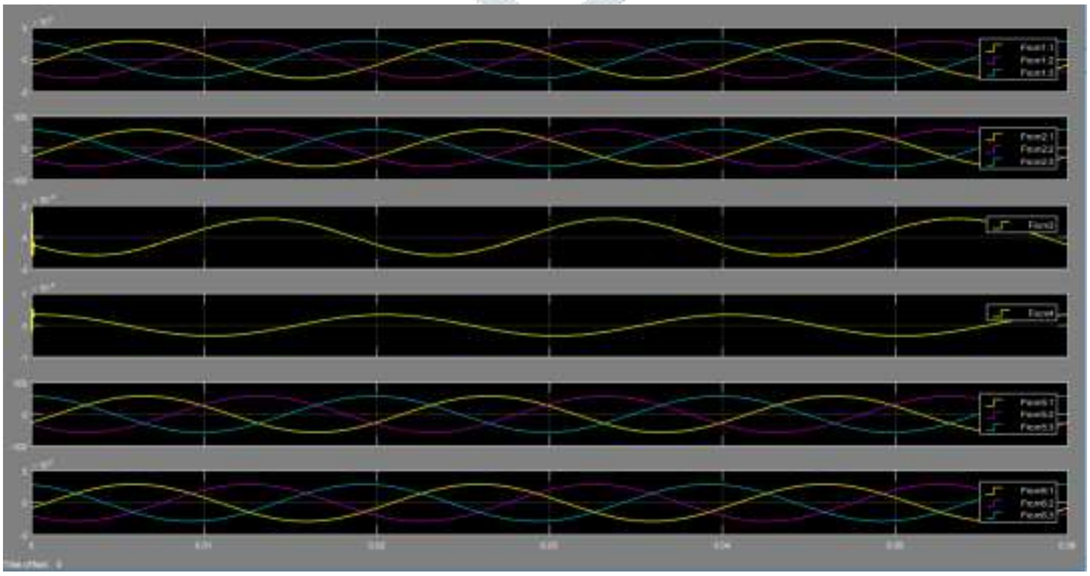

Figure 7: Simulated form of HVDC without filters but with smoothing reactor

Furthermore, most designers and researchers assumed that harmonic contents are filtered out only by either AC and DC filters or both of them, but this is an ideal. The figure also demonstrates that harmonics still exists even if filters are applied.

Similarly, as we have seen the effects of HVDC without filters and both filters and smoothing reactors, the effects of the absence of smoothing reactors is also given in figure 8 as follows.

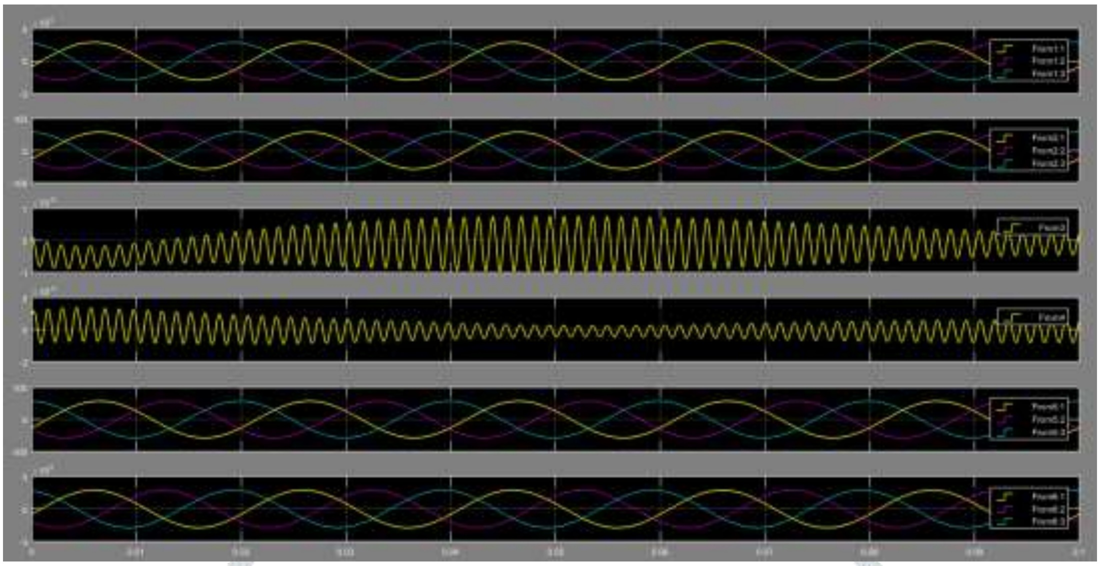

Figure 8: Simulated form of HVDC without smoothing reactors but with filter

As shown in the above simulated waveform, the filter tries to reduce the harmonic contents, but still these harmonics exist but their magnitude is reduced as time increases due to the presence of filters and absence of the smoothing reactors, so that they will be reduced more after we apply both components.

As we have discussed above the harmonic contents are not reduced as fast as possible in these all of the above cases (i.e. without filters and smoothing reactors, without filters only, and without smoothing reactors only), but their effects when applying these components on the overall model seems as follows.

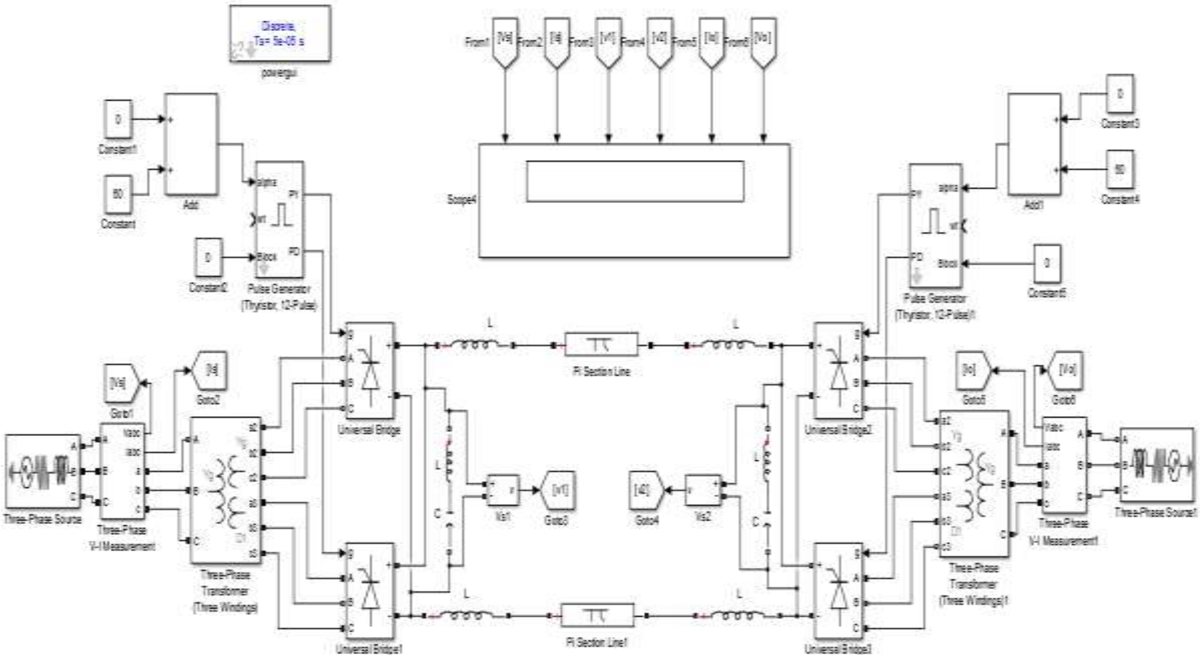

Figure 9: Block diagram of HVDC with filters and smoothing reactors

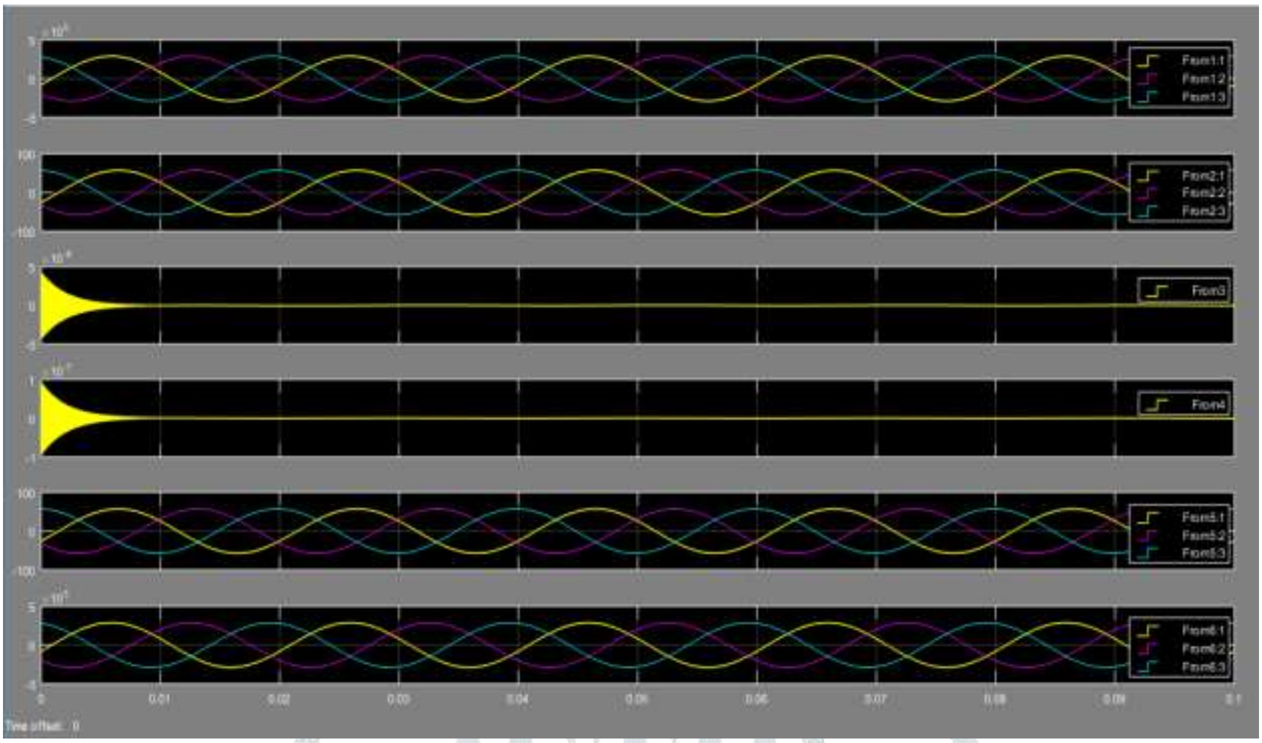

Figure 10: Simulated form of HVDC with filters and smoothing reactors

Figure 10 shows that harmonic filters are reduced more or filtered out. So, the result shows that in HVDC transmission lines harmonic contents can be present but they will be reduced more if and only if both filter and smoothing reactor are coordinately applied to these bipolar DC links. The overall simulation diagram is also drawn in the simulink model as shown below:

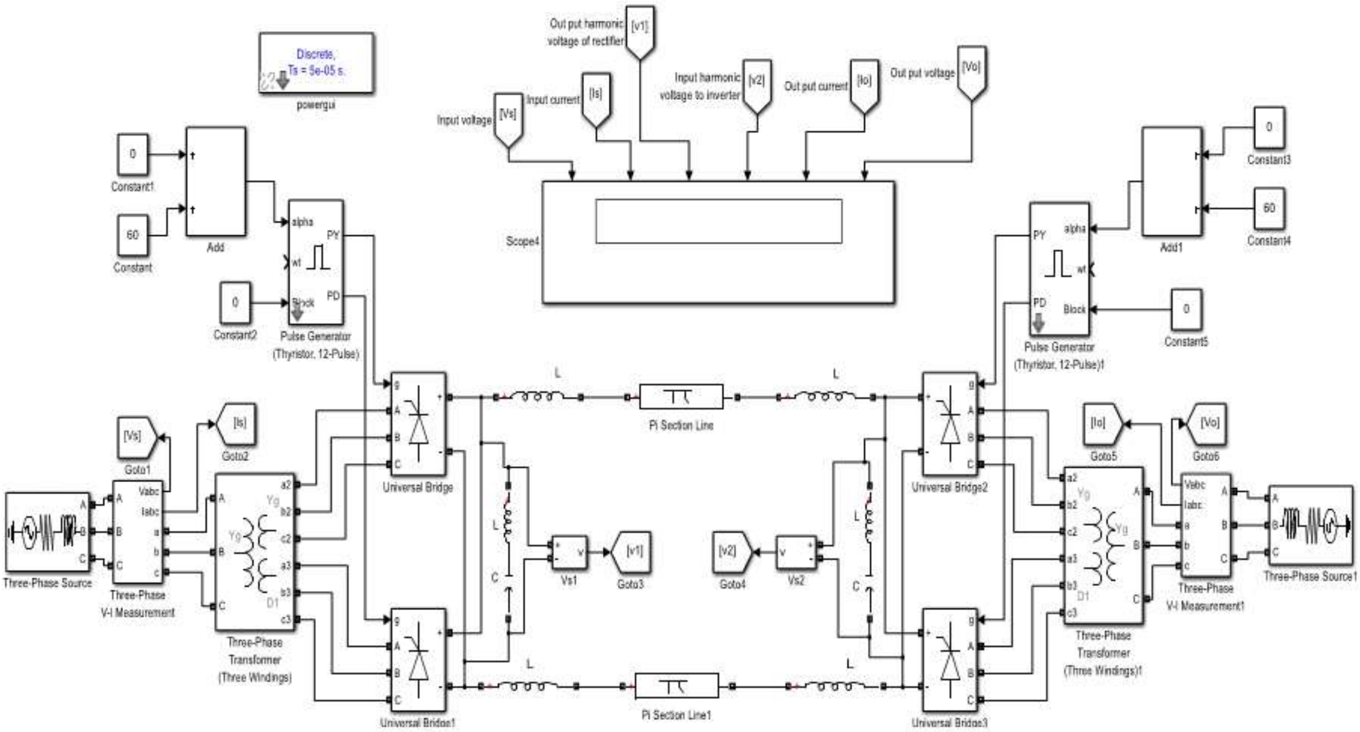

Figure 11: Overall Simulink circuit diagram of HVDC power transmission

The result of the above overall simulink circuit diagram model in Figure 11 is depicted in a complete waveforms as follows:

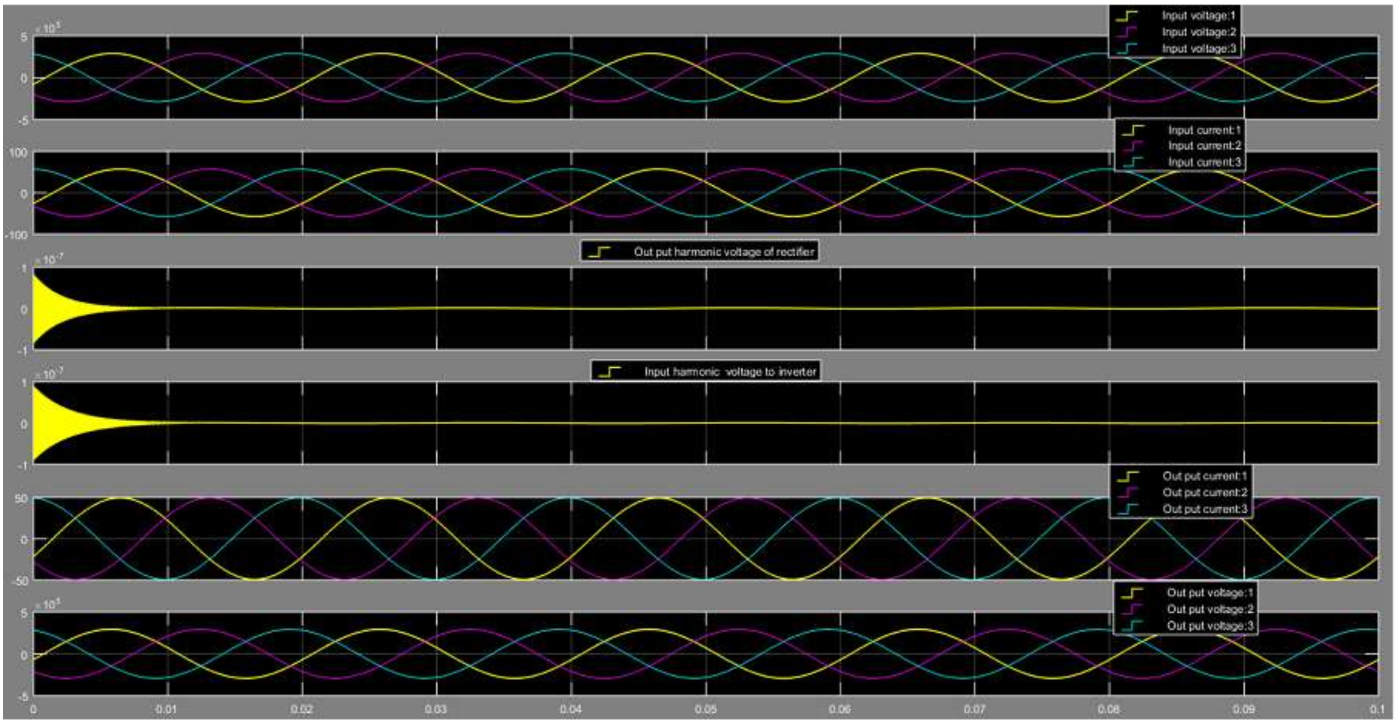

Figure 12: Complete simulated wave forms

Figure 12 shows that harmonic filters are reduced or mitigated more. That is why both filters and smoothing reactors are applied. Thus, our result understands that in HVDC transmission lines harmonic contents can be presented or exists but they will be more reduced if and only if both filters and smoothing reactors coordinately are applied to these bipolar DC links.

IV. CONCLUSION AND RECOMMENDATION

4.1. Conclusion

The design and model of HVDC transmission line from Ethiopia to Egypt was done successfully following the basic design criterias. The transmission voltage chosen was 800KV. The choice of conductor type and size was done on the basis of power losses, power and current carrying capacity and economic considerations. A 4×Finch ACSR conductor was found to be the best suited as pertains to the above considerations. As we have discussed in chapter two the components used to model this HVDC line are converter transformer, 12 pulse thyristor, bipolar dc link, harmonic filters, and smoothing reactors.

Evaluation of HVDC vs HVAC transmission system in terms of economical, technical, and environmental parameters has been carefully made, so that for this case HVDC will always give lower cost than HVAC.

From the harmonic simulation the characteristic harmonics (i.e. 5th, 7th, 17th, 19th, 29th ,31th) are cancelled out because of using 12 pulse thyristor converter and the rest harmonics were eliminated by using harmonic filters and smoothing reactors coordinately. All in all, we have designed and modelled HVDC line with mitigated/reduced harmonics applying 12 pulse thristors, filters, and smoothing reactors from Bahir Dar (Ethiopia) to Aswan (Egypt).

4.2. Recommendation

For the future project work it is recommended that, if it is possible, it would be more desirable to design the line if full information about the actual path followed by the transmission line and geological information by some kind of trip to area and map is collected for better design results.

It is also necessary if the land form, temperature, atmospheric pressure and wind data is known so that the design calculation became more realistic and applicable.

In this era of smart technologies, it will be smart for the power company EEPCo to continue to fulfil the neighborhood countries with HVDC line that have the lengths higher than 800km. For the next researchers it is recommended to design a system protection and converter station of the HVDC in detail.

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