

Simulation of HVDC Cable Transmission to an AC Optimum Signal

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Abstract

A High Voltage Direct Current (HVDC) link is used for a long-distance transmission cable to give electricity from one station to a far distance loads involving the power electronics devices. A higher non-linear power electronic device used in an HVDC system creates higher harmonic distortion that leading to inefficiencies of power transmission compare with an ideal power source which creates a smooth sinusoidal wave without harmonic distortion. A higher harmonics distortion produces a lower power factor that leading to power losses of an HVDC transmission. Therefore, a HVDC system of 11kV/132kV AC to 600 kV DC using a three-phase 6-pulse diode rectifier, LC filter, and 3 stages of boost circuit regulator is simulated. After the implementation of the 600kV direct current (DC) it step down using 5 levels of buck converter from 600kVDC to 6.144kVDC, having this an inverter was implemented to the near end of the system to convert from DC voltage to AC voltage step down to 415-V AC. This system is designed in blocks using Simulink from MATLAB software where the voltage and current waveform at the input source, the secondary of step up transformer, the rectified output, the boost output, the buck output, the AC inverter output, the secondary of the step down transformer, and the AC load were analysed and simulated. Harmonic distortion and power factor measurement are also analysed for the whole circuit.

Keywords: Rectifier, Boost, Buck, Inverter, Transformer, Ripple, Harmonic distortion, MATLAB

Introduction

High Voltage Direct Current (HVDC) is a generation of high-power direct current to enable power transmission to be able sustain enough power in a very long transmission cable. Due to demands of power cities to cities all area shows the very important usage of it. The HVDC circuit must be developed and analysed for harmonic-free in the transmission system and to improve power factor. The idea behind this paper was to optimize the voltage deliverance of high voltage direct current generation for the purpose transmission to long distance cable. The HVDC will reached upon a substation and at the substation it should going to a process of step down to a substation for the HVDC and an inverter to convert DC voltage to AC voltage and producing a 415-VAC for both domestic and commercial appliance usage.

HVDC system has advantages compared to the HVAC system. It is including a lower cost used with lower losses for a transmission line in high power electricity in long distance. HVDC system has capability to increasing the stability and prevents failure of transmission grid. However, there are some disadvantages of this technology such as the conversion of power, switching control and required availability and maintenance [2]. An HVDC system transmission that transmitting high power built with a bi-pole as two separate monopoles. A bi-pole consists of twelve pulses of switch with three winding transformers.

[1] Focus on implementation of having a positive output with Cuk converter. The Cuk converter circuit is modified with additional one capacitor in parallel to load resistance from the Cuk converter and extra one diode, the reason is the capacitor helps to boost the voltage level, while the diode is to avoid reversal negative voltage.

Since HVDC system contains power converter that has non-linear devices, it exhibits few disturbances in HVDC line, in this paper, the analysis focus onto filtering such voltage ripple in the voltage waveform and also harmonic distortion in the high voltage direct current generation for power transmission. Power converter consists of rectifier to convert the AC to DC and boost converter to step up the DC voltage. However, switch such as diodes, and MOSFET used in the power converter are non-linear devices [7]. A non-linear device creates ripple noise in the signal by means higher harmonic distortion and cause a non-unity power factor. Therefore, it creates imperfect output signal compare to the linear devices such as capacitor, resistor and inductor that have no harmonics contain in

their signal [6]. To minimize the ripple of the output signal, a filter is particularly designed.

In this paper, the design of rectifier is to obtain linear voltage of DC from AC voltage. The three-phase AC line used is 11 kV and step-up to 132 kV using three-phase transformers. This transformer secondary winding supplies the rectifier circuit to convert the AC into a DC signal. The produced DC signal is boosted using multi-stage Boost Converter to reach optimum value of 600kVDC. The reason of implementing Boost converter is because it has the properties to increase voltage from lower voltage value. The filtering system used is LC to filter the voltage noise ripple and for harmonic distortion. A multi-stage Buck converter is used to step down high voltage DC. Buck converter is implemented because it has the characteristics to lower the voltage from high voltage value. An inverter is connected after the buck converter to convert DC to AC voltage. The AC voltage is the step down using a step-down transformer to 415-VAC. To complete the simulation environment, MATLAB Simulink Tools are used to construct the circuit and to do the analysis for this simulation design.

Steps and Analysis

The work scope is focusing into simulation and design. By using SIMULINK of MATLAB-based software, the model creation is based on graphical programming environment for modelling and analysis purpose [3]. Based on this layout order the following steps are taken into creating the model circuit:

- Station construction - A generator produces an input of alternating current of 11kV AC, the transformer step up the voltage to 132kV AC and regulate it by a 6-pulse diode rectifier circuit to converting alternating current signal source to direct current signal source of $1.35 \times 132 = 178.2\text{kV DC}$.
- A LC filter is designed [4] to overcome high ripples due to non-linear devices used. This design is based on the resonance frequency, $f_r = \frac{1}{2\pi\sqrt{L \times C}}$
- Next is the DC voltage level increase by designing a Boost converter regulator circuit [8]. There are several stages of Boost converter circuit connected to obtain 600kV DC. The Boost duty cycle is D, where $\left(\frac{V_o}{V_{in}}\right) = \frac{1}{(1-D)}$. The critical inductor is $L_{cr} = \frac{RD(1-D)^2}{2f}$ and Capacitor is, $C = \frac{D}{R \times f \times \text{ripple}}$, while the resistance is $R = V_o / I_L$

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- d) By the end of long HVDC cable, a Buck converter is implemented and designed to reduce voltage. There are several stages of Buck converter circuit connected to step down the voltage to 6.144kV DC. The Buck duty cycle is $D = \frac{V_o}{V_{in}}$, inductor $L_{Cr} = \frac{R(1-D)}{2f}$, $R_{ipp} = \frac{1-D}{8 \times L \times C \times f^2}$
- e) Inverter circuit is designed [11] after Buck final stages to convert DC to AC voltage to be 4.792kV AC using the form $V_L = 0.78V_d$, a step-down transformer is implemented to reduce the voltage to 415-V AC.
- f) A power factor circuit is implemented and a total harmonic distortion (%THD) of voltage and current are measured at each stages of converter [5]. The total harmonics is analysed from the Fast Fourier Transform (FFT) in the Simulink. The measurement of total harmonics including the calculation of ripple on the waveform is taken at the output voltage and output current of the circuit.

MATLAB Simulation

Simulink by MATLAB R2014a software is used to design and analyse this work. Figure 1 shows the overall system of simulation design of block diagram used.

An 11kV three-phase AC generator source is established a connection to the three-phase transformer to step up 11kV to 132kV. From the three-phase step-up transformer, the AC input source from secondary winding is supplying an AC signal voltage to the 6-pulse uncontrolled rectifier circuit where it is operated to convert the AC signal into the DC signal. The voltage and current are only flow at the positive cycle where the negative cycle is blocked. However, on this path the ripple of the signal is high. Thus, because of the higher ripple percentage it can causes the system not to function efficiently and cause lower power factor [9].

The second part is introducing the harmonic filter that is used to reduce the ripple in the signal. Therefore, a LC-filter is designed and connected between three-phase diode rectifier and across an R load. A perfect DC output must be obtained after connected LC-filter where its ripple would be very low.

The investigation and measurement taken are in term of THD (%) using Fast Fourier Transform (FFT) and power factor of the power converter. It is measured relative to the direct current, component that producing direct current signal. Harmonic order of signal can be analysed through FFT Analysis. A small percentage of THD is needed to provide an efficient system for HVDC transmission. It can be summarized that after rectification process, a smooth DC cable is obtained with small harmonics distortion and higher power factor [10].

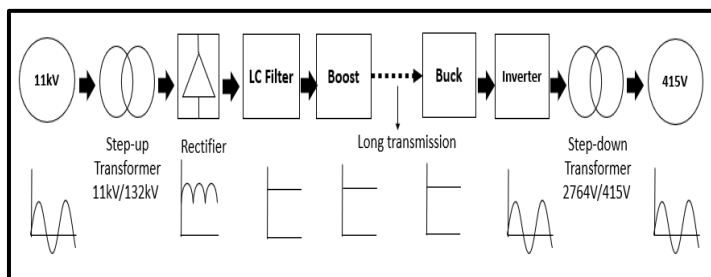


Figure 1: Block diagram overall simulation system

The third part from the block diagram is the Boost converter that is operated to step up DC voltage level. It is connected from the R load of rectifier. There are multistage of Boost converter regulator circuit connected in series. The level of DC voltage must be reach to 600kV with a small current. A small current is required in the system to prevent electrical equipment from losses and heating. The reason of using Boost converter is because Boost converter provides an efficient increase in voltage output from a smaller voltage input. Then a long cable of 600kV, and 1000 km is placed under Water Sea connecting two countries or two islands.

The fourth part of the block diagram is the Buck converter which operated to step-down DC voltage level. In this implementation, Buck converter circuit is designed and simulated. There are multistage of Buck converter regulator circuit connected in series. The reason of using Buck converter is because Buck converter provides lower output voltage from higher voltage, prior to multistage of voltage level. Fifth part of the block diagram is an inverter circuit which operated to convert lowered voltage of DC to AC voltages. After the conversion, a step-down transformer is implemented to produce a 415-V of alternating current.

Another study conducted to take reading of the power factor produced by the system. A power factor is measured from the connected blocks according

provided formula of apparent power divided with the real power. The circuit for power factor measurement is shown in Figure 13. This system aimed to obtain more than 0.9 pf. A power factor should be in the range of 0 to 1, whereas the higher power factor, the less electrical appliances to be malfunction.

Figure 2 shows the rectifier bridge, and Figure 3 shows the stages of Boost converters in Simulink, while Figure 7 shows the 5 stages of Buck converters. The simulated voltage for each stage are shown in Figures 4, 5, 6 for Boost and 8, 9, 10, 11, 12 for Buck. Table 1 summarizes the parameter values for Boost and Table 2 for Buck. Table 3 summarizes the values of voltage, ripple and THD for each stage in both Boost and Buck.

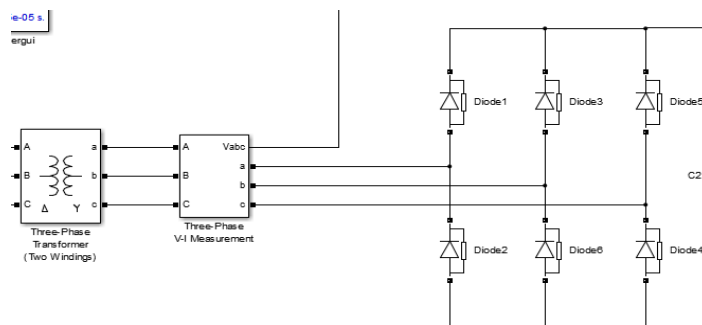


Figure 2: 6-pulses diode rectifier

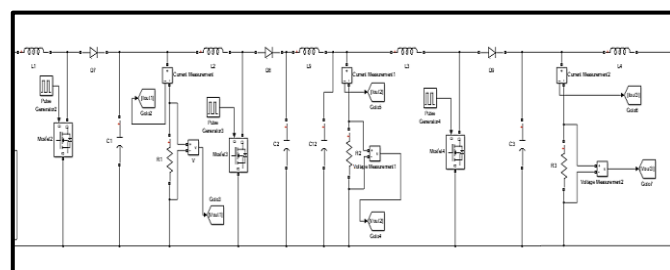


FIGURE 3: Multilevel of Boost Converter

TABLE 1: Parameter for Boost Converter Circuit

Duty cycle, D	Switching frequency, fs (Hz)	Ripple	Resistor Ω	Inductor (mH)	Capacitor, (μ F)
0.4	25000	0.00056	30000	85.950	9.842
0.4	25000	0.00006	40000	115.2	7.272
0.166	25000	0.00043	50000	115.740	2.4242

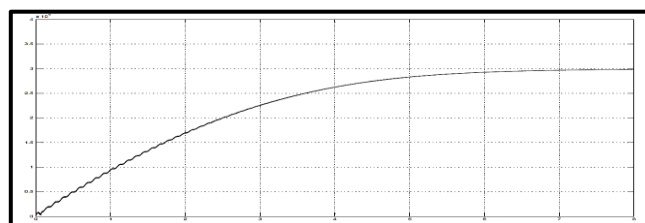


FIGURE 4: 1st level of Boost Converter 300kVDC

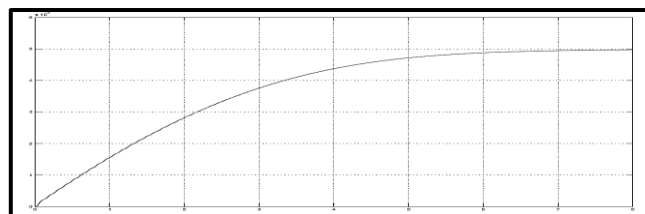


FIGURE 5: 2nd level of Boost Converter 500kVDC

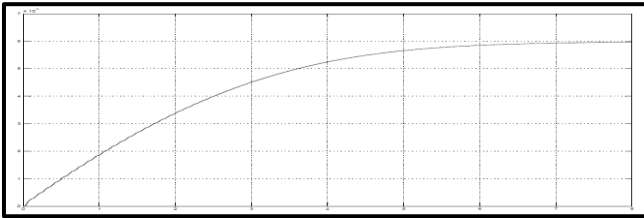
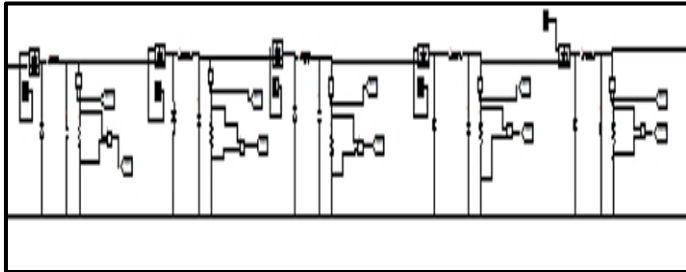
FIGURE 6: 3rd level of Boost Converter 600kVDC

FIGURE 7: Multilevel of Buck Converter

TABLE 2: Parameter for Buck Converter Circuit

Duty cycle, D	Switching frequency, fs (Hz)	Ripple	Resistor Ω	Inductor (mH)	Capacitor (μ F)
0.4	25000	0.000377	30000	360	3.333
0.4	25000	0.002197	40000	480	2.5
0.4	25000	0.018181	50000	600	2.0
0.4	25000	0.139393	60000	720	1.666
0.4	25000	0.016764	70000	840	1.428

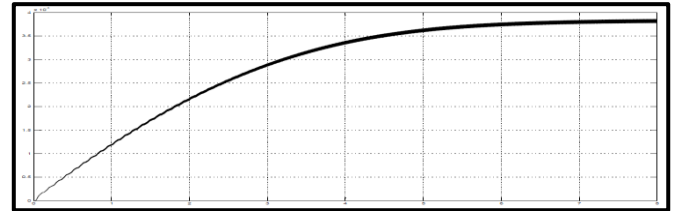
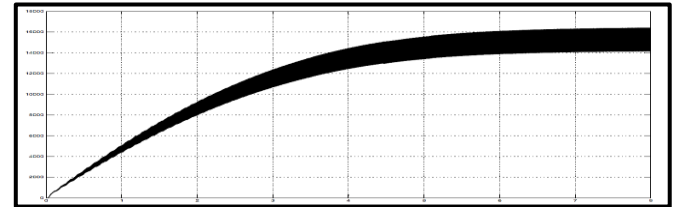
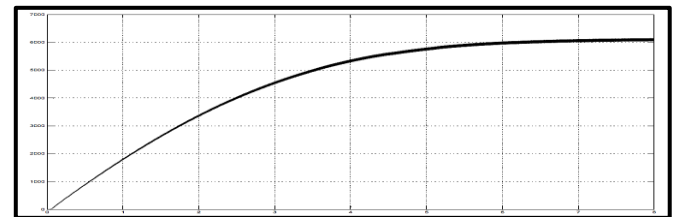
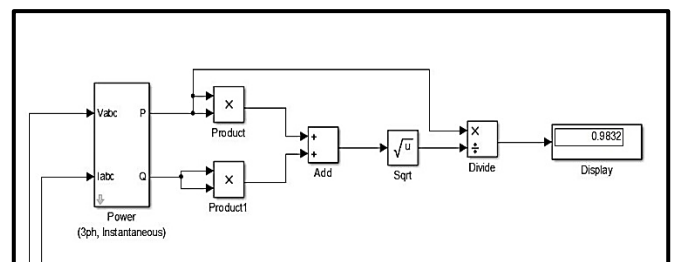
FIGURE 10: 3rd level of Buck Converter 38.4kVDCFIGURE 11: 4th level of Buck Converter 15.36kVDCFIGURE 12: 5th level of Buck Converter 6144kVDC

FIGURE 1.13: Power Factor Circuit with result of 0.98

TABLE 3: Overall Result for each Power Converter

Circuit	Stage(s)	Voltage Output	Ripple Voltage	Power Factor	THD (%)
Boost	1	300kV	0.00056	0.98	17.45%
	2	500kV	0.00006	0.98	13.87%
	3	600kV	0.00043	0.98	42.12%
Buck	1	240k	0.000377	0.98	7.04%
	2	96kV	0.002197	0.98	7.16%
	3	38.4kV	0.018181	0.98	7.09%
	4	15.36kV	0.139393	0.98	7.11%
	5	6144V	0.016764	0.98	46.21%

Converting direct current to increase voltage level by using multiple stages Boost converter, the filtering model is designed to reduce ripple of direct current signal by using LC filter. Thus, since there is two power converter, three stages of Boost converter was able to be accomplished, with a proper parameter and also result obtained, same goes with the Buck converter which accomplished to be simulated with proper parameter and also result obtained. An inverter also is implemented to suites the practicality since most appliances at home are using alternating current, then a 415V is produced from a step-down transformer which is implemented after the inverter. The step-down voltage is from 4.792kV line to 415V line. From Table 3, power factor is improved while the harmonics for Boost is sufficiently high, but the ripple is low. However, for Buck the ripple is high but THD is low with the exceptional of the last 2 stages.

Figure 14 is the Simulink block diagram of the inverter and figure 15 shows the 3-phase waveform on the load.

As the parameter values are obtained, the result is then simulated by graph and calculation. This also can be summarized of rectification process by converting alternating current to direct current signal using three-phase diode rectifier.

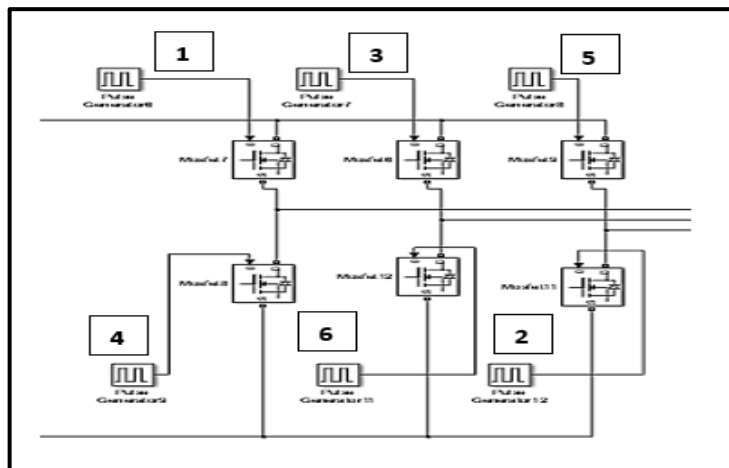


Figure 14: Circuit three-phase inverter



FIGURE 15: Three-phase 415Vac Output Voltage

Conclusion

The design started by a rectification process able to be accomplished with an input from generator to transformer and rectified to produce direct current (DC) supply. Power converter for both boost and buck DC transmission has been designed successfully using Simulink software from MATLAB. An additional inverter circuit is implemented to convert DC voltage to AC voltage and step-down by transformer producing 415-V AC. This designed system enable study on to implement alternative method to feed the transmission line overall, prior it can be an optional way for DC system to use in the future as a method to replace traditional power transport using AC voltage. Overall, this work demonstrates the concept of power converter and inverter from simulation and hence opens possible future works to improve the design and produce an efficient power converter for high voltage DC.

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