YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

POWER CONVERTER FAULT ANALYSIS IN HVDC TRANSMISSION LINE

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ELECTRICAL AND ELECTRONICS ENGINEERING

We certify that, as the jury, we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

POWER CONVERTER FAULT ANALYSIS IN HVDC TRANSMİSSİON LİNE

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Power transmission system has faced alot of challenges as the days goes by. Power demand has increased and its becoming increasingly difficult to acquire right of way for new lines, due to growth, population, urbanization and environmental issues. The limitations of HVAC make HVDC suitable for such expansion. Deeper research for the functioning of complex HVDC transmission system converter can be gotten by making the experimental modeling. This research will aim to provide an overview of the rationale for selections of HVDC system, the essential HVDC equations and rectifier control diagram. The thesis illustrates the MATLAB/SIMULINK simulations of a HVDC link using IGBT/DIODE based converter between a 500kV, 50HZ, system to a 330kV 60HZ system over 350m DC inter-connection through this system, analysis on the identifications of any abnormalities on the systems DC and AC will be shown. Moreover, harmonic content of AC increase by the use of power electronic components in the power system due to the harmonic content inside the HVDC it decreases the power quality inside the systems and hence thereby it should be reduced to an acceptable level below 5%.

Key Words: HVDC system, MATLAB/SIMULINK, IGBT/DIODE, Fault analysis, THD, Harmonic

ÖZ

HVDC ILETIM HATTI'NDA GÜÇ DÖNÜŞTÜRÜCÜ HATA ANALIZI

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Yüksek Lisans
Danışman: Dr.Ogr. Uyesi Mahir Kutay
November 2019

Nüfus artışı, büyüyen kentler, artan enerji talebi ve artan çevre sorunları enerji iletim sistemlerinin yetersiz kalmasına yol açmaktadır. Özellikle yoğun nüfuslu bölgelerde yeni HVAC iletim hatlarının yapılması için yeterli alanı bulmak giderek zorlaşmaktadır. Yüksek güç iletim kapasitesine sahip ve daha az iletken kullanan HVDC iletim hatları bu tür kapasite arttırımlarımda HVAC ye göre daha ekonomiktir. Bu tezde, 500kV, 50HZ ve 330kV 60HZ iletim sistemlerini birbirine bağlayan, arka arkaya IGBT/DIODE tabanlı bir dönüştürücünün, sistemde oluşan herhangi bir anormallik sırasında verdiği cevabın MATLAB/SIMULINK analizleri yapılmıştır. Ayrıca, HVDC'nin HVAC'ye dönüştürülmesi sırasında güç elektroniği elemanlarının kullanılması nedeniyle oluşan harmonik bileşenlerin %5 seviyesisini aşmaması için farklı süzgeç tipleri kullanılarak analizler yapılmıştır.

Anahtar Kelimeler: benzetim, servis sistemleri, üretim sistemleri, rassal modeller, sistem bakışı

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Ahmad Usman Mustapha

İzmir, 2019

TEXT OF OATH

I declare and honestly confirm that my study, titled "POWER CONVERTER FAULT ANALYSIS IN HVDC TRANSMISSION LINE" and presented as a Master's Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Full Name

Signature

………………………………..

November 20, 2019

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SYMBOLS AND ABBREVIATIONS

ABBREVIATIONS:

AC	Alternating Current
DC	Direct Current
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
MATLAB	Matrix Laboratory
PSCAD	Power System Computer-aided Design
EMTDC	Electromagnetic Transient Design and Control
VSC	Voltage Source Current
FIE	Fuzzy Inference Engine
SCR	Silicon Controlled Rectifier
TE	Transporting End
AE	Accepting End
MTDC	Multi-Terminal Direct Current
AEC	Accepting End Converter
WF	Wind Farm
ABN	Alternating Bus Network
TR	Transformer
NCC	Natural Commutated Converter
CCC	Capacitor Commutated Converter
LCC	Line Commutated Converter
FCC	Force Commutated Converter
IGBT	Insulated Bipolar Gate Transistor
GTO	Gate Turn Off Thyristor

PWM Pulse Width Modulation

BED Break Even Distance

Pf Power Factor Correction

UK United Kingdom

EP Maximum Voltage

RMS Root Mean Square

SYMBOLS:

+ Positive.

- Negative.

Π Pie.

α Alpha.

β Beta.

γ Gamma.

δ Delta.

I Current.

V Voltage.

R Resistance.

X Reactance.

N Number.

L Inductance.

Q Reactive Power.

$\mathscr{M}$ Ignition angle.

CHAPTER 1
INTRODUCTION

The electrical power is in the form of an alternating current. After the generation process, the power is been giving out as an AC. It is also been shared to different location or regions as AC, and except for some different kinds of industrial machines, there final mode of consumption is in AC form.

In some cases, however, it is important and has more and more advantageous benefits to bring direct current scheme to the supply of electrical power. This is true because in some situations, it may be the most efficient method to transmitting power. AC systems have some limitations especially when the system cannot be in synchronism due to difference in frequencies or for long distances which is only economical to use DC transmission. In HVDC, power is been produce more especially in the form of an AC, transmitted as DC and converted back to AC at the other end.

1.Background of the study

The world has been developing rapidly over the past few years. In order to sustain their development, power systems have had to expand. This has led to interconnection of all kinds of power systems worldwide (Weimers, 2005). The escalating rate of industrialization worldwide has led to the utilization of electrical energy. This growing demand for power has led to the search for efficient means of power transmission at increasing power levels. High voltage alternating current (HVAC) which is used in some countries example Nigeria, tends to be a problematic over long distances and is not environmentally friendly, Therefore HVDC is been suggested.

HVDC transmission application falls into two basic categories which can be used interchangeably. The categories are

1. Back to Back; in which no distance transmission between them.
2. Having a distance of transmission which can operate in different forms.

2. Statement of the problem

Power transmission system has faced a lot of challenges as the days goes by due to urbanization and environmental issues, it is becoming increasingly difficult to acquire right way for new lines. Power demand has increased due to growth and population thereby making it necessary for expansion. It can also be seen that transmission grid upgrade cannot keep pace with power demand. For HVAC, adverse weather condition is a challenge. This Thesis will tend to give a way forward about it.

3. Aims and Objectives of this thesis

The main focus of this study is to make a research on the performances of the HVDC especially power converters for HVDC transmission. The objectives to be studied on include

1. Derivation of converter equations
2. Simulation of HVDC scheme using the MATLAB/SIMULINK
3. Elimination of the harmonic contents on the AC sides of the system

4. Scope and Limitations.

Although the use of DC for daily application is much more than that of the AC, HVDC transmission is having only made its debut in 1954, it is still a new area of study. The thesis does not intend to model a comprehensive system with HVDC link. Control model and small signal stability will not be analyzed. A simulation program/apparatus will be used to run and test some of the parameters.

5. Methodology for the study

The following methods will be adopted in the course of the research

1. Review of relevant literatures on operation of line commutated converter HVDC and their configurations.
2. Modeling and Simulation of HVDC converters to determine
    - (i) Reliable state response of converters
    - (ii) Abnormal analysis behavior on the converters using MATLAB/SIMULINK
3. Discussion of results obtained from the simulation
4. Conclusion and Recommendation for future work

6. Layout of the thesis

This study consists of an abstract, text of oaths, acknowledgement sections and the below categories

1. Chapter 1: INTRODUCTORY PART: This sections explains the study background, aims and objectives of the research, problem statement, methodological approach for the research.
2. Chapter 2: LITERATURE STUDY REVIEWS: This sections explains the past related works that has been carried out before and also it gives the method in which to use in the course of this studies. Moreover, it also explains all the necessary topics and subtopics that is concern or related to this thesis.
3. Chapter 3: METHODLOGY: This sections explains about the techniques of rectifications, six pulse bridge control converter, current relationship in a circuit bridge system, method of inversion, control of HVDC converter system. In which they are the methods/techniques that were been employed to use in this thesis.
4. Chapter 4: RESULTS AND DISCUSSIONS: This sections consists of the Simulink design, the results obtained and the necessary discussions on the results obtained.
5. Chapter 5: CONCLUSIONS: This section concludes the work done throughout this thesis and provides some few recommendations on improving efficiency for the systems to be designed in the future.

CHAPTER 2

LITERATURE REVIEW OF SOME PAST RELATED WORK AND SOME TECHNICAL BACKGROUNDS.

2.1. Literature Review

Tie Ma (2017), Opined that with the daily increase in the creation of newly invented DC transmission modern devices, the demand for using the HVDC system were been put to use in any project has increased remarkably in the world. Certain factors were also being considered in the design process such as the reliability and flexibility in the manufacturing procedures. The unit's sections that make up the HVDC systems were been discussed such as the converters and others. The use of PSCAD/EMTDC for the modelling process where been use in the simulation process for the HVDC transmission systems, in other to simulate the waveform shape for a normal starting process and the system short circuit abnormalities. The waveform is being analyzed, Theoretical comparisons in terms of calculations were carried out also.

Dhayani et al (2015) Denote that the capacity for any power system to retain its normal conditions that is been expose to an unwanted physical signal is called stability. HVDC transmission system is on the virtue of increase daily due to the remarkable progress that were achieved on the technology of power electronics in the past few years. One of the most important concepts that needs to be understood is the interactions between AC systems and HVDC networks, so that the control of HVDC can function in a way that it can increase the reliability, durability and stability of an entire electrical grid systems. Different studies were carried out on the conditions of the HVDC performances such as the Faults conditions on both the AC and DC systems, Steady state operations and others. The modelling techniques were carried out with the use of MATLAB/SIMULINK environment for the simulations

Martial Giraneza (2013), Found out that with the recent and newly inventions in the area of power electronics it has taken out most of its specific restriction that HVDC use to have before. The HVDC is now one of the most technique that is being use in the transportation of a larger quantity of electrical power from one place to the other over a longer distances and also for the connection of the its asynchronous grids. With this recent invention in the HVDC, there has been a greater increase in the demand of an electricity far beyond its capacity utility. With this increase there is the needs to put the use of independent power providers which have been considered by the electricity market. Certain conditions where been created for the grid integration for the independent power providers. The use of VSC-HVDC has been taken as one of the source to be connected to the independent power provider's networks for the unit's section to the grid. The use of this VSC-HVDC is more advantageous in terms of its control independent on active and reactive power. The use of MATLAB/SIMULINK is adopted as the tool to be use in the analysis for the modelling of different kinds of grids that are been connected, Independent power provider's devices model where been performed through the use of the VSC-HVDC systems, Performance of the system model and its dynamic responses were been simulated in the MATLAB/SIMULINK environment.

Hossain, et al, (2014), Noted that nowadays HVDC transmission system is dependent on the newly findings on power electronics devices such as the semiconductor devices. HVDC model is been detailed by the use of filters, converters and others are being created in other to increase the balancing points in the transmission process of an electrical power. The modelling procedure is being carried out with the use of an engineering software package such as the MATLAB/SIMULINK. Certain conditions for current and voltage is analyzed for their steady state conditions. Abnormal conditions were determined. With this technique proposed on the use HVDC system it is been opined to be of more advantageous, economical value for using in terms of carrying electricity to some faraway location.

Rastogi, et al (2012), Express that the electric movement of power systems uses a DC system for the transportation of a larger amount of electricity, in comparison with use of AC systems. For faraway movements of the electricity the use of HVDC is inexpensive and has very minimal rate of electrical power losses. HVDC is mostly preferably for a very longer distances of transmissions. The reason as to why is prefer is to enable to the inverter to interchange the energy into DC for the sending process. The devices used are very expensive. With the use of the HVDC technology the electric losses that mostly occurs can be reduce up to 3% of 1000km. Different connections can also be used for any AC networks that are not having the same frequencies and voltages or differences in electrical grids with same frequency but with differences in their timing zones. MATLAB/SIMULINK are use in the simulations HVDC. The modelling is carried out between two systems of HVDC transmissions having different frequency and voltages in other to determine the responses on the AC and DC systems, Frequency responses and also steady-state rising and step responses were carried out.

Benish Paily (2015), Express that the sensing and the quick responses to the removal of any abnormalities are much more needed to secure and safe guard the optimal functioning of the HVDC networks. The HVDC networks, has a lots of AC and DC abnormalities that use to arise at any time. However, it is of utmost concern that needs to have the ability to sense any abnormalities in the entire systems and to be able to categorize them for better prevention and detection purposes. There are a lots of approach that can be use for the sensing of the abnormality in the systems and to also categorize them in the HVDC networks by the use of the adopted techniques which is the signal processing method. However, it is also noted that the use of wavelet transform can be use in sensing any occurrence of an interruption in the network signals and to also direct were the abnormal situations in the system is located. The main focus of the thesis is the identification of faults on both the DC and AC at different ranges together with the line and also some faults problems that occurs at the converter side of the AC network. However, another different technique is adopted for the identification and categorization of abnormalities in line-commutated converter HVDC networks. Another method for the faults detection is adopted that's by the use of fuzzy logic for VSC-HVDC networks. The use of the fuzzy inference engine (FIE) is to sense the AC abnormalities that's happening in the side of the rectifier and also on the DC sides. In some cases, the techniques do not show the line system in which the problem happens or located. Therefore, in other to know and classify were the problems occurs on both the AC and DC sections on the HVDC systems, the FIE has to be recreated with an appropriate inputs of an algorithmic data's, therefore the FIE can have the ability to locate different kinds of abnormal occurrence that happens in the system and the corresponding locations where the problem is created in the HVDC systems.

Fuad et al., (2017), And many others expertise that electrical power is one of the most dependable sources of energy in the world, due to it can be transformed into any desirable types of energy and it can easily be transported from one region to the other. The mode of transferring the energy we use AC due to the creation of the AC current is more productive as compared to the DC current. The challenges that do happens in the transferring of the electricity to a longer ranges results to the loss of more powers from the AC current than the use of the DC procedures. However, for a longer movement of the electric powers, the use of converters is implored in other to make the conversion easier. Therefore, the use of HVDC system is that the reusable source of energy such as the solar systems, they are being kept at a certain locations and they create a DC current. In other for the electric energy to be transported for its final consumption, there is the to use the converter in other to convert it from DC to AC form. The simulations of a dual 3-phase converter are analyzed. In this dual converter, one of the circuit system can either be connected as an inverter or rectifier by the continuous altering of the firing angle for the conduction devices. The use of 3-phase source is linked together with a controlled rectifier comprising of the silicon controlled rectifier, in which the silicon controlled rectifier can either be switched ON or OFF while using the pulse gate and the time delay units for the control, so that the output can be controlled. After the modelling process is carried out, some certain factors were noticed as to regard to the output which is possible to be use for a 3-phase controlled rectifier as an inverter by the continuous mutating of the firing angle of the SCR.

2.2. Classifications of Different Systems of HVDC Transmissions

As we know the DC lines can be classified base on their mode linking by either single, double or more. The systems can also join together even at a differences in voltages and frequencies. For us to link or join these two systems together, Various classification of DC connections are adopted and listed according to (Bahrman, 2008; Mohammed et al., 2017)

1.Mono-polar DC lines systems
2.Bi-polar DC lines systems
3.Homo-polar DC lines systems
4.Back-back DC lines systems

2.2.1. Mono-Polar DC lines System

According (Melaku, 2012; Koganti et al., 2015; Alstom, 2010) State that the mono-polar HVDC lines can also be categories into two different forms as Mono-polar lines with Earth returns and Mono-polar line with metallic returns.

A mono-polar DC system with return path as Ground: This system mostly it comprises of more than one units of six-pulse converters, in which they are either arrange in the series manner or parallel way via the ending paths. It has only one conductor in it and the return is either through the earth or ocean As it can be shown below in fig 2.1 (Alstom 2010).

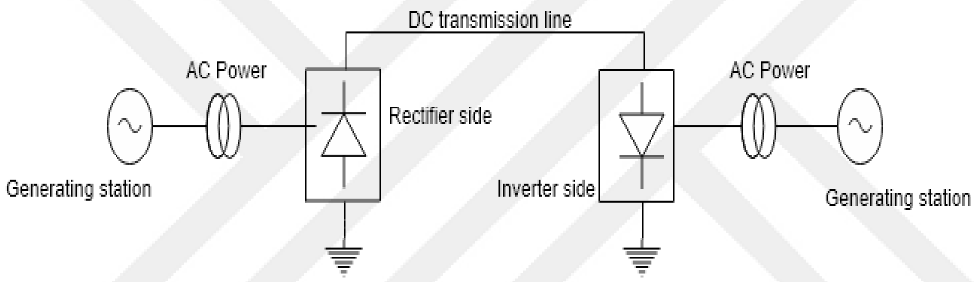


Figure 2.1. Mono-polar line with return path as Ground

A mono-polar DC system with return path as Metallic: In this kind of system it is comprises of a system with a single higher voltages and a single common voltage conductor. As it will also be shown below in figure 2.2

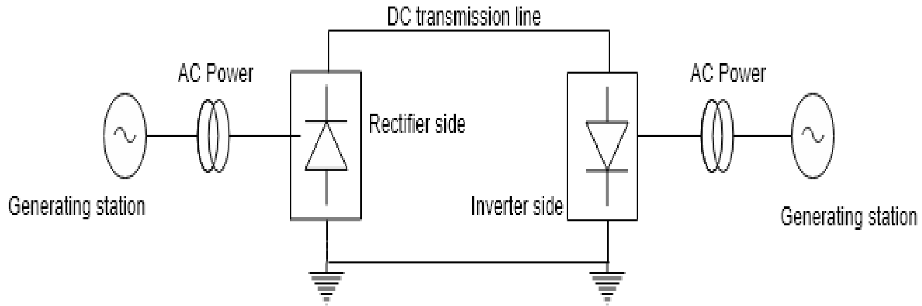


Figure 2.2. A mono-polar DC system with return path as metallic

As we can see it is conveniently good to start the HVDC systems with this kind of configurations for so many reasons. Firstly, it is the cheapest kind of configuration to use in terms of when cost is also taken into account or considered. Secondly, it is the first step for a bipolar configuration, that is a mono-polar configuration can later on be transformed in to a bipolar system with time also without encountering any difficulties or complexity (Alstom, 2010).

2.2.2. Bi-Polar DC Lines Systems

Bi-polar dc lines configuration system as the name express it is comprising of two different kinds of polarity or conductors in the system, these polarities that are present in the system are the positive and negative terminals. Mostly this conductor that are available in the circuit are the positive terminal and the negative terminal. These two conductors are of the same rated voltage and are been configured in a series arrangement at the end of the dc lines. The negative terminal of this circuit is grounded in other to ease the flow of the power in a forward direction only. The meeting point of this circuit can either be grounded at one end or both at the ends as it can be shown also in figure 2.3. If it is grounded at both ends, then automatically it means it can function on its own that’s independently. The benefits of using this system of configurations over two linked mono- polar is that there is a reduction in term of when its cost determination, due to the single availability or absence of the path of return way and it has a very minimal loss that are associated to it. While the disadvantage here is the lacking of the return way because of the jointed component it will distort both the polarities in that systems (Alstom, 2010, Ali et al., 2017)

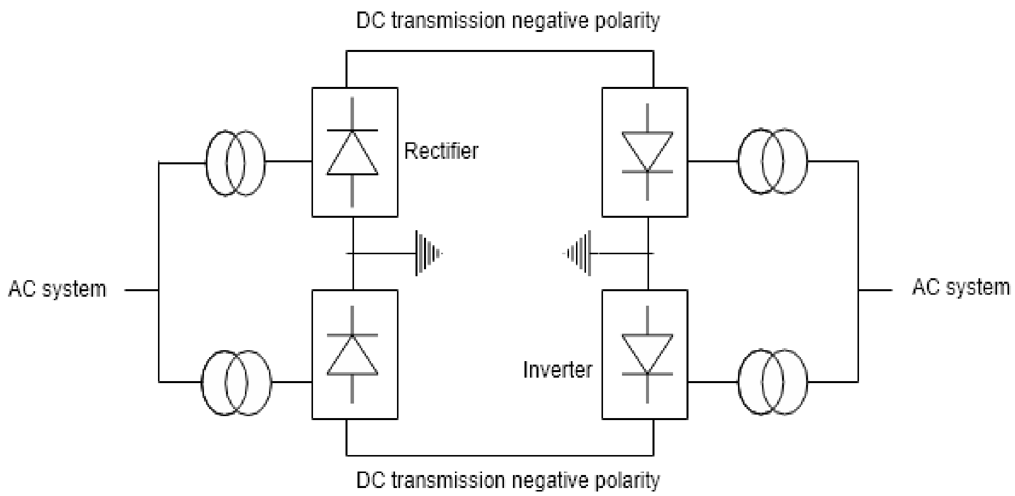


Figure 2.3. Bi-polar DC line systems

2.2.2. Homo-Polar DC Lines Systems

Homo-polar as the can express also, it consists of more than one or two conductors that are linked together having the same polarity which can either be the negative or positive electrodes and they also function in a parallel arrangement. This connection between the rectifier and the inverter of the system is done without the use of DC line system (Ali et al., 2017; Koganti et al., 2015). As it can be shown below also in figure 2.4.

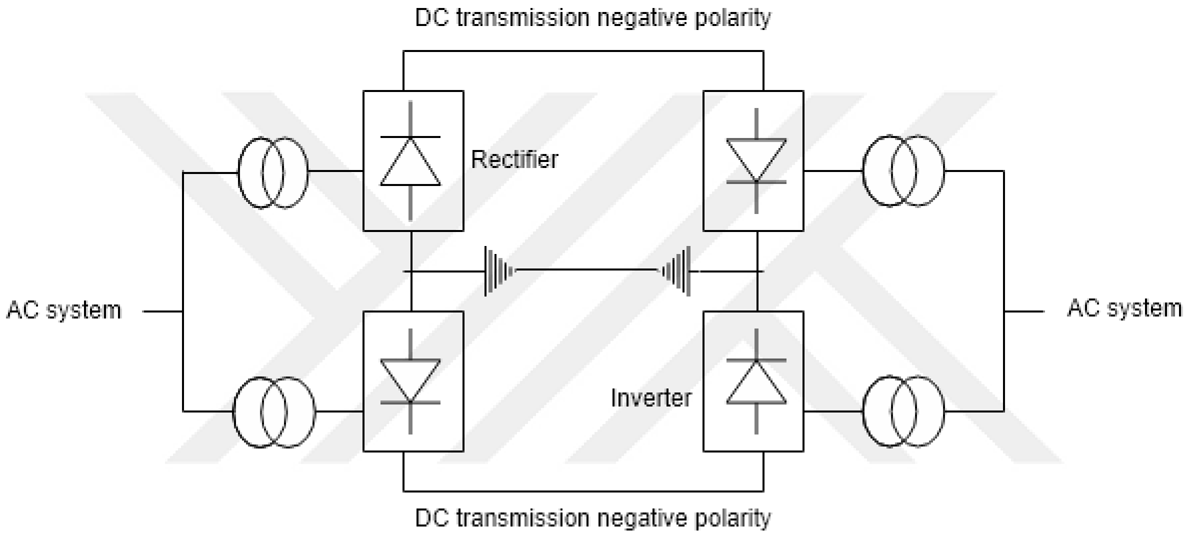


Figure 2.4. Homo-polar DC lines system

2.2.3. Back-Back (B2B) DC Lines Systems

In this system of configuration, these two converters that's the rectifier and the inverter has no any separation of distances between them. This is mainly used to make an interconnection between two AC links with different frequencies (Sharad et al., 2017; Alstom 2010;). Simple diagrammatical representation can be shown below in figure 2.5

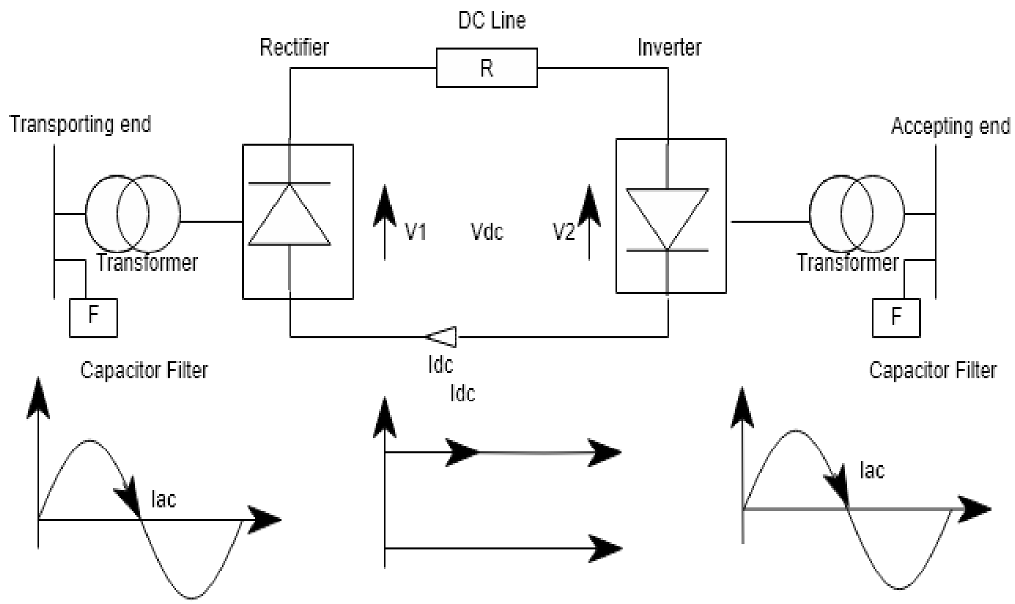


Figure 2.5. The System Back to back DC lines system

As we have denoted above, the alternating current (AC) power is connected together with the first converter that is function which the rectifier from the transporting end (TE), which transformed AC into DC. The final output of this converter is the DC power which functions independently on its own with the AC frequency supply. This DC power is transported via the conducting path, which is the DC line as shown in the figure above, is also linked to the DC points of the inverter. This inverter is working as a line-commutate network and it gives a free passage to the movement of the DC power into the accepting end (AE) of the AC systems (Alstom, 2010).

2.3. Multi-Terminal DC Lines Systems

A multi-terminal dc lines (MTDC) system, express that this kind of configurations is consist of more than one or two converter stationary (Jicheng et al., 2012; Anas 2017). However, some of this converters can be working or functioning as the rectifier for the transformation of AC-DC, while the others can be functioning as an inverter for the conversion of DC-AC (Jicheng et al., 2012). This mode of arrangement techniques can be interchangeable by the switching processes. The easiest path of creating an MTDC configuration from a functioning of a two points terminal system in other to bring in the idea of tap-pings. Parallel working of the converters and the bi-polar can also be seen as MT-operations. As can be shown in figure 2.6

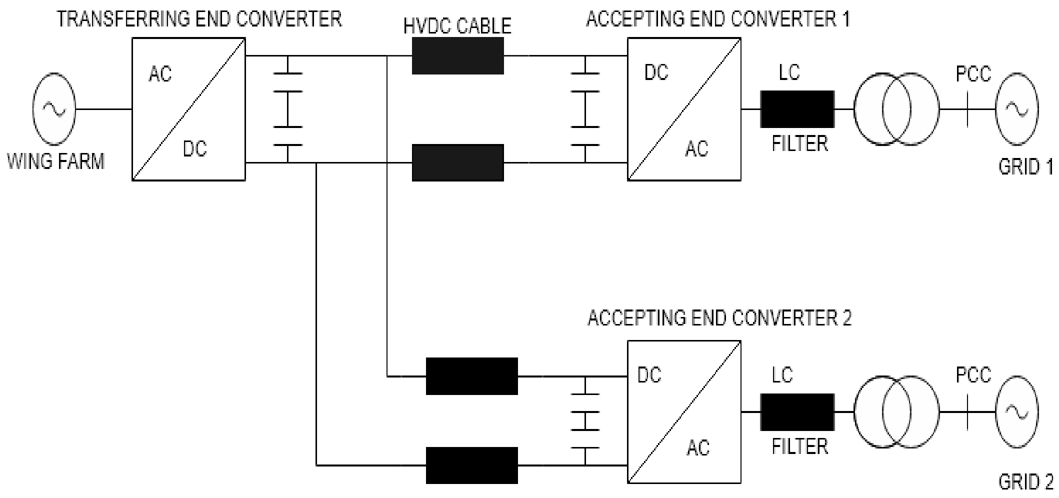


Figure 2.5. Multi-terminal DC lines system

As the figure 2.5 shown above, it can be seen how the wind farm (WF) is joined together with the rectifier side for the transformation of the AC-DC, the power of the DC is move through the line cable to the other side of the converter which are known as the Accepting end converter 1 (AEC) and Accepting end converter 2 (AEC) respectively. Again, this power of the DC is retransformed again back to the AC and are link to the AC grids that is passing through the filtering point and the transformer side (Banish 2015).

2.3.1. Classifications of The Multi-Terminal DC Lines Systems

The multi-terminal dc lines are divided into two (2) different classes which can be classified and explained below with their various circuit diagrams and explanations

2.3.2. Series Mode Connections

This mode of connection as the name points out, they are being joined together in a series arrangement to each other in the systems. However, a simple representation of this kind of connections will be seen below in figure 2.6 with a three-point terminal systems for the MTDC.

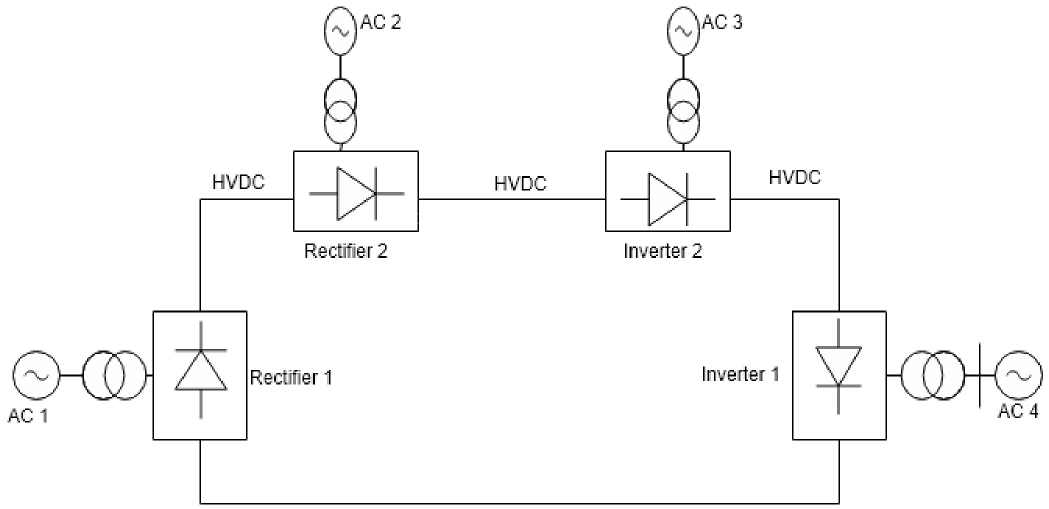


Figure 2.6. A series mode connection MTDC network

In this kind of arrangement in the circuit system, the flow of the electrons that's is the current is kept or set by either one of the terminal converter points and are readily available in all the stationary points.

2.3.3. A Parallel Mode Connections

This mode of connection, as the name suggest they are being connected adjacent or opposite to each other in the circuit systems. In this adjacent or opposite connection, the dissociation of one or other single parts of the sending sections can or will cause a break or interference of the power within the power converters that are presents inside the circuit system as can be shown in the figure 2.7 below. This opposite connection in the network can also work without imploring the use of the High Voltage DC circuit breaker

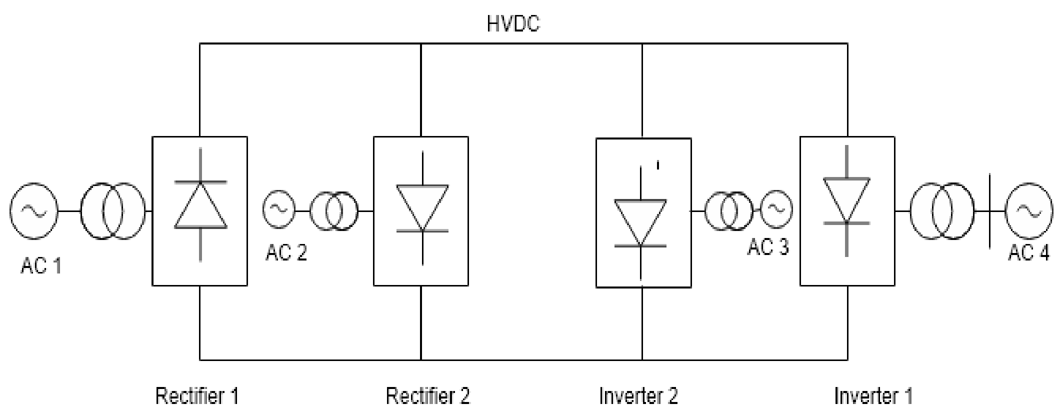


Figure 2.7. A parallel mode connection MTDC network

The most common challenges for the control of this adjacent inverter system is that this high voltage dc inverter system is working or function in the most productive or well organized modes.

2.3.4. Merits of The MTDC Network Configurations

The merits of this system can be categorize below

1. This MTDC network is way too economical to be use and also it is very flexible to the network

2. The oscillation frequency in the inter-linked AC system can react fastly to be damped

3. The massive load of the AC system can be strengthen by the application of the MTDC network techniques.

2.3.5. Implementation of The Network MTDC Configurations

The application of the MTDC network configurations can be listed as follows

1 The transportation of a very large quantity of power to many remote production sources to many load stations

2 The networks are linked between two or many AC networks by the adjacent MTDC network connections

3It gives support to massive load metropolitan AC systems by the use of the MTDC network configurations

2.4. Network System of HVDC Components

HVDC as a network system, it comprises of many different sections of units or components that are associating with each other in the entire systems, so as to function or operated in an efficiently. A simple representation of the entire electrical system of the HVDC will be shown below in figure 2.8

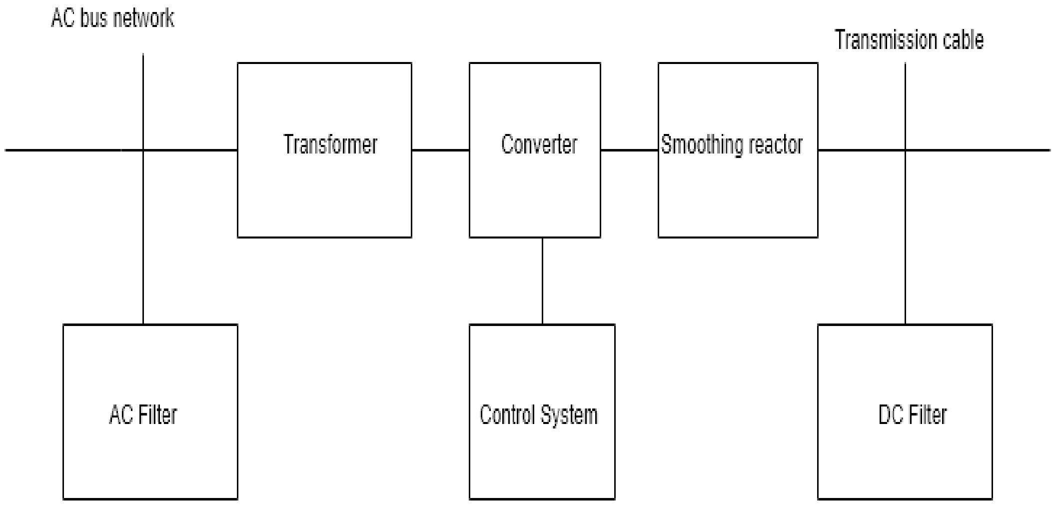


Figure 2.8. HVDC network systems

Larruskain et al., (2005) and Girneza, (2013) express that the power of the AC located at the AC bus network (ABN) is been converted after it has been filtered and is again re-converted back into DC. It is also being transferred via the smoothing reactor system into the DC filter terminal, before it will be transported into the lines system for transmission. The backward steps are carried out at the accepting end where it is being retransformed back into the AC.

2.4.1. AC Harmonic Filter System

Harmonics is said to be any presence of an unwanted signals in the systems that's causes any interruption or changes in the waveform (Snehal & Dnyaneshwar, 2016). Converters are said to creates harmonics that are associating to the AC bus network in the system as can also be viewed from the above figure. The functioning of the HVDC converter systems are where the sources of the unwanted signals or harmonics creation of the AC harmonic currents comes from in the system (Siemens, 2007; Alstom 2010). The HVDC being one of the nonlinear-loads such as the power electronic converters, it creates harmonics that are been taken up by the AC filters which in reverse it gives it to the power reactive in the systems (Bhunesh, 2011). In any converter locations, there is the production of unwanted harmonics due to the following factors been consider, shunt join together to the switchable AC system filters that are connected to the ac bus network (Manmek et al., 2004). Alstom, (2010) went further to say that the AC filters harmonics are being easily open to be in on or off state automatically with the help of the circuit breaker of the AC network in the systems. On the other hand, Larruskain et al., (2005) state that on the side of this AC system in the converter it has two main purpose to execute which are to be listed below.

- To take up the harmonic currents created by the HVDC network
- To give or produce the reactive power to the system

2.4.2. Transformer Converter

This converter transformer (TR) is the connection between this two devices i.e. the thyristors and the AC networks by (Alstom, 2010). Typically, this transformer converter system is connected as an 'earthed grounded star-system twisted and fluctuating-star and secondary delta rotation point' (Alstom, 2010). The converter system serves as a connection in between these two systems that is the converter and the AC system, in other to provides various purposes which includes the following below:

- It gives separations between the systems
- It gives the appropriate or needed amount of voltage to the HVDC converter in the system

This HVDC converter transformer changes the voltage point level of this AC network bus to the desired level of the voltage control entry to the system (Larruskain et al., 2013).

2.4.3. HVDC Smoothing Reactor Systems

Siemen, (2007) and Padiyar, (2005), Express that the HVDC network for the transportation of power it needed a HVDC system smoothing reactor. This equipment gives a certain purpose as to which can be listed below

1. Restriction of specific fault current in the DC movement
2. Reduction of the current harmonic, consisting of the limited communication devices interaction such as the telephone interactions
3. Reduction of the unwanted ripples that are present in the DC lines systems.

Alstom, (2010), view that this smoothing reactor initially is a very big 'air-vital/air-enclosed reactor' and is been situated at the extreme end of the higher voltage points in the DC converter systems, which is kept at or beneath a value of about 500KV dc. When the value is greater than this rated value given, the system tends to divide among the inactive point and the higher voltage terminal in the system. Melaku, (2012) opinion that the larger the inductance reactor of the system, the lower the amount of the leftover of the unwanted currents in the systems.

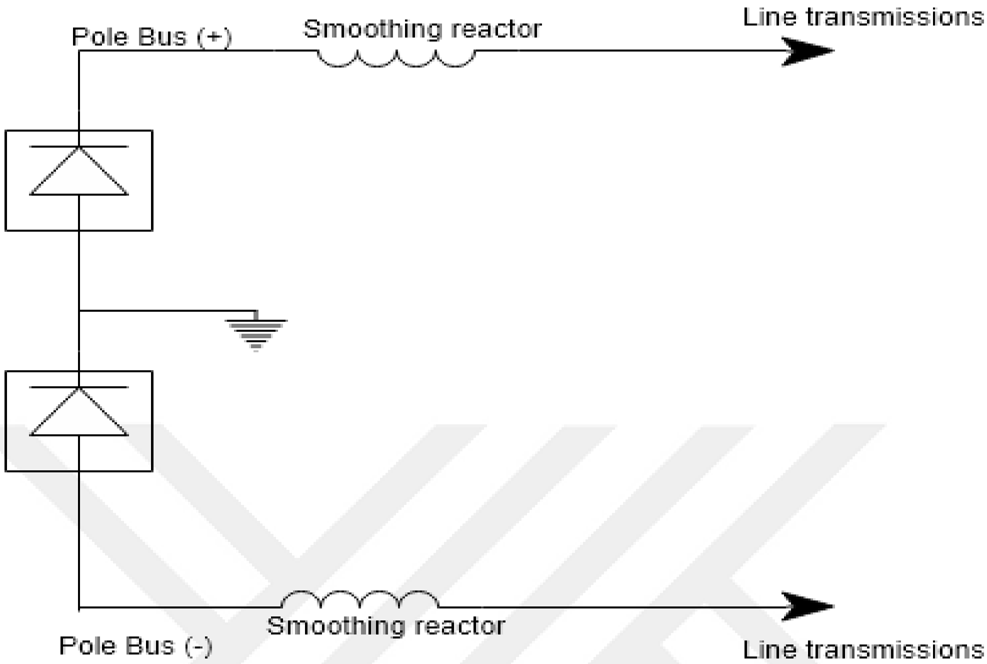


Figure 2.9. HVDC smoothing reactor system

2.4.4. HVDC Protection Network and Control System

Similarly, like the functioning of the AC systems for the DC abnormalities, they are entirely being affected by the inefficient functioning of the controller's system and others (Girneza, 2013). Padiyar, (2005) subject that the interruption of the power system transmission, protection systems and control systems, are entirely view by the use of switching method and the equipment controls such as the surge control arresters, earthed terminal electrodes and others. The aim of this creation was purposely for the HVDC control technique, due to it is very reliable, dependable in terms of transferring of energy that is working very efficiently in the systems. Also it can be simple in its energy movement which can sense or detect any unexpected occurrence changes in the system demand to the entire system balance (Siemen, 2010).

2.4.5. HVDC Converter Systems

Generally, the purpose of this HVDC rectifier and inverter which are called the converter system in any electrical systems where needed, whenever there is a needs to replacing of any electrical power components, these components can be either be of the current, frequency and voltages. The converter system is the place where the transformation or interchange do takes place such as the changes from the AC-DC and DC-AC. HVDC, now uses modern systems which is the thyristor system based converter (Roberto, et al., 2000; Girneza, 2013). Roberto, et al., (2002) denoted that with the use of commutation techniques which can be define as the natural interruption of any currents in a given circuit or system, it consists of more than one classification of the power electronic converter, which is readily available in the system which can be discuss under the sections below

2.4.5.1. Natural Commutated Converter System (NCC)

This natural commutated converter is also known as the line commutated converter (LCC), the conventional use of the HVDC system it uses the LCC, due to its merits of benefits over the use of the HVAC network due to their capacity to interlink to an ac systems non-asynchronously systems and their capability to transport power economically to a very far distances (Qahraman, et al 2006). Its comprises of a six-pulse, however, due to the recent advancement in power electronic nowadays converters are built up of 12-pulse valve (Uhlman, 1971). This NCC it is now used widely nowadays in the HVDC networks. The parts that is responsible for carrying out the process of transformation in the system is called the Thyristor’s unit and it is capable of not allowing the free flow of a very large amount of voltage amounting to about 10KV (Roberto, et al., 2000). The LCC function at the rated frequency of about 50-60HZ when there is a presence of more than one electric air-condition systems (Varma & Charturved, 2018). According to Mathur, et al., (2002), The basic schematic of the LCC it is built up of a rectifier bridge, consisting of 6-thyristors in the system. Each of this is join together to either one of the 3-phases of the transformer converter, in some instances, it changes simultaneously only at every 60 degrees. taken into the account, the LCC produces harmonics in the system, that is been created on both sides of the AC and DC points when the connections are been used (Qahraman, et al., 2006).

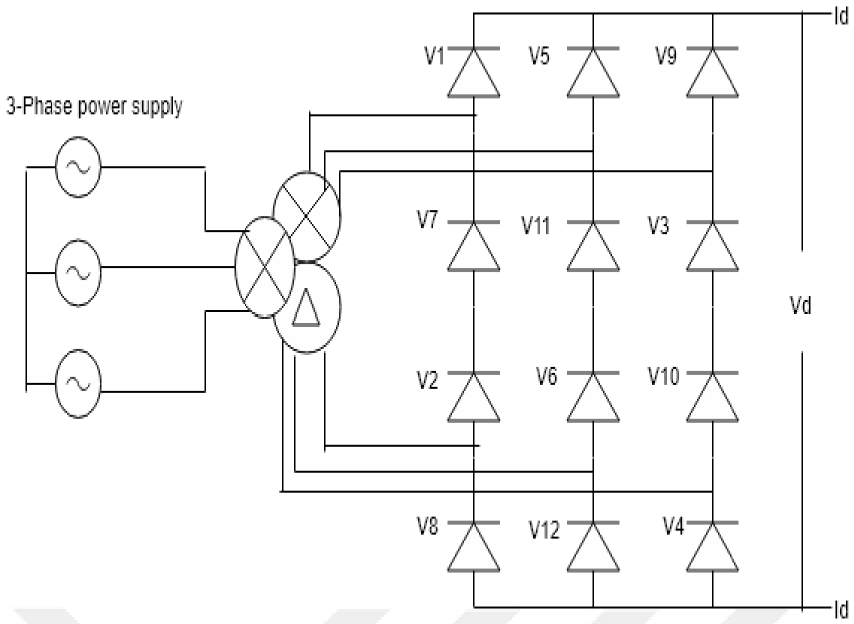


Figure 2.10. A natural line commutated converter system

An expansion of this connection, it consists of a 12-valves of the 12-pulse bridge. The AC system is divided into two different 3-phase power supplies before any conversion takes place. These supplies are being connected to the star point network while the others are connected to the delta point terminal with a 30 degrees' phase differences between them. So that the AC production of the voltage and current unwanted harmonics in the system is removed (Melaku, 2012). For this particular reasons, the 12-pulse bridge rectifier is now widely applying on the line commutated converter networks (Mehdi 2016).

2.4.5.2. Capacitor Commutated Converter System (CCC)

Khatir et al., (2015) and Roberto et al., (2000), pointed out that, this capacitor commutated converter is a standard HVDC system converter that gives the capacitor a replacement with a connection to the valves system and the transformer. The principal task of this idea is that the capacitor gives the on and off process to the voltage commutation. Roberto et al., (2002), went further to express that, with the use of the capacitor commutation it enhances the failure commutation achievement in the system converter, when they are linked with a weaker system.

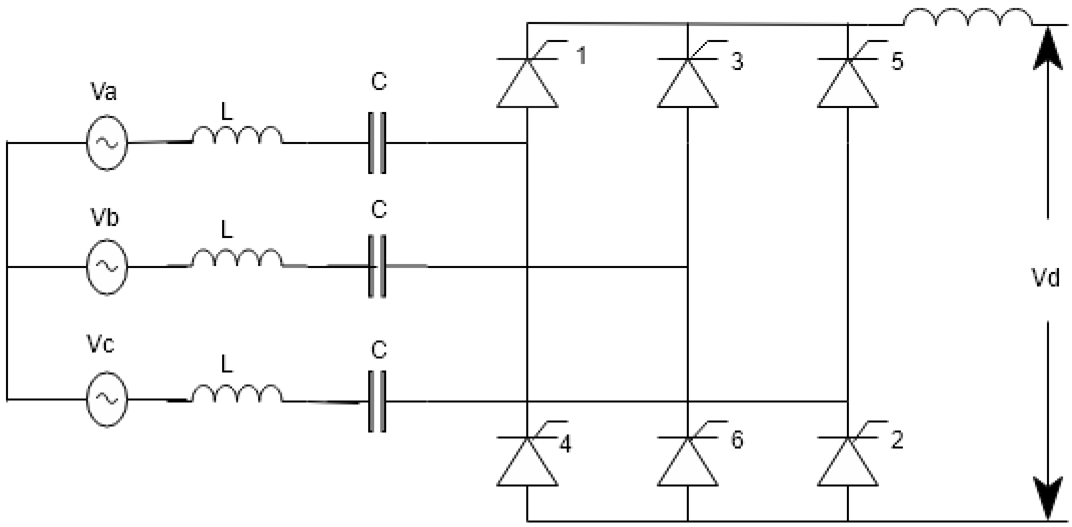


Figure 2.11. A capacitor commutated converter system

Figure 2.8, Enlighten the above circuit network for the 6-pulse capacitor commutated converter system valve category, it is sketched as a traditional system converter and it is also being furnish with the capacitor arrangement in series way. The connection of the valve systems is in phase with each other and the transformer network. One of the most essential advantages is that the capacitor that are arranged in series are been charged with the terminal polarity point of the system in which it can helps in the task of the commutation operations. This benefaction enables the system to work with the CCC with a very minimal power reactive absorption as in contrast to the then traditional converter.

2.4.5.3. Force Commutated Converter System (FCCS)

This converter system according to Roberto et al., (2002), views that this network can also be called as a voltage-source converter system. These networks only differ from the LCC in their creation process, the FCCS are created with a semiconductor device such as the Insulated bipolar gate transistor (IGBT) and The Gate turn off thyristor (GTO). This semiconductor device possesses the capacity to either turn the system in an ON state or OFF state and they are widely applied in this system units. The transformation process is carried out with the techniques of pulse width modulations (PWM) in the system. With the techniques implored, it will be able to generates an amplitude or an angle phase differences by interchanging of the patterns of the PWM with a certain distance. This method of the PWM has the chances to manage or run all the powers in the system such as the reactive and the active powers separately. Consequently, they can have a great impact on the system in terms of keeping the maintainers of the weaker AC networks (Qahraman et al., 2006).

2.4.6. DC Harmonic Filter Systems

Alstom (2010) and Siemens (2007), has systematically reviewed that during the working of the converter network, the harmonic voltages are being created at the terminal points of the DC unit of the converter, there is the presence of a sinusoid alternating current harmonic parts that is lay over on the ending terminal voltage of the DC network. This harmonic AC parts of the voltage will finally proceed to the AC harmonic movement of the currents inside the circuit of the DC system. The DC harmonic filter is physically similar to an AC filter system (Bhunesh kumar 2011).

2.4.6.1. Operation of The DC Harmonic Filtration Systems

The harmonic voltage that results to be in the dc section of the converter system can alter the alternating current that are lay over on the dc current in the transportation line. These AC current coming from the excessive frequencies can generate an intervention in the adjacent communication systems such as the telephones devices despite their restriction by the HVDC smoothing reactors (Rajpoot et al 2017). The current harmonics of smaller frequencies can be of hazardous to the life of people and the systems through the injected voltages. Hence, this DC filtration circuit that are arranged in the equidistant to the poles, are very good effective techniques in solving this problem in the systems (Siemens 2007).

2.5. DC Transducers Networks

The DC linking transducers can be classified into two different classes namely

1. DC voltage measurement of the system
2. DC current measurement of the system

2.5.1. DC Voltage Measurement

This measurement is carried out by the use of the visual division of voltage or the resistive voltage dc division. The resistive division of the voltage, it consists of a series connection between the resistors in the system and are therefore, the measuring of the voltage can be extracted over the lower end of the voltage resistor. The visual transducer voltage senses the power and durability of the electric field that are close to the network bus bar.

2.5.2. DC Current Measurement

This measurement is carried out all on the protection and control system that needed the action of a computerized systems. This computation can be made by the production or creation f a magnetic field within the computation head that is enough or adequate to neutralize the magnetic field that is close to the network bus bar via the computation head system.

2.6. Factors for Choosing Either AC or DC Transmission

Akash (2018) Point out that the current movement in the DC moves only on an onward direction. While in the AC cases, the electric current is not stable it changes its direction of flowing frequently. Not only in the current movement but also in the voltage situations because its reverses its movement due to the changes that occurs in the flowing of the current and also presented some points that needs to be put into considerations which can be detailed below.

(a) Cost of the transportation of the power
(b) The efficiency in the system
(c) Performance of the system

Larruskain (2006) Expertise that the extensive on most of the electricity power transportation uses the 3-phase of the alternating current. The logic after this idea of the HVDC over the AC to transport the electric power in a particular situation are usually countless. The idea that tends to support the HVDC usage are

2.6.1. Investment Cost

Ahmad and Mahir (2019) factors out that the HVDC transportation line value is smaller than that of the AC line for the same purpose of transporting the amount of electric power. Alternating current are broadly used for a very short ranges, that is they are mostly used for household and industrial purpose. The use of the AC for transportation purposes in this area it can cost less in its procedures and its frequency can simply be controlled unlike when trying to apply the use of AC for a very big project its frequency tends to be very complex to control and also as it can be viewed that it has some specific restrictions. Direct Current does not have any specific clampdown attached to it and require less investment cost in it. DC transportation does not require too much use of conductor like the AC systems. The use of both AC and DC for transmitting purpose have been in use recently due to how we can both used in them in transporting an electrical power from one far away location to the other by the means of converters such as the rectifier and inverter. Below investment cost of both AC and DC transmissions can be shown

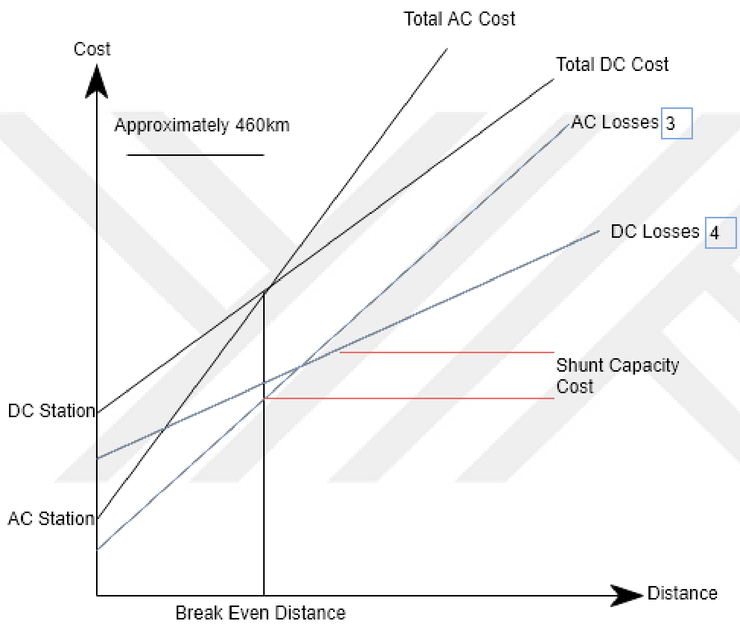


Figure 2.12. Variation of cost with length line for AC and DC transmissions

Johan and Lina (2008) Went further to view that the graphic above describes the overall price for the two systems that's the AC and DC systems final outcomes relies on the transportation range. The Break Even Distance (BED), whereas the HVDC end results, will results to more of advantageous in terms of its economical than its identical HVAC, but it will also rely on the environmental circumstances and others. The losses in the power for the two networks shown in (3) and (4) when it is undergoing the process of transportation, it is ben observed that the DC network has a very minimal rate of losses for if an equal quantity of the electrical power is transported. Subsequently, it is also being observed that the HVAC transportation is more convenient for a shorter distance usually below the 460km as indicated in the about figure and also the HVDC movement of the electricity is more conducive for longer distance usually it can exceed or to be more than 460km also.

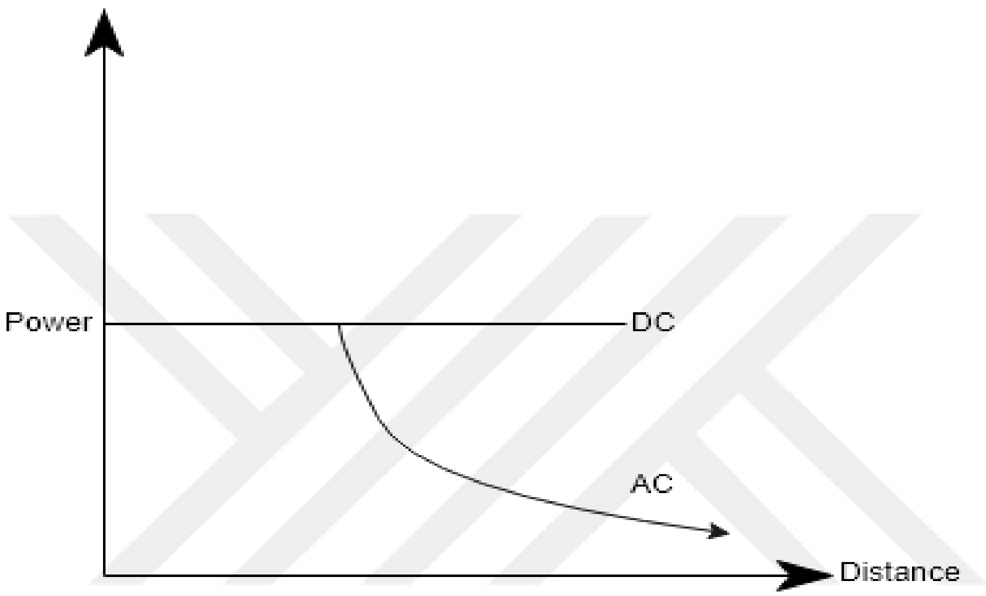


Figure 2.13. Power transfer capacity Vs Distance

HVDC is much more productive in as compared to the HVAC, due to the DC has more good control system that are very quick at the response to the recovery from faults (Aleekseeva et al 2002).

2.7. Comparisms Between HVDC and HVAC System of Transmission

Table 2.1. Comparism between AC and DC system

Advantages of HVDC transmission lines	Disadvantages of HVDC transmission lines
	1.The converters are very costly

1. Exceptional power for each one of the conductors 2. Has a very small tower for the transportation of power 3. Absence of current charging 4. Insulation needed for the conductor is not needed much 5. The use of earth as return path 6. Requires less cost for the line creation 7. Absence of effect skin 8. Losses in the lines are very minimal 9. Less communication systems interactions or interferences such as the telephone devices 10. Absence of restrictions on the distances by its stability 11. Connections between two difference AC networks having different voltages and frequency in the system 12. Conductors can function separately on their own in the circuit 13. Limited to right way	2. There are the needs for reactive power control in the system 3. Production of an unwanted signals coming from the nonlinear loads 4. Complexity in the circuit breaking system

2.7.1 Merits of DC Electrical Power Movement Over AC Electrical Power Movement

1. The “Lower insulation class of the line”, is very advantageous in terms of its economical aspect. The maximum voltage in respect to the DC network is close to about 0.7071 of the maximum voltage also in respect to the AC network.

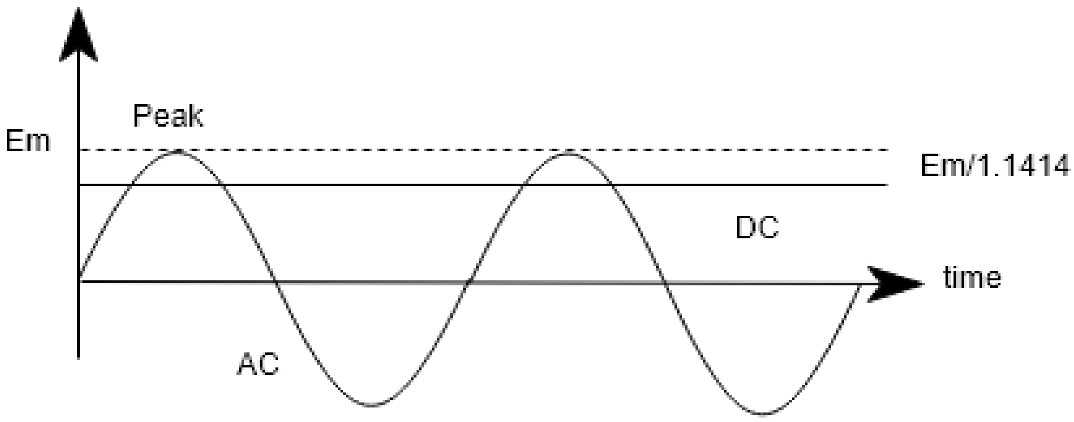


Figure 2.14. Contrast between the max voltage for the DC and AC

2. Considering the situation of the DC, its power correction factor (pf) is constant having a value of 1 per unit (pu). It consists of an exceptional power transportation effectiveness or efficiency.

This Direct current (DC) electrical power it has no any different "Imaginary part" like in the case of the Alternating current (AC) electrical power. So, firstly there is absence of the "reactive power" that is being produce by the reactance. Since the DC electrical power movement consists of a more and more "real power", which are being utilize for the exact power utilizations than the AC electrical power movement, it has an excessive power movement effectiveness as can be shown in figure 2.15

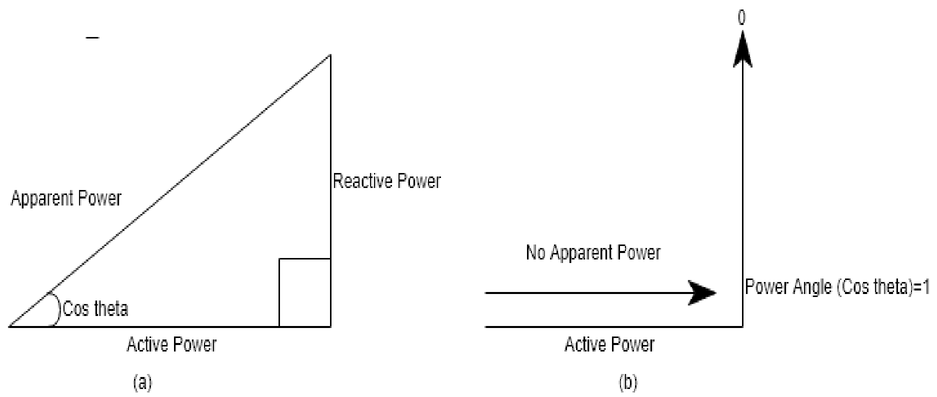


Figure 2.15. Contrast of Power factor correction for DC and AC

3. Exchange in Power, the back to back HVDC network has pointed out a new technique for the implementation of the power exchange between two (2) different

networks that are working at frequency differences. As an example we can consider the case of AC and DC networks having different frequency of 50Hz and 60Hz diagrammatically it can be shown in the following Figure 2.16 below showing the connection exchange between the two systems having at different frequency.

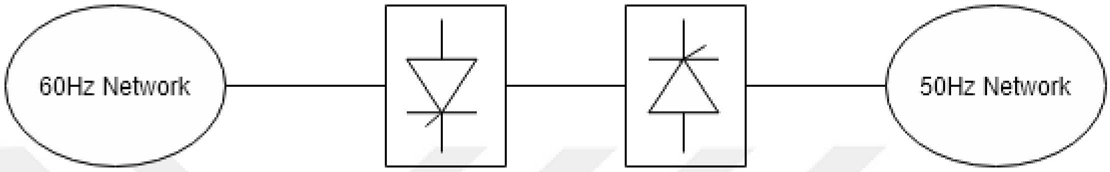


Figure 2.16. The connections between the systems having different frequencies

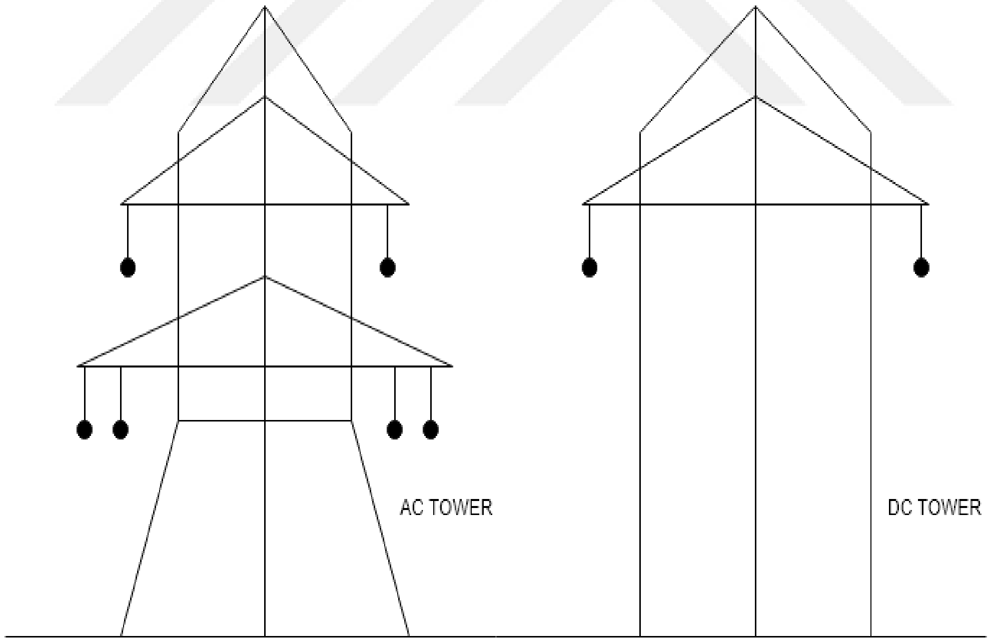


Figure 2.17. Tower length size for 1000mw line transmissions in terms of the comparisons between the AC TOWER and DC TOWER

As we can denote above, we can see that the HVDC system line for the transportation is very less in terms of its cost value as compared to that of the line AC system. In some situations, it is also right that the DC terminal point station it has a very higher costs, due to the points that they have to carry out the operation of transformations from the converters such as the rectifier and inverters. But across a certain range, the break-even distance the system will always give a lesser cost.

CHAPTER 3
METHODOLOGY OF THE THESIS

Firstly, this research has explained and provides the introductory insight to the past related review work that has been carried out before and also its gives the basic principles what the HVDC is all about and their configurations. In this chapter which is the methodological section of the research. The converter systems will be studied and also to examined their equations will be derived. Based on this equation and the explanations about the power converters operations are, the simulations will be carried out to find the reliable or "steady state conditions and fault analysis" of the HVDC by applying or implementing the use of MATLAB/SIMULINK environment.

3.1. Rectification Control System

Rectification can be opined to be define as the transformation of any AC into a constant DC system by the use of a constant dc voltage value, the "on and off" device is the "diodes" in the network circuit (fewson, 1998, p.27). The valve system basically works in a single direction to which it is moving from the positive (+) terminal points of the system to the negative (-) terminal points in the circuits and when it is undergoing its operations there is a few leakage of voltages over it in the circuit network. While examining the converter parts of the rectifier network, the valves system and the other sections such as the transformer sections are being presumed to be in an ideal condition or state that is, there is no any leakage of the voltage. The direct current (DC) load is presumed to also possess an unlimited inductance system from which it moves that the dc system is sustained to be discharged or free from any unwanted disturbances or ripples (wadha, 2010, p.119). In some countries like the united kingdom (UK), the production and transportations of an electricity power are carried out by the process of an AC. The electrical station powers use a "synchronous generators", known as the alternators to produce a voltage of around 11KV, or more than that, at the frequency rate of about 50Hz (fewson, 1998, p.27).

The secondary section of the transformer can also be join together in other to produce or creates a three (3) different classes of phases such as the 3,6 and the 12 period to which it can provides to the rectifier system terminal valves. The bigger the value of the period, the smaller the ripples are being satisfied inside the DC system production. But in the case of the six (6)-phase interconnection it is pointed out that it is efficiently good from entire the experimental perspectives or opinions (wadha, 2010). Figure 3.1 will display the voltage and the current waveform in the three (3)-phase transformer supply. When the electrical grids system is not applied, the working process take off immediately starting from the (-) and the (+) terminals of the excessive potential or prospective.

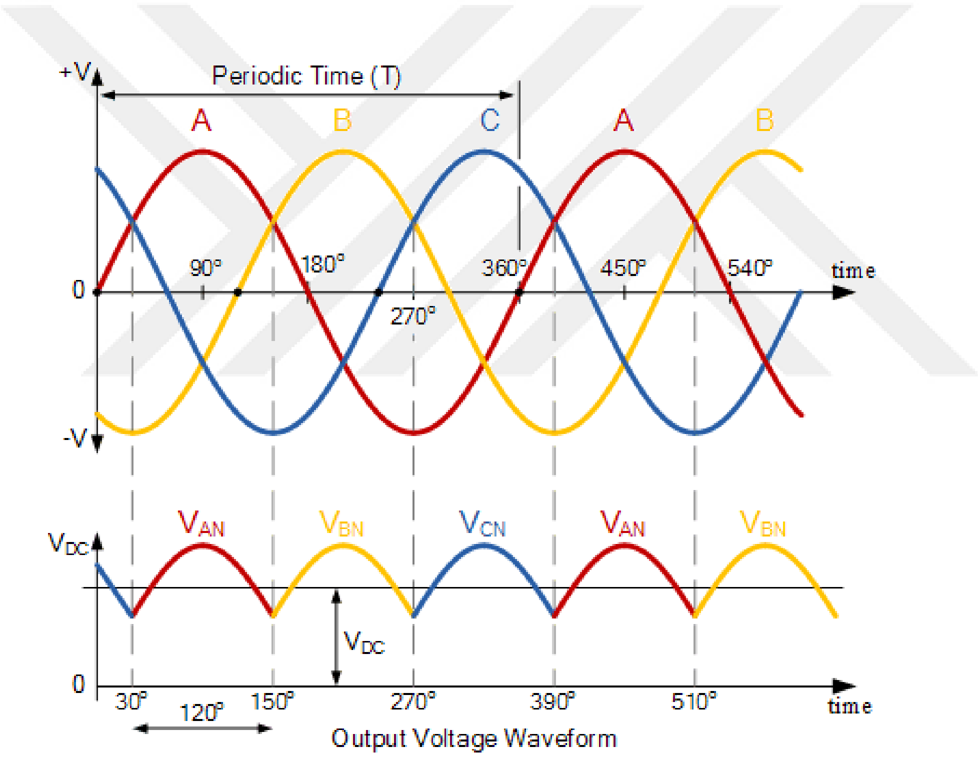


Figure 3.1. The wave-forms of the positive (+) voltage and the rectified current in each of the phases. [Adopted from: electronics-tutorials.ws/power/three-phase-rectification.html]

From the above figure, it is now known that the transformation from one of the (+) terminals to the other sections it will start-off immediately from the “electrical angle” as to which can be that the operation process started to take off at the 30 degrees and it continuously reach to the 150 degrees as to which it can also be express in the following form “$(\frac{\pi}{2} - \frac{\pi}{3})$ and $(\frac{\pi}{2} + \frac{\pi}{3})$” to which it can be deduced as follows

The median equation value for the DC voltage will be

$$Vdc = Vm * sin * \frac{\pi}{n} \tag{3.1}$$

For 3∅, the number (n)= 3, there for the new voltage median can also be deduced mathematically by inserting the n=3 into the above equation of figure 3.1 it will yield to the below expressions

$$V_{dc} = (3 * \sqrt{3/2} * \pi) * E_p = 0.827 * E_p \tag{3.2}$$

As we can see that the voltage provides to the maximum voltage (Ep), The Ep can also be taken same to the root mean square value (RMS) which can also be said that the median DC final voltage output of the rectifier system can be deduced mathematically also in the form of the RMS as

$$V_{dc} = 3 * \frac{\sqrt{3}}{2\pi} * \frac{E_p}{1.4141} = \frac{0.8270}{0.7071} * V_{rms} = 1.17 * V_{rms} \tag{3.3}$$

Therefore, also can deduced the DC current load as

$$I_l = \frac{V_{dc}}{R_l} \tag{3.4}$$

Where

I= Circuit load current

Vdc= Load voltage of the DC circuit

R= Resistance load of the circuit

Ep= maximum or the peak voltage

Also for 6∅, the number (n) =6, therefore the new median voltage for this equation can be deduced as it follows below when 6 is being replaced with n

$$V_{dc} = V_m * \frac{\sin * \pi}{6} \div \frac{\pi}{6} = \frac{3 * V_m}{\pi} \tag{3.5}$$

3.2 Six(6) Pulse Bridge Control Converter

The rectifier bridge is one of the most experimental network circuit that is normally use for the transformation process of an alternating current (ac) into its equivalent direct current (dc) for any HVDC transportation of an electrical power to a long distance (wadha, 2010, p.123). According to Adamson & Hingorani, (1960) argue that whenever the consideration of an alternating voltage is provided the direct output voltage is twice as that of the two (2) positive terminals that operates concurrently and also the power is twice also.

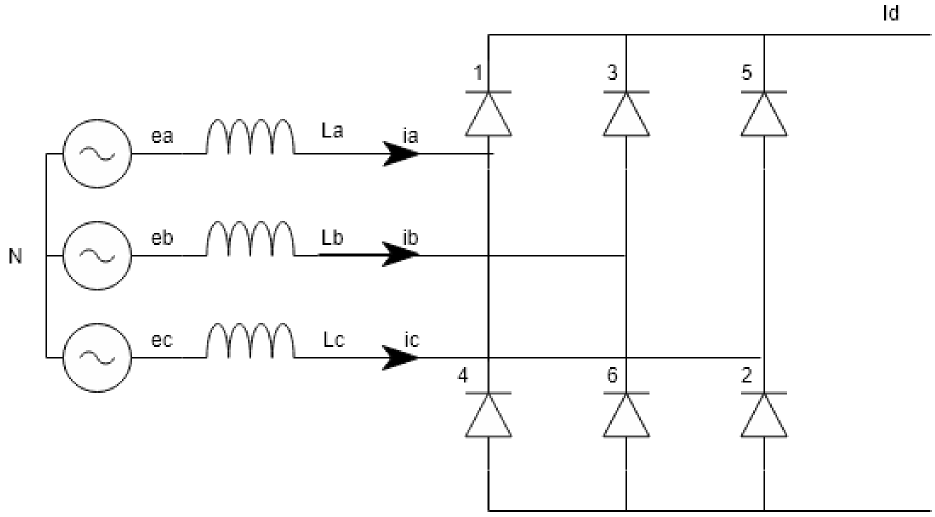


Figure 3.2. The bridge circuit rectifier

As we can describe the above operation of the circuit rectifier. The diodes basically operate in the succession of D1, D2, D3, D4, D5 and D6, so the changeover that happens in between this diode and the succeeding ones occurs concurrently in the above and below of the half bridge of the rectifier circuit.

Each of this diodes that are in the circuit operate at 120 degrees, in each 360 phase, so that the continuous operations of every sets of this diodes are D1 and D2, D2 and D3, D3 and D4, D4 and D_5, D_5 and D_6 and finally D6 and D1.

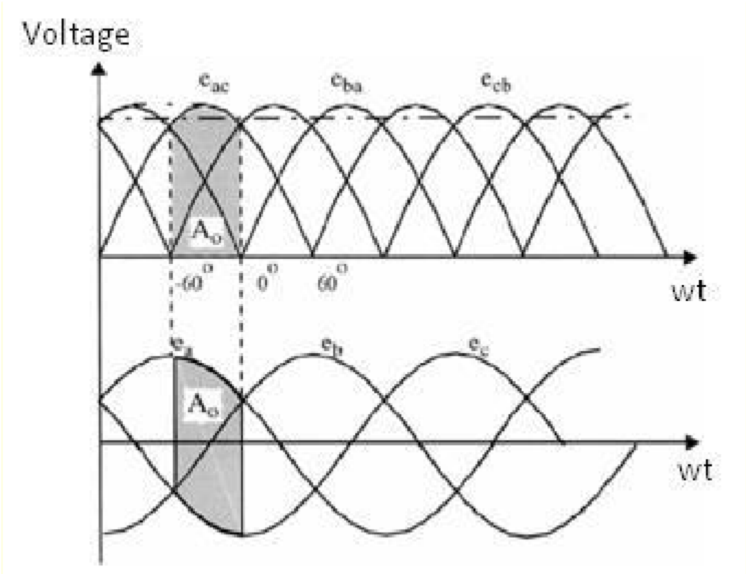


Figure 3.3. The six pulse bridge rectifier voltage output with no angle delay

As we can see in the above figure it is operating with a zero (0) angle delay. Therefore, we can mathematically deduce its median DC voltage as

$$V_o = 3 * \sqrt{3} * \sqrt{2} * V_{rms} \div \pi \qquad (3.6)$$

In this above mathematical expression we can see that the root mean square voltage is the number of the line-neutral (L-N) voltage phase in the circuit.

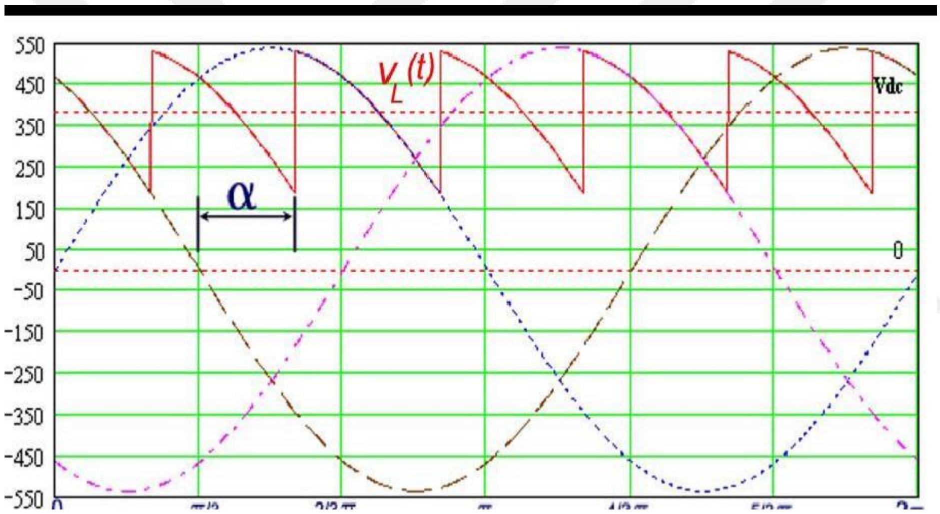


Figure 3.4. Six pulse bridge rectifier waveform voltage with an angle delay

In order to express the voltage rectifier in operation with the considered angle delay (α). It can be written mathematically by substituting the equation of 3.5 into our new expression of 3.6 which can be derived as

$$V_{dc} = V_o cos\alpha \qquad (3.7)$$

This implies that the above expression is derived from the output voltage dc with the control grid is being multiplied with the output voltage dc without any angle of firing together with the angle of the cosine.

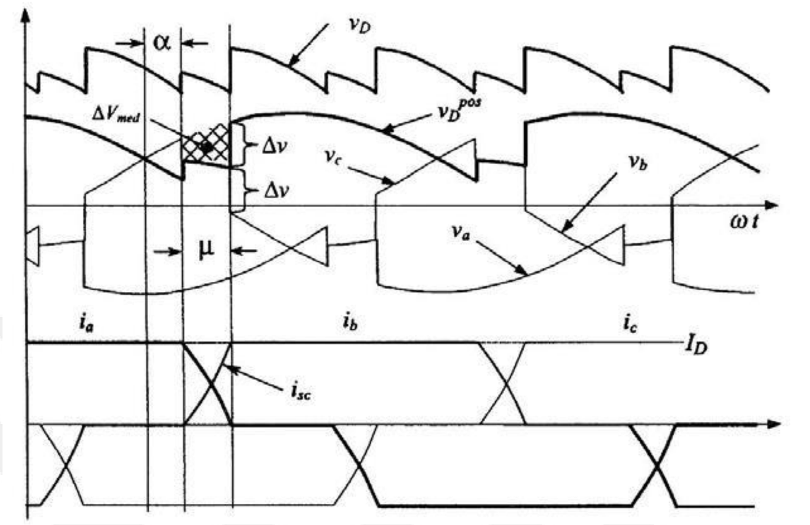


Figure 3.5. Output voltage and current shape form with an overlap angle

As we describe above we can note the effects of the overlapping on voltage output rectifier is being in a distorted manner during the process which it also tends to make the final rectifier output of its to in a damaging process which is the voltage rectifier (vd) as we can view from the describe figure above. Therefore, we can also deduce its expression mathematically below as. The output voltage with an overlap angle

$$V_o cos\alpha - \frac{V_o}{2}[cos\alpha - cos(\alpha+\gamma) \quad (3.8)$$

Therefore, reducing the above expression of 3.7 into 3.8 as

$$V_{dc} = \frac{V_o}{2}[cos\alpha + cos(\alpha+\gamma) \quad (3.9)$$

According to the book of Mohan et al (2003, p.465) and others expresses that the "real power transfer P_d" for each pair of the 6-pulse system converters can be obtain as

$$Pd = V_d I_d = 1.35 V_{ll} I_d cos\alpha \quad (3.10)$$

And also its power reactive can be deduce as

$Q1 = 1.35 V I_d cos\alpha$ (3.11)

Where $V = V_{LL}$

Therefore, for the satisfied transfer of power Pd, the power reactive needs Q1 has to decrease to as low as it can be, Particularly, Id has to be kept at a very low rate, so as to reduce the $I^{2}R$ losses on the dc line transportation. In other to decrease Id and Q1 , denoting that the V_{LL} is always constant, so it means, we have to take the lower value for the α delay in the operation of the rectifier system.

3.3. Current Relationship in a Circuit Bridge System

In the situation of a "bridge circuit" double valves are operating concurrently. The two valves have almost a close similarity to the non-identical phases that is the double phases are being short circuited. Therefore, taking inductance (L) as the units of henries for every period and for the immediate current in the circuit as (Is), then we can mathematical expression of describing the entire circuit network can be deduced below as

$$2L\frac{di}{dt} = \sqrt{3}V_m \ sinwt \quad (3.12)$$

Or we can also express it in terms of Is as

$$Is = -\sqrt{3}\frac{V_m}{2L}\frac{1}{w}coswt + A \quad (3.13)$$

At the first stage of it when taking $w * t = \alpha$, Is=0 and for the last stage of it also when taking the $wt = \alpha + \gamma$, Is=Id

We can mathematically reduce our expressions into the following form as

$$A = \sqrt{3}\frac{Vm}{2wL}cos\alpha \quad (3.14)$$

And also taking Is=Id

$$I_d = \frac{Vl}{\sqrt{2X}}[cos\alpha - \cos(\alpha+\gamma) \quad (3.15)$$

Where our VLL is the root mean square for the L-L voltage

The expression for the bridge circuit can also be expressed in the following form as

$$Vd = \frac{Vo}{2}[cos\alpha + \cos(\alpha+\gamma)] \quad (3.16)$$

Therefore, regard to the Vo as the rectifier bridge voltage without any control of grid and an angle of overlapping

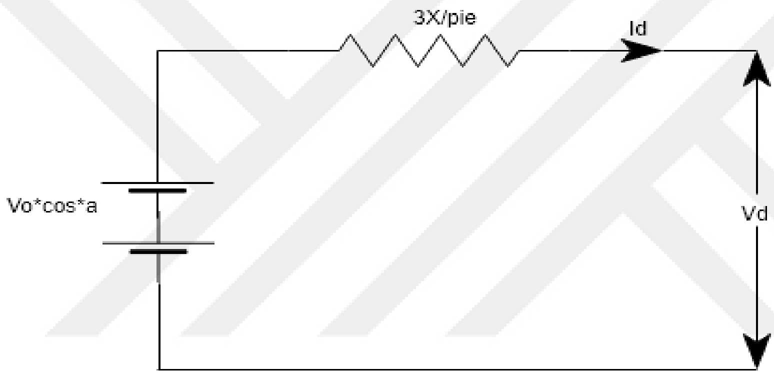
We can deduce our final expression as

$$Vd = V_o cos\alpha - 3XI_d/\pi \quad (3.17)$$

Therefore, the reactive power absorption in place of the active power can be deduce as follows

$$Q = 1.35VI_d sin\alpha \quad (3.18)$$

$$Cos\emptyset = cos\alpha - 3XI_d \div \pi Vo \quad (3.19)$$



.

Figure 3.6. Circuit representation of a working bridge rectifier

Also we can denote that the V_d can be differ by increasing the Vo in which in reverse it can be differing by replacing or substituting the tap replacement of the transformer (TR) and by the replacement of an alpha (a). This implies that $3X_c I_d/\pi$ stands for the drop voltage due to the commutation and not the physical drop resistance.

3.4 Techniques of Inversion Control System

In the book of (fewson, 1998, p.66) Explains that the inversion is the process of a transformation from any direct current sources (DC) to any alternating current load (AC). And further went to express that, the "semi-conductor switchable" process in the system can either be a thyristor, IGBTs and others. Wadha, (1998) went further to express that, in the situations of the valves, the operations only begin in a forward or single way and are therefore, the current in the system converters does not changes back. With the working of the rectifier the output end of the current which is Id and the voltage ending output which the Vd are in such that the load inside the systems consumes the power. In the operation of the inverter, it needed to transmit or convey the power from the DC to the AC system in which this can only be achieved by the making of a setback or altering the median voltage direct inside the system. Therefore, for an inversion, the voltage to the alternating system has to be in existence on the primary side of the TR and also the control grid for the converter is necessary. When the grid control is being considered, the voltage output is $Vo * \cos * \alpha$ it will result to zero as at when it reaches to a situation where by the α=90 degrees and in turn when the α is between 90 degrees and 180 degrees. It implies that our voltage will results to be negative in this case when the control grid for the α is being placed at 90 degrees and 180 degrees also.

In the hypothesis of rectifier, the "ignition angle" is being represented as α and it is the angle in which the firing is being delayed from an immediate action when the voltage commutation results to zero and expanding. In the situation of an inverter, its "ignition angle" is represented as beta (β) which can also be explain as (π − α) and its β is the same as writing it in the form of an expression as (γ + δ). Therefore, we can obtain the expression for the output voltage as

$$V_d = -[Vocos\delta - I_d R_c] \tag{3.20}$$

And also

$$V_d = -[Vocos\beta + IdR_c] \tag{3.21}$$

Where,

$$Rc = 3X/\pi \tag{3.22}$$

In the above explanations, we have seen that the rectifier can also function as an inverter when the "angle of ignition" is moving from 90 degrees to 180 degrees. We can hereby also write the expression of the inverter in form of its angle of extinction as

$$\gamma = 180 - \alpha - \mu \tag{3.23}$$

Whereby the μ represents our commutation angle of overlapping in the expressions.

Therefore, from the above expression derived in (3.20 and 3.21) we can reduce our voltage to the inverter as

$$Vd1=Vd2=\frac{V_d}{2}=1.35V_{ll}\cos\gamma-\frac{3\omega L_s}{\pi}I_d \quad (3.24)$$

Therefore, we can write our reactive power and the real power as

$$Q1=1.35V_{ll}I_d\sin\gamma \quad (3.25)$$

$$P=V_dI_d=1.35V_{ll}I_d\sin\gamma \quad (3.26)$$

In Equation 3.25 and 3.26, γ has to be very low, so that the transfer power stage to decrease I^2*R losses on the dc line transportation due to the Id and to decrease the power reactive needs by the converter system. And also in other, to decrease the value of the γ it is authorize to reach the "minimum extinction angle" that is mainly focusing on the adequate "turn-off time to the thyristors"

3.5 Control of HVDC Converter System

The movement of the current in the dc line transportation is been define by the total differences in the dc voltage among the two system of the converters that is between the Points A and Point B as can be viewed in the below figure 3.6a (Lasisi and Olayemi, 2014). Noting that all the terminals in the system which are the positive and negative poles are working under the same state which can be shown in figure 3.6a below. It describes that the positive terminal pole for example, it comprises of a "12- pulse converters" A and B. In the system point A is presumed to be working or functioning as a rectifier, and the dc voltage is explained as VdA while point B is also presumed to be working as an inverter, and also its dc voltage is describing as VdB. Therefore, it is being also describe as the difference that is fixed to the inversion mode of function, so as the VdB will have the positive integer or value (Mohan et al, 2003).

Therefore, in a reliable state it can be deduce as from figure 3.6a as

$$I_d=\frac{V_{dA}-V_{dB}}{R_{dc}} \quad (3.27)$$

Where $V_{dA=}$ voltage of the dc at the point A

$V_{dA=}$ voltage of the dc at the point B

R_{dc}= sum total of the entire line resistance

And the power transportation to the point B will written as

$$P_d = V_{dB} \;\; * \frac{V_{dA} - V_{dB}}{R_{dC}} \qquad (3.28)$$

Where, Rdc is our dc resistance for the positive transportation line conductor. Experimentally, the Rdc is low and its Id becomes as a consequence to the low difference among the two big voltages in the above equation (3.27). Therefore, one side of the converter is put on to monitor and control the transportation line voltages and also monitor the Id. Since we know that the inverter is functioning at a fixed $\gamma = \gamma_{min}$, it is preferably to be selected to the inverter in figure 3.7, to monitor the V_d. Then Id and therefore the level of the power to be monitored by the rectifier. Figure 3.6a and b will be shown below

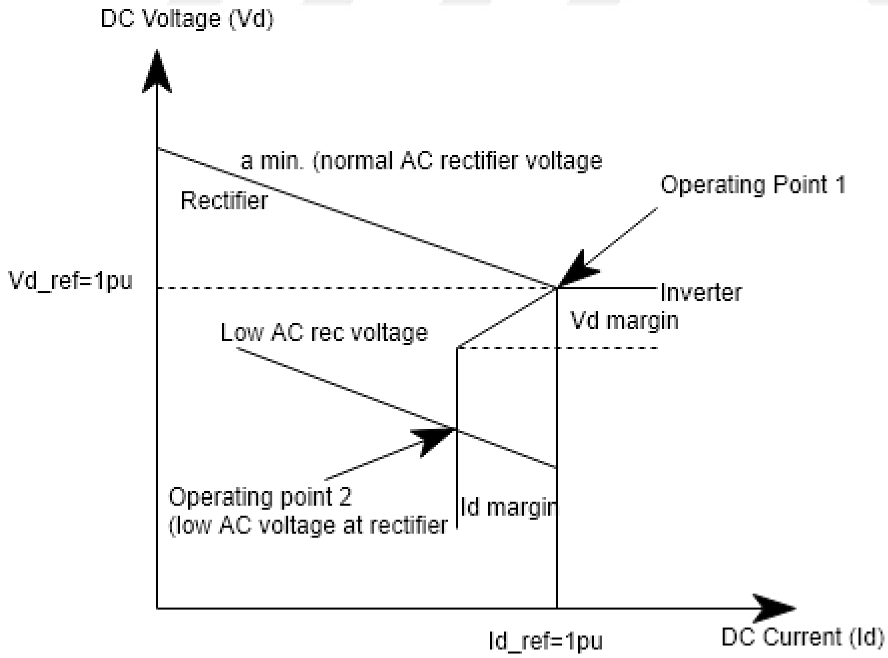


Figure 3.7. Shows the rectifier and the inverter control characteristics in the Vd-Id plane.

In figure 3.7b. Vd is selected to serve as the rectifier voltage, that is Vd=VdA. At the fixed "extinction angle γ = γmin", the inverter creates a voltage Vd in figure 3.7a which can be deduced as

$$V_{dC} = 2 * 1.35 * V_{ll} * \cos * \gamma_{min} - \left(\frac{6wLs}{\pi} - R_{dC}\right) * I_d \tag{3.28}$$

Assume, the above equation (3.28) to be a positive terminal, the fixed "extinction angle" working for the inverter will eventually end up in the Vd-Id characteristics as shown in figure 3.7b.

This rectifier can be monitored in order to keep the Id same as it reference point which is the Id, ref in the above 3.7b. The exact current Id is determine, and the error calculation is (Id-Id, ref), if it turns out to be positive, there will be an increment in the angle delay (α) to the recitifier, and if the error turns out to be negative, α will be decremented. While the inverter system monitors the "voltage reference value" in the system

CHAPTER 4
RESULTS AND DISCUSSION

This section of the thesis will show the MATLAB/SIMULINK final design and the simulations that were carried out on the analysis of the HVDC transportation system for the 12 pulse converters in other to observe the reliable state conditions of the system when fault is not applied and also to observe the situations and effects of the faults when it is applied at both the rectifier and the inverter sides of the systems, Moreover the phase voltages and the currents will also be observed to see there per unit current and voltage situations. The use of modern power electronics devices or equipment were adopted in the course of carrying out the simulations processes.

4.1. Matlab/Simulink HVDC Based IGBT/DIODE Transmission Model Description

The MATLAB/SIMULINK design is a DC connection that is usually operating for the transportation of an electrical power from 450Kv, 60Hz system to 345Kv, 50Hz system. The converters in the system are the rectifier and the inverter which are created based upon the “12-pulse converters” that are implore to be working with the combination of a “6-pulse bridge IGBT/DIODE system” that are being join together in a sequence or series arrangement. This converter is being linked through the use of a long line transmission modelling of about 450km that is being disseminated for the line specifications or parameters, and also there is a presence of two (2) smoothing system reactors consisting of a value of 0.75H. The tap interchanger transformer is not run by the system and the tap constant is presumed. Inside the transformers on both the inverter and the converter rectifier blocks subsystem a fixed number of value is applied for the factor value on the TR voltage corresponding to the primary location has a value of 0.90 on the rectifier system side and also the inverter side is having a value of about 0.96 corresponding to it also. The needed power reactive which is always needed by this system that is the rectifier and the inverter is accessible or provided by the pair group of the capacitors banks of 11th, 13th and the higher pass filtering having a number of 150Mvar on the four different filters that where available in the systems. Circuit breakers are also implored in which they are been use to add harmonics on the AC side of the inverter and also on the DC side of the system rectifier. The DC protection functions are created inside the rectifier and the inverter side ofthe networks. On the DC fault rectifier protection system, it is used for sensing and to pressure the angle delay onto the location of the inverter side in other to put out the abnormal current in it. The function of the controlling master block is to commence the taking off operation and ending operation of the converter as well as the ramping up and down of the reference current. As we can notice also the system is given at a discrete time of about 50 micro seconds which can be shown in figure 4.1

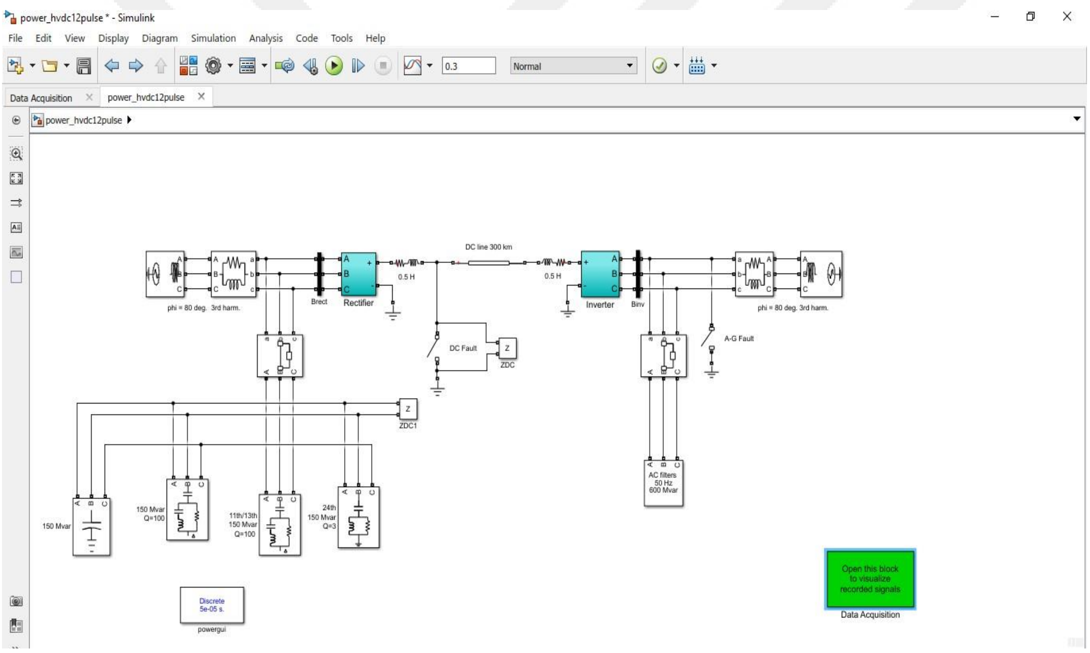


Figure 4.1. Matlab/Simulink HVDC IGBT/DIODE Based transmission model

The power electronics modern devices that will be use in carrying out this analysis model to the above transmission model system are the IGBT/DIODE.

4.2. Three phase harmonic filter

The three (3) phase harmonic filtration this are element that are used in some electrical power systems to prevent or to reduce the voltage instability and also for power factor (pf) correction. Nonlinear components example electronic converters that produces current or voltage disturbances known as the harmonics, that are been put into the electrical power systems (Anuradha et al 2014). The final instability of the currents moving throughout the entire impedance systems it manufactures a voltage harmonic disturbance. The most commonly used filtrations that are use can be detailed below:

(1) Band-Pass Filtrations, this are the types sieves used in the purification of a lower harmonics order namely 5^{th},7^{th} and 11^{th}, 13^{th}.
(2) High-Pass Filtrations, this are the types of sieves used in the purification of a higher harmonic order and also it encloses a very broad distance of frequency. The most used category of high-pass filtrations is the Type-C high pass filtrations, produce or give power reactive and to avoid equidistant resonances. It can also grant the purification of low order harmonics example are the 3^{rd} order harmonics, while keeping a constant of losses at zero (0) to the fundamental frequency (Dyaneshwar et al 2016).

The most commonly variety of the sieves that can be constructed with the Three-Phase Harmonic Filtration design are shown below

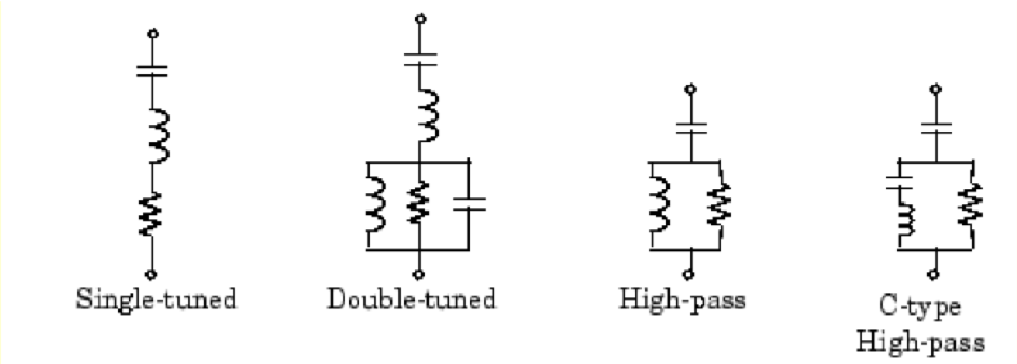


Figure 4.1. Three-phase harmonic filters

The easiest filtration category is the single-tuned filtrate. The categories of the models briefs the explanations of the quality(Q) factor versus the formula that is use in summing the reactance power Q*C and also the loss that occurs. “The quality factor Q of the sieve is the quality factor of the reactance at the tuning frequency’’ $Q = \frac{nX_L}{R}$.

The quality factor finds the bandwidth B, that assess the sharpening of the infrequency which can be shown in the below diagram.

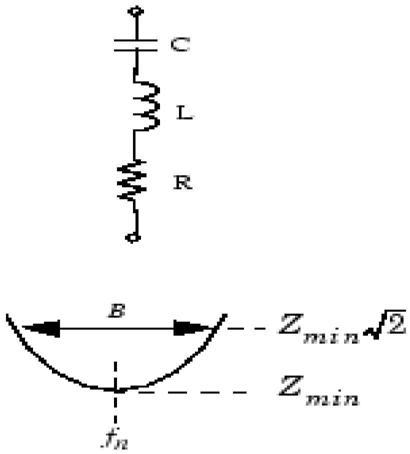


Figure 4.2. Single tuned sieve with impedance graph

Some specification for the filters include the following details below:

Tuned harmonic order $n = f_n / f_1 = \sqrt{X_C / X_L}$

Quality factor $Q = n\, X_L / R = X_C / (nR)$

Bandwith $B = f_n / Q$

Reactive power at f_1 $\quad Q_C = \frac{V^2}{X_C} \times \frac{n^2}{(n^2-1)}$

Active power at f_1 $\quad P = \frac{Q_C}{Q} \times \frac{n}{(n^2-1)}$

Where

f_1 = lowest frequency

f_n = infrequency.

n = harmonic order f_n / f_1

V = nominal line to line voltage

X_L = reactance of the inductor at the fundamental frequency can be deducted as = $2\pi f L$

X_c = reactance of the capacitor at the fundamental frequency can be deducted as = $\frac{1}{2\pi f C}$

The double-tuned filtrations operate the same act as a double single-tuned filtrations even though it consists of some benefits: the loss associated to it is smaller in quantity and the impedance significance of the frequency of the equidistant resonance that rises up that are enclosed by the two infrequencies is smaller. The double-tuned filtration comprises of a "series LC circuit and a parallel RLC circuit. If f_1 and f_2 are the two tuning frequencies, both the series circuit system and the parallel circuit are tuned to approximately the average geometric frequency"

$$f_m = \sqrt{f_1 * f_2}$$

The quality factor Q of the double-tuned filtrate can be explained as the quality factor of the equidistant R, L components of the average frequency

$$f_m \quad Q = R / 2\pi f_m . L$$

The high-pass filtrate is a single-tuned filters where the R and L components are linked in parallel rather than the series connections. The coupling finalized in a broad-band filtration consisting of an impedance at a very higher frequency's defined by the resistance R.

“The quality factor of the high-pass filter is the quality factor of the parallel RL circuit at the tuning frequency”:

$$f_n \quad Q = R/2\pi f_n L$$

The C-type high-pass sieve is the changing of the high-pass filtrate, whereby the inductor L is being substituted with a series L*C circuit tuned at the lowest frequency. At the lowest frequency, the resistor are thereby neglected by the resonance L*C circuit and the loss that are associated to it is ineffective.

The quality factor of the C-type sieve point is again explain by the equation as:

$$Q = R/2\pi f_n L$$

4.2. Simulation Results and Discussions

Below is the discussion and results findings that where been obtained after carrying out the Matlab/Simulink analysis which can explain and details about the results that were obtained and also with the observations that where been notice from the analysis of it under some certain conditions which can also be listed accordingly when the figures where been put into the thesis work. During this simulation in the converter the transformation device will be carried out with power electronic devices so as to compare the results obtains under this analysis.

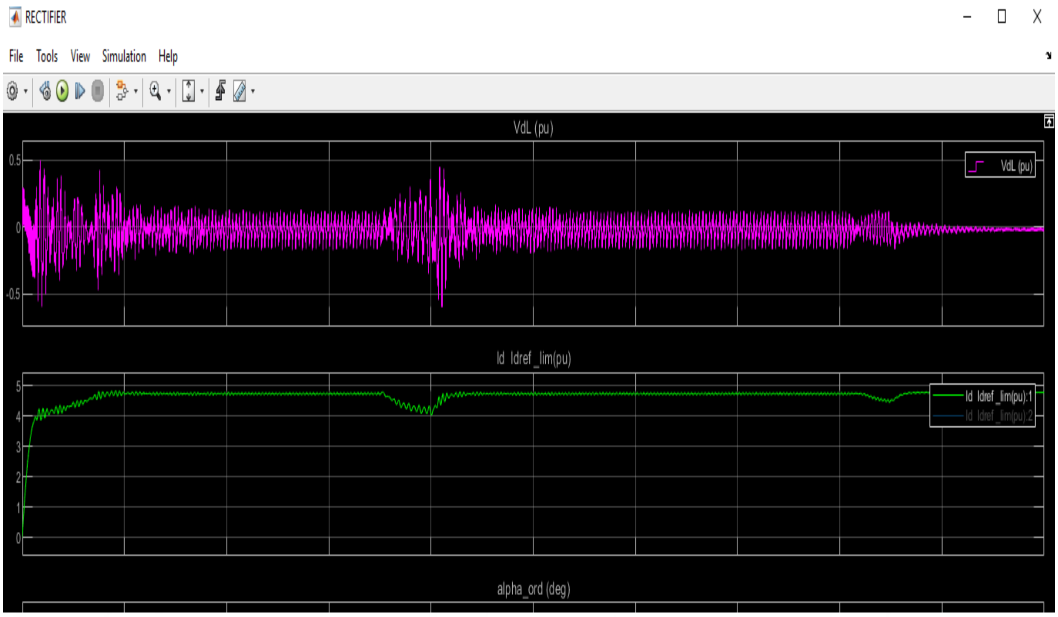


Figure 4.2. Shows the reliable state condition at the rectifier section without any DC abnormal behavior.

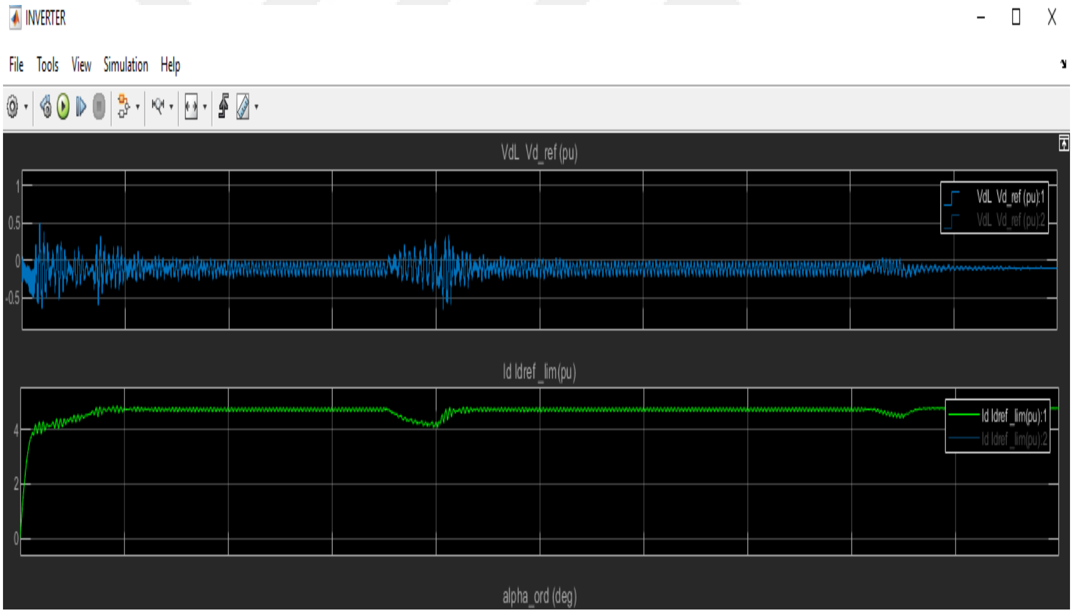


Figure 4.3. Shows the steady state condition at the inverter section without any fault

The above figures 4.2 and 4.3 shows the absence of fault at both rectifier (transferring point) and the inverter (accepting point). The results show the current and voltage in the above figures. In this figs above it is clearly shows that's at the rectifier side its voltage is not stable in nature at a time t=0.130seconds. After the time passes or elapses it can be duly seen or observe that the voltage at the side of the inverter which is the accepting point becomes stable or constant. The current and the voltage values at the accepting point which is the inverter are almost the same as compare with the transferring point which is the rectifier side with a little small delay. In contrast with the sending and the receiving point. The sending end is more steady than the receiving end.

4.4 DC Line Fault at the Rectifier and the Inverter

By turning off the steps that are used on both the voltage and current in the controlling master block and also on the controlling block at the inverter by lowering the switching position downward and also to interchange its factor multiplication to 1, we can now observe what happens to the voltage at 0.7seconds in the transferring to accepting voltages sides.

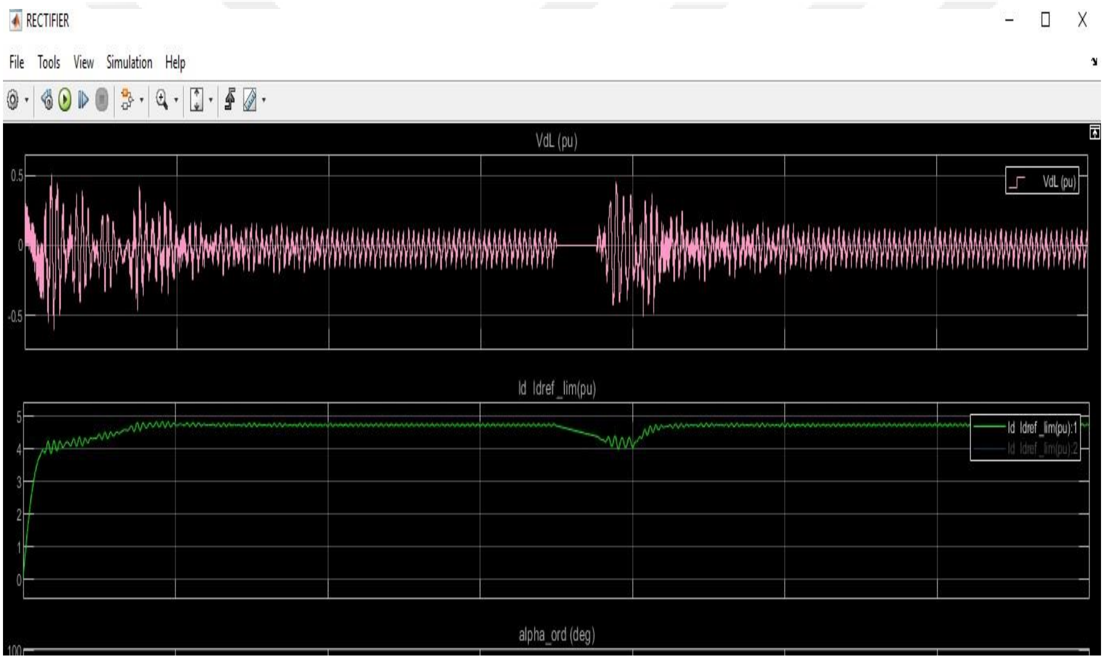


Figure 4.4. Rectifier at DC line fault conditions

The following observations were carried out on the DC line fault that happens at the rectifier side. We can observe that the voltage at the transferring point is not stable due to the occurrence of so many fluctuations from the starting point at t=0-0.25seconds as can been seen from the graph with a little stabilization starting from 0.25- 0.69seconds. before it finally results to becoming zero at 0.7-1.4seconds. After the clearance of the fault the voltage value becomes constant at the receiving end.

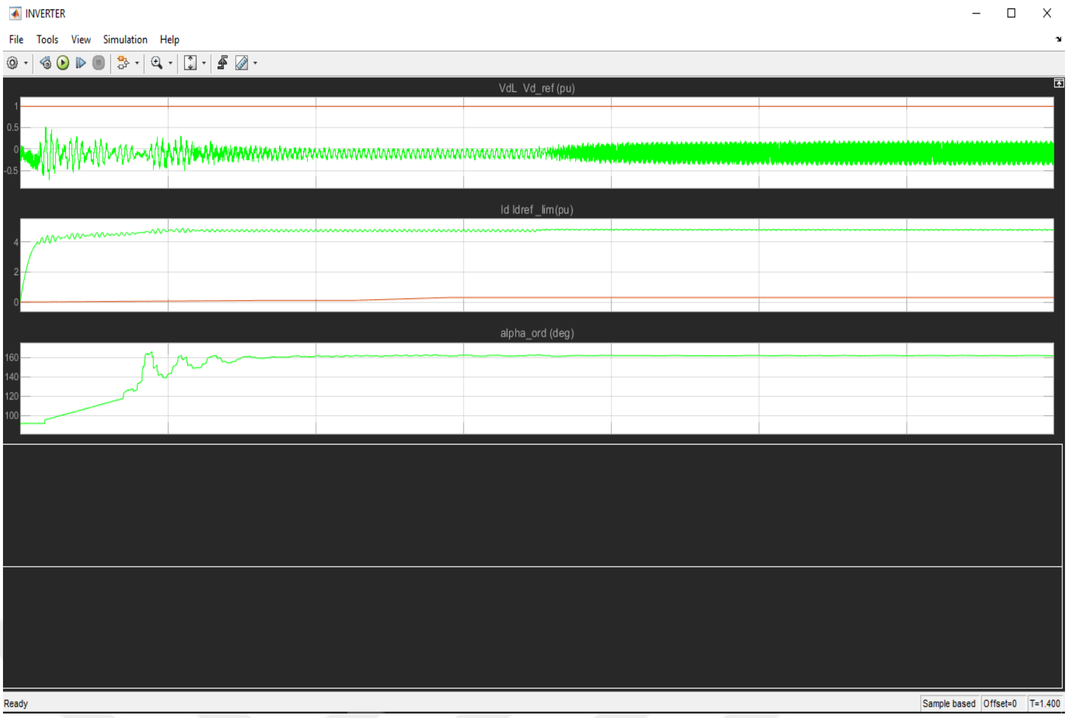


Figure 4.5. Inverter at DC Line fault Condition

Now, after the clearance out of the abnormal condition the voltage finally results to be in constant. While the reference current can be seen that it maintains its stability after the occurrence of the dc line abnormal conditions. We can also notice that after the recovery of the faults at time 0.8-0.95seconds the voltage results to becoming too damping which may results to the slower performance of the process and it may lead to serious effects stronger than the AC systems.

4.5 AC Fault condition

At the single line to ground abnormal conditions, we will now change the "fault timing" in order to implement the abnormal behavior on the converter systems.

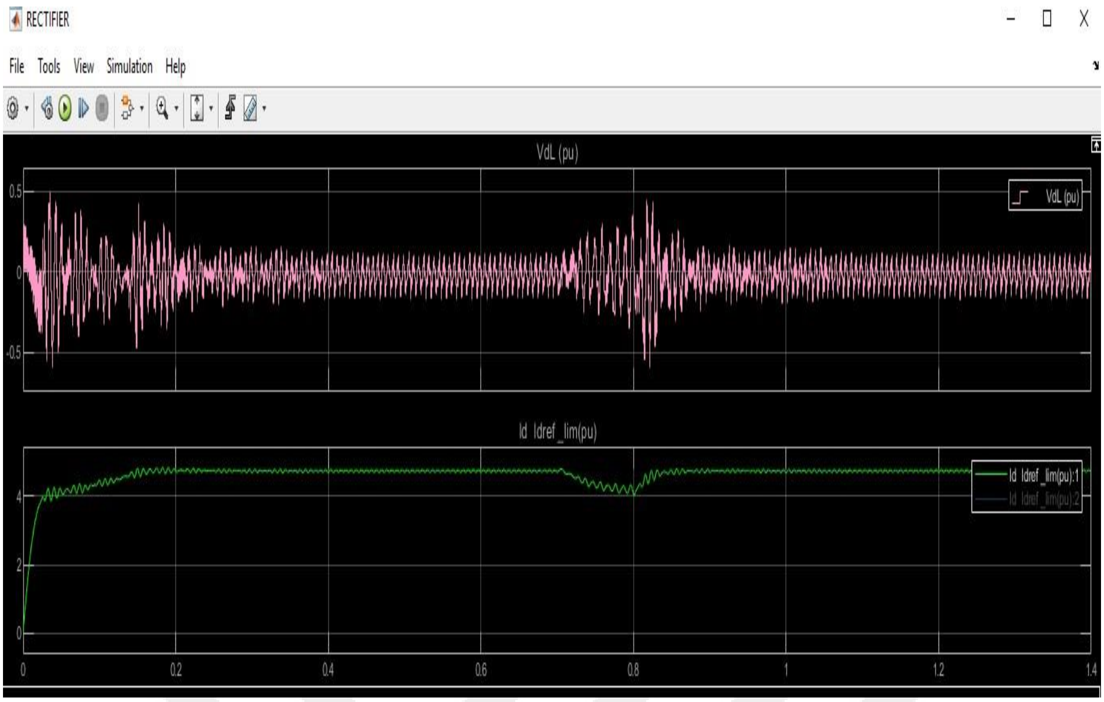


Figure 4.6. Single line to ground faults at the rectifier

During the AC abnormal conditions on the DC transportation we can observe that the instability of the voltage with value of V_{dc}=0.6 pu in which the fault results to dropping of the voltage to Vdc=-0.6 pu and it begins to recover slowly at a t=0.9-1 seconds. While the Id_ref also drops to 4 pu with a minimum angle of 15 degrees.

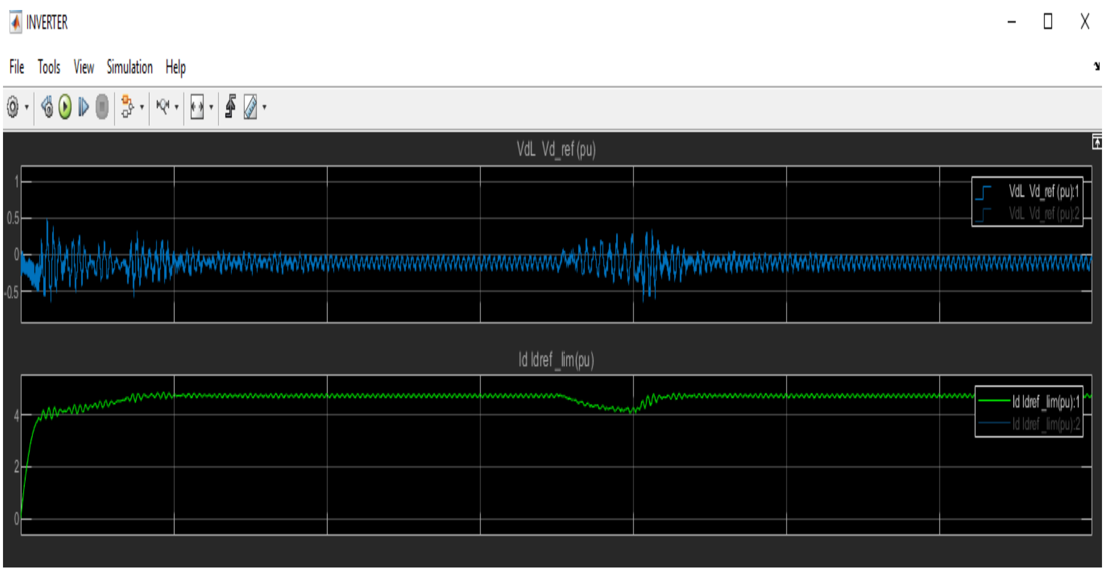


Figure 4.7. AC fault at the Inverter

The fault on the inverter reduces the DC voltage to Vdc=0.49pu and it causes an increment to the DC current Idc=4.5pu. This furthermore, explains that the reduction of voltage on the inverter and the increase in the current can easily cause a commutation failure and it can also cause problem to the stability of the AC grid power.

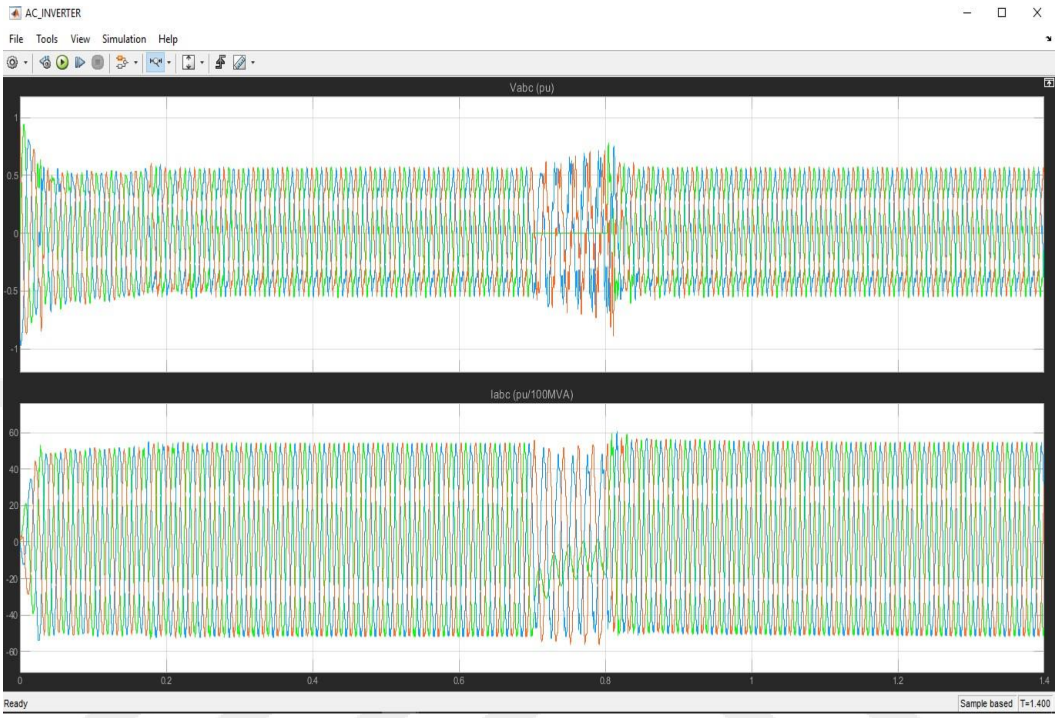


Figure 4.8. Shows the variations of Voltage and Current on the 50Hz part for an AC line fault at the inverter section.

We can observe that the phases that are having the problem during the occurrences of the AC fault are phase A and phase C while phase becomes zero.

Comparation of the theoretical datas obtained from the design

$V_d=2*(V_{do}*Cos*(a)-R_{c*}I_d)$

$V_{do}=(3*\sqrt{2}/\pi)*V_c$

$R_c=(3/\pi)*X_c$

$V_c=0.94*199.9kv/0.89=213.4kv$

Mathematically alpha is taken from the above results as a=15.9 degrees, $X_c=0.239pu$ on 1200MVA

The theoretical voltage corresponds with the converter voltages

R=4.49, R=1

$V_d = V_{inverter} + (R_{dcline} + R_{inductor}) * I_{dc}$

=499.9kv + (4.5 +1)*1.99=510.8kV

The overlapping angle can also be gotten since the theoretical values depends on the α, the DC current I_d and the reactance

$V_{dc} = (3*\sqrt{2}/3.14)*213.4 = 288kV$

$R_c = 3/3.14*9.874 = 10$

$\mathscr{M} = \alpha*\cos[\cos*(\alpha) - X_c*I_d*\sqrt{2} \div V_c] - 9$

Inserting all the values into the above equation we have

$\mathscr{M} = 18^{\circ}$

Checking the voltage and current FFT and Output waveform of the system when the circuit breaker open and close to the system

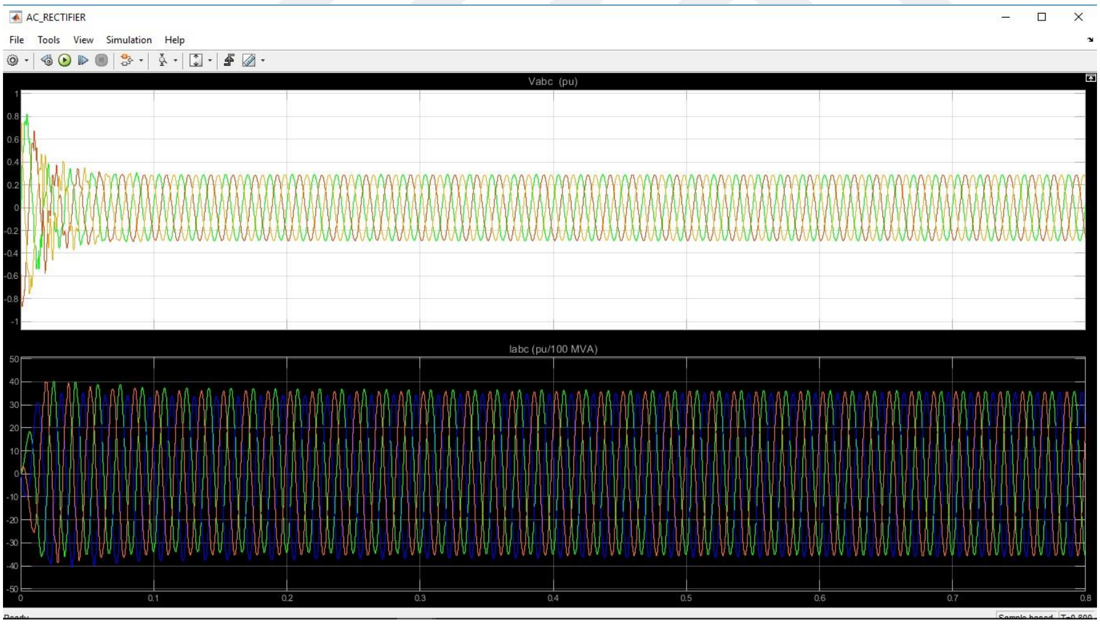


Figure 4.9. Output waveform of the current and voltage when the filter is off

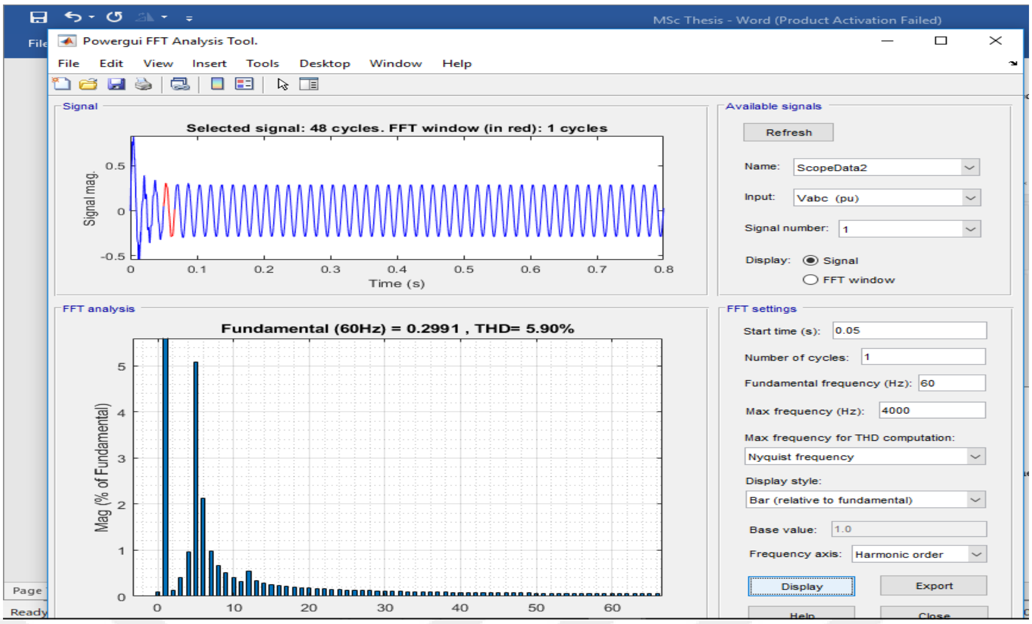


Figure 4.10. Shows the FFT analysis voltage output at 5.90% when the filter is off.

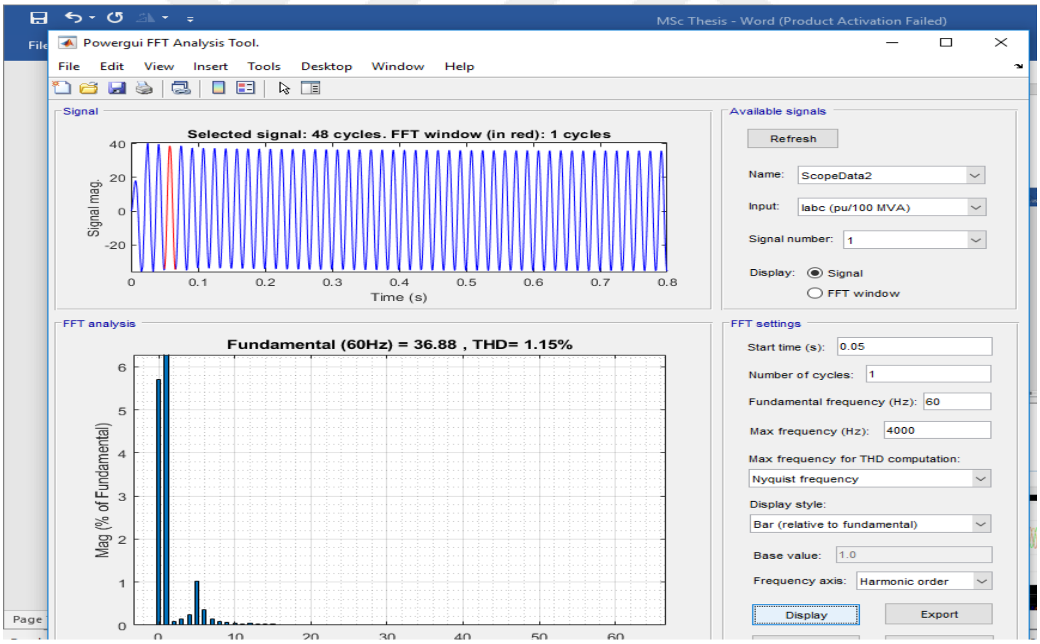


Figure 4.11. Shows the FFT analysis of the current at 1.15% when the filter is off

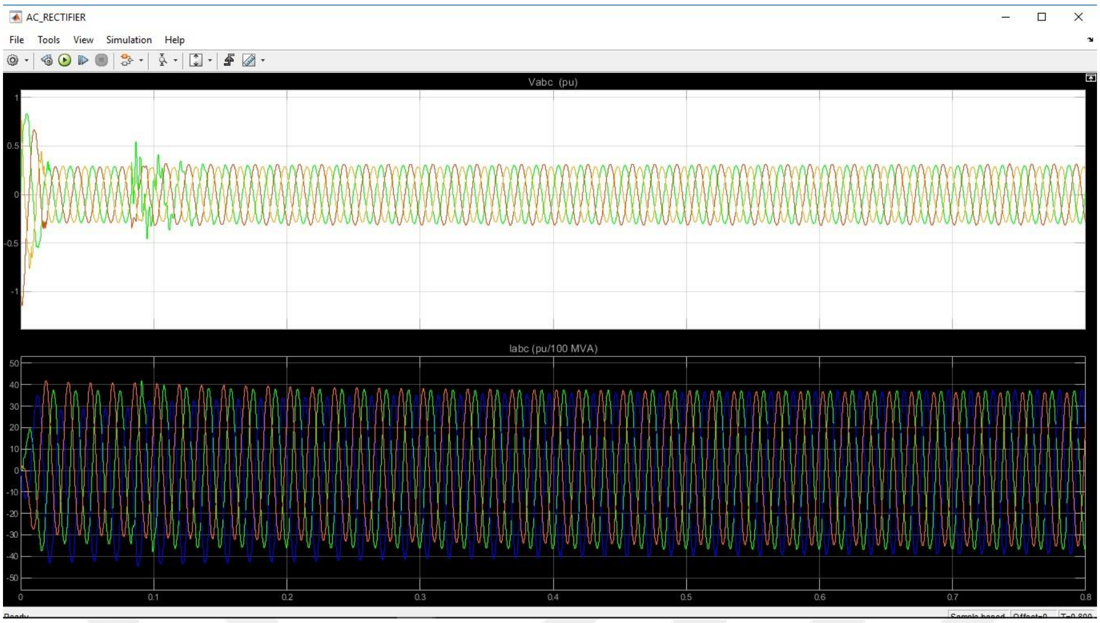


Figure 4.12. Output waveform of the current and voltage when the filter is on.

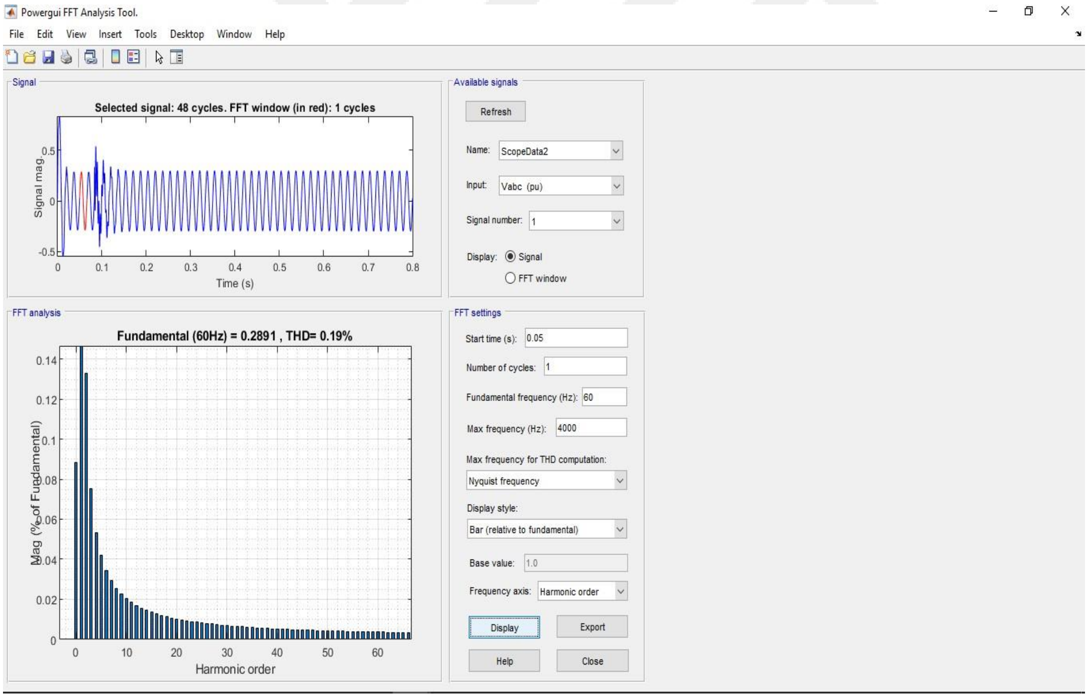


Figure 4.15. Shows the FFT analysis of the voltage with filter on

The FFT analysis of the voltage is at 0.19% which shows that it is within the accepted range below 5%

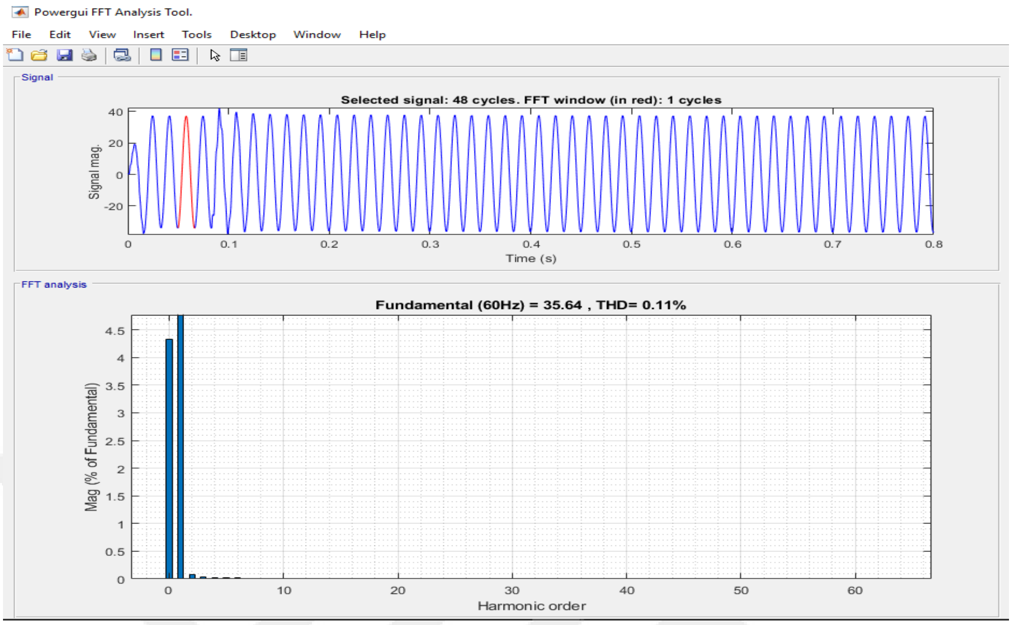


Figure 4.16. Shows the FFT analysis of the current with the filter on

The FFT analysis of the current waveform is at 0.11% which means it is within the accepted range below 5%.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

It has been observed that for so many points of views that this DC transportation network is much more dependable and it has a higher reliability that the AC network. Also for so many countries around the globe are now working with the HVDC transportation due to its economic benefits and a very minimal rate of power losses in the world. Studies has also enlightened us that it is now workable to work with the HVDC in an opposite or parallel linking with the HVAC. Although deep studies are still in continuous to observe the control parameter, improvement have also been made to the modern power electronics devices which are usually used for the conversion process and also they are used in this thesis to study their performances in order to see how the devices where been use to control the entire network to the improvement of their power capacity transfer. The current and voltage relationship were also carried out under there reliable state condition and also their abnormal condition where implemented at both converters that were used in the system. And it has also found out that voltage and the current were largely depended on the types of abnormal condition that occurs to it. The first device that is used in this experiment is the IGBT. It has also duly observed that the thyristors have a better performance and has a faster recovery to any abnormal occurrence than the IGBT. Infact most of the devices that were in use now are the very light triggered thyristors in which they do not require any provision for their switching process and are therefore decrementing the cost of their terminal apparatus/equipment.

Further studies are currently now on the move extensively on the VCS base HVDC network. In this newly technology, the IGBTs are implemented and they can automatically switch off currents and are having a higher conversion process, which deduce that there is no need for an active voltage commutation and power reactive can be maintained separately. There are also no needs for power reactive compensation, in which it will further decrement the price of applying or using the network because the decrement in the size of the filtrations. Although most VSC transportation systems in nowadays operation are working with a very lower voltage than the thyristors based High voltage DC transportation networks.

It is now presumed that the SC level after the abnormal occurrence is not underneath the minimal specification for the satisfaction converter working. All the energy that is available and the transient dependability that is still in existence in DC networks with thyristors valves are about 0.95% of more. The mean resultance failure rate of the thyristors in a valve is below 0.6% per functioning throughout the year.

From the results that is been analyzed after the simulations. It is observed that the HVDC network when they are being linked to AC network it can return back to its normal condition quickly after the occurrence of any faults. The results presented demonstrate the performance of the controller recovery of the HVDC links from various disturbances in the system.

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