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Thème:

Transmission line (TL) Fault Detection using wavelet in MATLAB

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Summary

Our thesis focused on identification of simple power system faults using wavelet-based analysis of transmission line parameter disturbances. The major faults in transmission lines are line to ground fault, line to line fault and three phase faults. These faults can be identified and classified using discrete wavelet transform. During the occurrence of faults, the grid current and voltages undergoes transients. These transients can be analyzed using discrete wavelet transform and the fault can be classified. The maximum detail coefficient, energy of the signal and the ratio of energy change of each phase currents are calculated from the transients produced by each phase due to faults using discrete wavelet transform (DWT) and thus Identification and classifying transmission system faults.

Keywords: Transmission line faults, fault detection, zero sequence current, discrete wavelet transform.

Résume

Notre thèse concentrée sur l'identification des défauts simples du système électrique à l'aide d'une analyse basée sur les ondelettes des perturbations des paramètres de la ligne de transmission. Les principaux défauts des lignes de transmission sont les défauts ligne à terre, les défauts ligne à ligne et les défauts triphasés. Ces défauts peuvent être identifiés et classés à l'aide d'une transformée en ondelettes discrète. Lors de l'apparition de défauts, le courant et les tensions du réseau subissent des transitoires. Ces transitoires peuvent être analysés à l'aide d'une transformée en ondelettes discrète et le défaut peut être classé. Le coefficient de détail maximal, l'énergie du signal et le rapport de changement d'énergie de chaque courant de phase sont calculés à partir des transitoires produits par chaque phase en raison de défauts à l'aide de la transformée en ondelettes discrète (DWT) et donc de l'identification et de la classification des défauts du système de transmission.

Mots clé : Défauts de ligne de transmission, détection de défaut, courant homopolaire, transformée en ondelettes discrètes.

ملخص

ركزت أطروحتنا على تحديد أخطاء نظام الطاقة البسيطة باستخدام التحليل القائم على المويجات لاضطرابات معلمات خط النقل. الأخطاء الرئيسية في خطوط النقل هي خط إلى خطأ الأرض ، خط إلى خط خطأ وثلاثة أخطاء المرحلة. يمكن تحديد هذه الأخطاء وتصنيفها باستخدام تحويل المويجات المنفصلة. أثناء حدوث الأعطال ، يخضع تيار الشبكة والفولتية للعبور. يمكن تحليل هذه العابرين باستخدام تحويل المويجات المنفصلة ويمكن تصنيف الخطأ. يتم حساب الحد الأقصى لمعامل التفاصيل وطاقة الإشارة ونسبة تغير الطاقة لكل تيارات طور من العابرين الذين تنتجهم كل مرحلة بسبب الأعطال باستخدام تحويل المويجات المنفصلة وبالتالي تحديد وتصنيف أخطاء نظام الإرسال .

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*I thank above all **"God",** the Almighty, for giving me the strength to follow,*

As well as the audacity to overcome all difficulties.

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From the Department of Electrical Engineering, University of Ouargla

More specifically the network team,

Many thanks to everyone who contributed closely Or by far to develop this work

Dedications

I dedicate this work to my dear parents

May God grant them long life

To my family

To my brothers, my friends

And to all those who have helped me directly or indirectly to carry out this work.

Labadi Khaled

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Abbreviations

AC	Alternating Current
AG	Phase A To Ground
CWT	Continuous Wavelet Transform
DFT	Discrete Fourier Transform
DWT	Discrete Wavelet Transform
DCT	Discrete Cosine transform
DTE	Electricity Transmission Directorate
FFT	Fast Fourier Transform
L-G	Phase-To-Ground Fault
LL	Two Phase Fault
LL-G	Two Phases-To-Ground Fault
LLL-G	Three Phases-To-Ground Fault
MRA	Multi-Resolution Analysis
STFT	Short Time Fourier Transform
WT	Wavelet Transforms

Symbols

a	Wavelet scaling factor
b	Center location of the wavelet function
C	Wavelet coefficients
t	Time period
$g^{\omega,t}$	Fourier transform function
MHz	Megahertz
X	Received signal
w^{*}	Complex conjugate of w
N	Zero-mean white Gaussian noise
τ	A shift or translation parameter
$\Psi_{a, b}$	Wavelet transform function
ψ(x)	“Mother” wavelet
ω	Frequency value (Fourier transform)
ψ	Wavelet function

Introduction

Introduction

The definition of the legacy electric power system is the one-way flow from a centralized power generation plant to customers (consumers). (The generation system, transmission system, and distribution system) are the three subsystems that make up the traditional electric power system. The transmission system is made up of transmission lines and a transmission substation, where generation voltages are step-upped and transmitted to supply distribution substations after stepping-down to distribution substation level on the transmission lines. Electricity is supplied to end-user consumers through the distribution system. [1]

The transmission line is one of the main components in electrical power system which works as medium for transmitting electrical power generated to the consumers. In order to ensure a continuous electricity supply at the consumer side, maintenance and protection should be in high concern. However, most of the time, fault occur without a warning and can be at any place due to weather condition, failure of the equipment, error by human mistakes and others. [2]

A power system in compasses a vast network that extends across a large geographic area, interconnecting entire countries or even multiple countries. It comprises various components, including generators that convert mechanical energy into electrical energy to generate power. Transformers are employed to modify the voltage levels as per specific requirements. Transmission lines facilitate the transfer of electrical energy from one end of the system to the other. Additionally, there are several other devices such as relays and circuit breakers that play a vital role in protecting against faults. Faults are an unwanted connection between two different conductors. There are several causes of faults, weather conditions, human error and equipment failure are some examples of it. These faults can have severe consequences, potentially causing damage to equipment or even the entire power system. Furthermore, they can trigger fires, jeopardize the safety of operating personnel, and, in extreme cases, result in loss of life. [3]

The fault in the power system is mainly categorized into two types they are symmetrical fault and unsymmetrical fault. The fault cases are classified as one of ten different types of faults viz. Single line to ground faults, Line to Line faults, Line to Line to ground faults and a three-phase faults.

Introduction

The Fourier transform is a valuable tool for analyzing the frequency components of a signal. However, when we apply the Fourier transform across the entire time axis, we lose the ability to determine the exact timing of a specific frequency occurrence. To address this limitation, the short-time Fourier transform (STFT) utilizes a sliding window to compute a spectrogram, which provides information about both time and frequency. Nevertheless, the STFT encounters another challenge: The length of window limits the resolution in frequency. The wavelet transform offers a potential solution to this problem. It operates based on small wavelets that have finite durations. By employing translated versions of these wavelets, we can accurately identify specific locations of interest within the signal. Furthermore, the scaled-version wavelets allow us to analyze the signal in different scale.

This thesis discusses the How to Apply Wavelet Transform for Fault Identification & Classification in MATLAB Simulink Software.

Wavelet transforms are modern mathematical techniques that leverage group theory and square integral representations to decompose a signal, or field, in both space and scale, and potentially in different directions. They use analyzing functions, called wavelets, which are localized in space. To achieve scale decomposition, the chosen analyzing wavelet is dilated or contracted, before convolved with the signal. The limited spatial support of wavelets is significant because it eliminates the influence of signal behavior at infinity. As a result, wavelet analysis or synthesis can be performed locally on the signal, in contrast to the Fourier transform, which is inherently nonlocal due to the space-filling characteristics of trigonometric functions. Wavelet transforms have been applied mostly to signal processing, image coding, and numerical analysis, and they continue to evolve. [4]

Our work is organized as follows:

The first chapter is devoted to general information on Power System, and faults that can occur within the system,

In the second chapter discusses and explores wavelets and wavelet transforms, generations of wavelets, Types of wavelet transforms, and why we use wavelets, and similarities and Dissimilarities between wavelets and Fourier Transforms

The third chapter is devoted to the Diagnosis of Transmission Line Fault Using Wavelet

Finally, a general conclusion will complete our thesis.

Chapter I

Power System in general

I.1. Introduction

In our time, it is nearly impossible to imagine daily life without electricity, highlighting the importance of efficient and uninterrupted electricity production. To meet the ever-growing demand for electricity consumption, it became necessary to invent and construct power plants capable of generating electricity in large quantities. Once the electricity is generated, it must be efficiently transported and distributed to consumers. Within a country, the responsibility of Energy Transportation and Public Distribution is to facilitate the transmission of electrical energy between the production points and the consumption points. The primary objective of an energy network is to ensure the reliable supply of electricity to meet consumer demands.

I.2. Priorities of the Power System

The Figure. 1.2 illustrates a global view of the electrical network. There are four levels: production, transportation, allocation and distribution. [5]

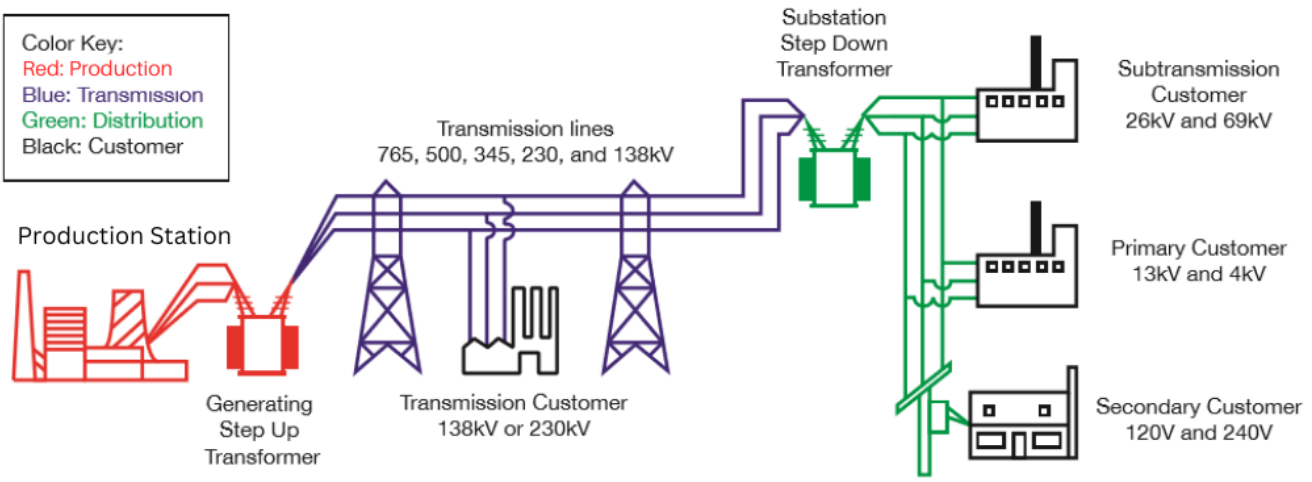

Fig I. 1 Global view of the Power System

I.2.1. Production

The production is used to produce electrical energy thanks to turbo-alternators that transform the energy mechanics of turbines in electrical energy from a primary source (gas, oil, hydraulics. . .). The primary sources vary from one country to another, for example in Algeria, natural gas covers more than 70% of the production, in France, 75% of electricity is of nuclear origin. In general, each production source (power plant) groups together several turbo-alternator groups to ensure availability during maintenance periods, for example, the Jijel central office in Algeria is composed of three groups 196 MW, that of Cap Djenet in Boumerdes 4 groups of 168 MW. In addition, we find in the industrialized countries with higher and higher installed powers to meet the growing demand in electrical energy, for example the Gravelines nuclear power plant in France 6 × 900 MW, the Trois-Gorges hydroelectric power plant in China 34 × 700 MW and 2 × 50 MW (which has become the largest power plant in the world in 2014).

I.2.2. Transmission

An alternator produces the electrical power under medium voltage (12 to 15 kV), and it is injected in the Transmission network through transformer stations to be transmitted under high or very high voltage in order to reduce losses in the lines. The level of the Transmission voltage varies according to the distances and the powers Transmission, the greater the distances the higher the voltage must be, the the same goes for the power. For example, the Transmission network in Algeria uses a voltage of 220 kV (see 400 kV for some lines in the south in particular), the European network uses 400 kV, and the network north American 735 kV.

I.2.3. interconnection stations

The distribution network originates in the transmission network from the interconnection stations THT/HT(MT) and is used to supply large industrial consumers under high or medium voltage, and to distribute the powers in different rural or urban regions. This type of network uses typical 60 and 30 kV.

I.2.3. Distribution

The distribution is used to supply consumers with medium or low voltage (typically 400 V), thanks to MT/BT transformer stations.

I.3. Organization of the Power System

The Power Systems have the function of interconnecting the production centers such as the hydraulic, thermal power plants...etc. with consumer centers (cities, factories...etc.). The energy electric power is transported in high voltage and/or very high voltage to limit the Joule effect losses (the losses being proportional to the square of the intensity of the electric current), then gradually lowered at the level of the end user's voltage. The Power System are constituted by all the devices intended for the production, the transmission, distribution and use of electricity from Power Plants to the most distant country houses (Fig I. 2). [6]

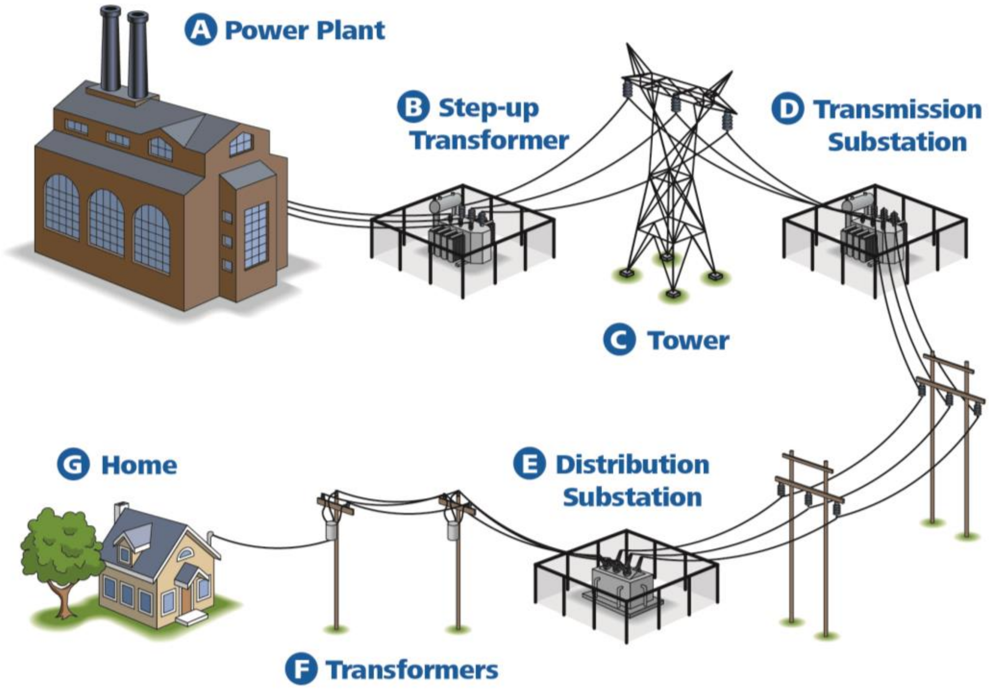

Fig I. 2 Organization of the Power System

In order for the electrical energy to be usable, the System must meet the following requirements:

- To ensure the customer the power he needs;
- To provide a stable voltage whose variations do not exceed ±10% of the nominal voltage;
- To provide a stable frequency whose variations do not exceed ±0.1% Hz;
- To provide energy at an acceptable price;
- To maintain rigorous safety standards;
- Please pay attention to environmental protection;

I.3.1 Power stations

There are five main types of power plants: Fossil fuel power plants (coal, oil and natural gas) so-called conventional thermal power plants, nuclear power plants that are also power plants that can be described as thermal, hydroelectric power plants, power plants solar or photovoltaic, wind power plants.

I.3.1.A. Thermal Power Plants

Thermal power plants produce electricity from the heat that is released from the combustion of coal, fuel oil or natural gas. They are often found near rivers, lakes and seas, as huge amounts of water are required to cool and condense the steam coming out of the turbines. Combustion gives off a large amount of heat used to heat water in the boiler (or steam generator). We then have pressurized water vapor. This pressurized steam causes a turbine to rotate at high speed which drives itself an alternator which produces a sinusoidal alternating voltage. At the outlet of the turbine the steam is cooled to turn into water, then returned to the boiler (Fig I.3).

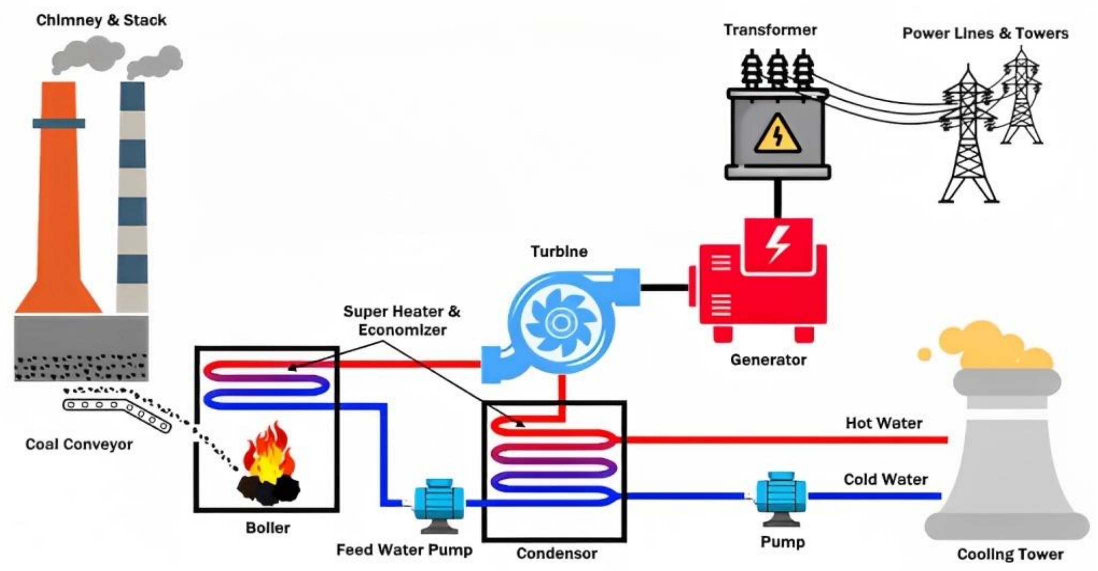

Fig I. 3 Thermal power plant

I.3.1.B. Nuclear Power Plant

These power plants also use thermodynamic conversion cycles, nevertheless their "boiler" is a nuclear reactor (Fig.I.4). The nuclear energy obtained as a result of reactions of fission of uranium and plutonium is the heat source used. Nuclear power plants produce radioactive waste and present a risk of accident.

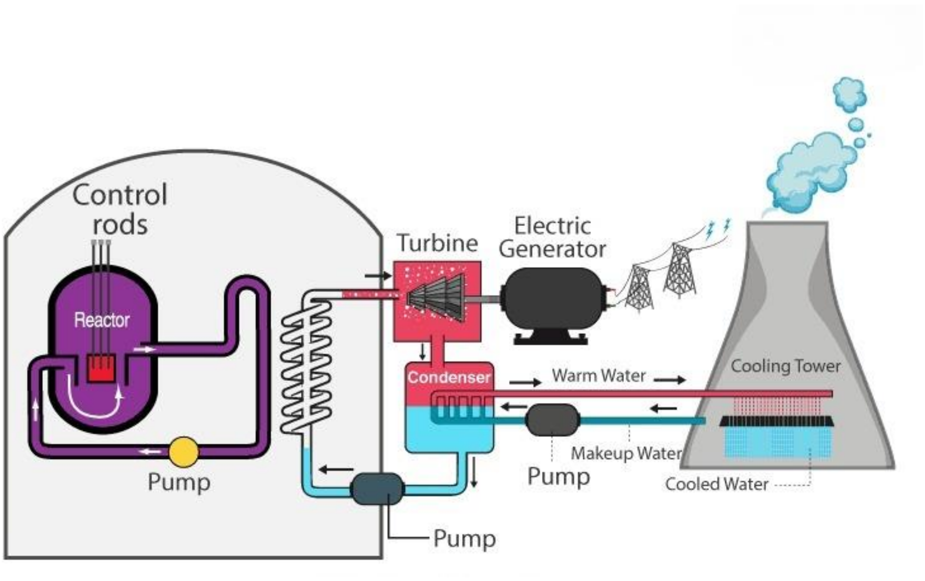

Fig I. 4 : Nuclear power plant

I.3.1.C. Hydroelectric Power Plant

Hydroelectric power plants convert the energy of moving water into energy electric. The energy coming from the fall of a body of water is first of all transformed into a hydraulic turbine in mechanical energy. This turbine drives an alternator in which the energy mechanical is transformed into electrical energy (Fig.I.5).

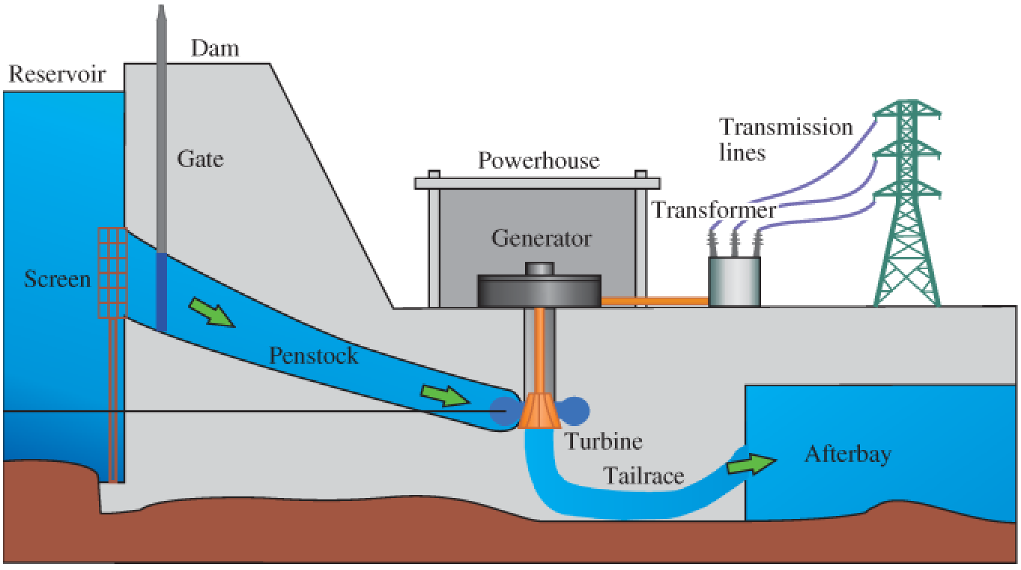

Fig I. 5 Hydroelectric power stations

I.3.1.D. Solar or photovoltaic Power Plant

A first process consists in making electricity with solar energy using the light radiation from the sun, which is directly transformed into an electric current by cells based on silicon or other material having light/electricity conversion properties. Since each cell delivers a low voltage, the cells are assembled into panels (Fig.I.6). Another method uses mirrors to concentrate the flow of energy towards a fireplace where water is vaporized to drive an alternator.

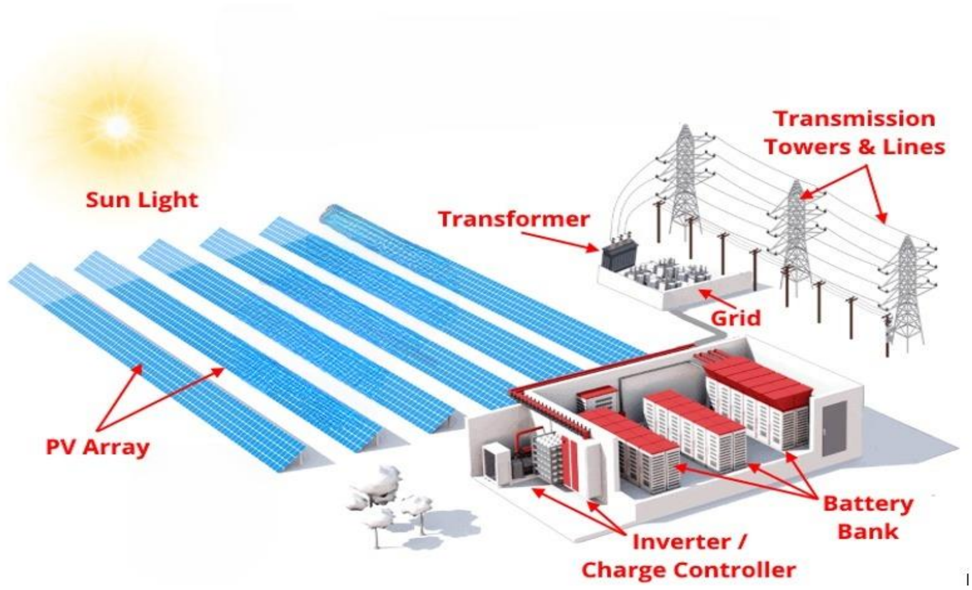

Fig I. 6 Solar or photovoltaic power plants

I.3.1.E. Wind Power Plant

The energy of the wind comes from that of the sun that heats up air masses unevenly, causing differences in atmospheric pressure and therefore air circulation movements. The energy wind turbine is a renewable energy, available everywhere (in different quantities) and of course without rejection pollutant in the atmosphere. The wind turbine transforms the translational power of the wind into rotational power. An alternator It is connected mechanically to the axis of the blades (rotor) to produce the three-phase voltages. A device for regulation makes it possible to obtain a constant rotation speed compatible with the frequency of the network (50Hz), (fig I.7).

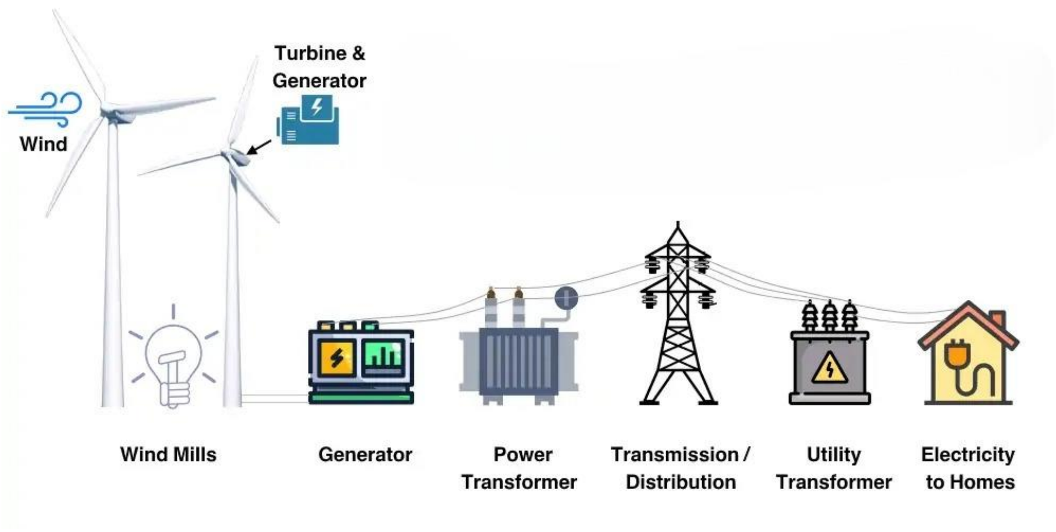

Fig I. 7 Wind power plants

I.3.2. Electrical substations

Substations make it possible to adapt the voltage according to the lines and networks, but also to direct the electricity and "monitor" it remotely on the different lines it uses. We distinguish, according to the functions they perform: interconnection substations, transformer substations and mixed substations. [6]

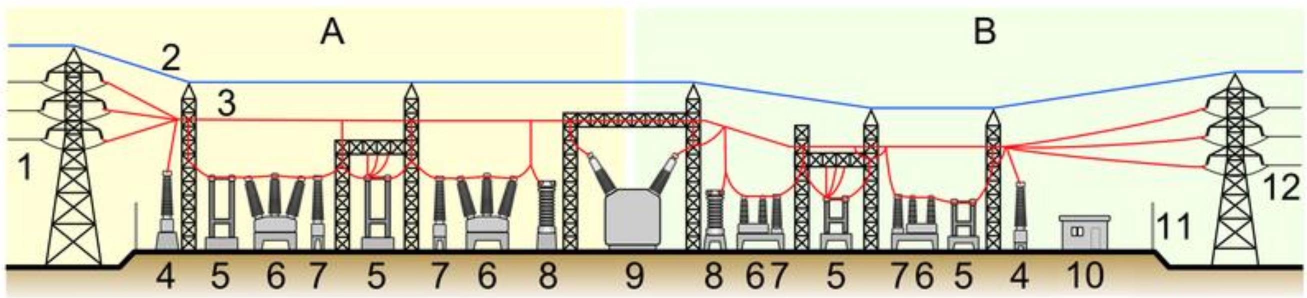

Fig I. 8 Power appliances in a substation (A: primary side, B: secondary side)

The stations contain a number of Power appliances that participate in the proper functioning of the network: 1. Primary power line; 2. Guard cable; 3. Power line; 4. Voltage transformer; 5. Disconnector; 6. Circuit breaker; 7. Current transformer; 8. Lightning arrester; 9. Power transformer; 10. Secondary building; 11. Fence; 12. Power line secondary.

I.3.2.A. Power transformers

They modify the electrical voltage upwards (by example from 20 kV to 400 kV at the output of power plants) or downwards (for example from 63 kV to 20 kV for deliver energy to distribution networks) (Fig I.9).

Fig I. 9 Power transformers

I.3.2.B. Measuring transformers (current and voltage)

They are used to allow the measurement of voltage or current when these have a value too high to be measured directly. They must transform the voltage or current proportionally and without phase shift. They are intended for powering measuring devices, meters, relays and others analogous devices (Fig I.10).

(a) Transformateur de courant (b) Transformateur de tension

Fig I. 10 Measuring transformers

I.3.2.C. Circuit Breakers

They protect the System against possible overloads due to currents fault (lightning, priming with a tree branch) by turning portions of the circuit on or off (fig I.11)

Fig I. 11 Circuit Breakers

I.3.2.D. Disconnectors

They ensure the visible breaking of an electric circuit and direct the current into the substation (fig I.12).

Fig I. 12 Disconnectors

I.3.2.E. Sets of bars

In electrical distribution, a busbar designates a copper or aluminum conductor which conducts electricity in an electrical panel, inside the electrical equipment or in a electrical substation. The busbars are typically either flat bars or tubes (Fig.I.13). They are considered as low impedance conductors to which several electrical circuits can be connected at separate points.

Fig I. 13 Sets of bars

I.3.2.F. Insulators

Insulators provide electrical isolation between conductor cables and supports. They are used in a chain, the length of which increases with the voltage level: it takes approximately 6 insulators at 63 kV, 9 at 90 kV, 12 at 225 kV and 19 at very high voltage of 400 kV. The chain of insulators also plays a mechanical role, it must be able to resist the forces due to the conductors, which are subject to the effects of wind, snow or frost (Fig I.14).

Fig I. 14 Insulators

I.3.2.G. Surge Arresters

Surge arresters are devices intended to limit over voltages imposed on transformers, instruments and electrical machines by lightning and switching operations. The upper part surge arrester is connected to one of the wires of the line to be protected and the lower part is connected to ground by a low-resistance earth connection, generally less than one Ohm (fig I.15).

Fig I. 15 Surge Arresters

I.3.3. Overhead lines and underground cables

Electricity is transported and distributed by overhead or underground electrical lines, with high voltage. The production sites are chosen according to the natural environment (watercourses for cooling a power plant or hydraulic production, ores, gas, etc.). Electricity therefore has to be transported. In electricity, the more the value of the voltage increases, the more the value of the intensity decreases. So the less intensity we carry, the less chance we have of losing it and the smaller the section of the electrical conductors. The voltage carries the intensity and the intensity is transformed in thermal and mechanical energy. The system might seem simple but there are many constraints. The first: the risk of ignition (electric arc in the air) from 1000 Volts. While the electrical conductors are "bare" above ground, they need specific insulation underground, the thickness of which increases with the voltage. [7]

Fig I. 16 Aerial MT network

Fig I. 17 Underground HTA cable

I.4. Fault in power system

I.4.1. Analysis

Under normal conditions, a power system maintains balance with all equipment carrying their designated load currents and bus voltages staying within specified limits. However, this equilibrium can be disturbed by the occurrence of a fault within the system. A circuit fault denotes a failure that disrupts the regular flow of current. One specific type of fault is the short circuit fault, which arises when the system's insulation fails, leading to a low impedance path between phases or phase and ground. As a result, high currents surge through the circuit, requiring the the operation of protective equipment to prevent equipment damage. Short circuit faults can be classified as follows: [8]

- Symmetrical faults
- Unsymmetrical faults

I.4.2. The different types of power system fault

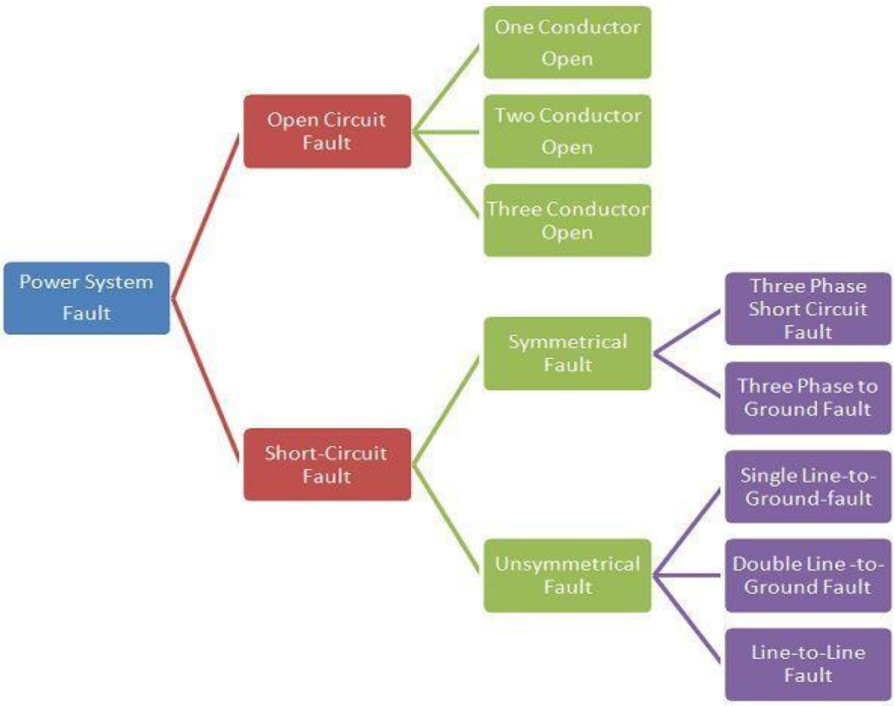

Fig I. 18 different types of power system fault

I.4.3. Open Circuit Fault

The open circuit fault mainly occurs because of the failure of one or two conductors. The open circuit fault takes place in series with the line, and because of this, it is also called the series fault. Such types of faults affect the reliability of the system. The open circuit fault is categorised as:

- Open Conductor Fault
- Two conductors Open Fault
- Three conductors Open Fault.

The open circuit fault is shown in the figure below.

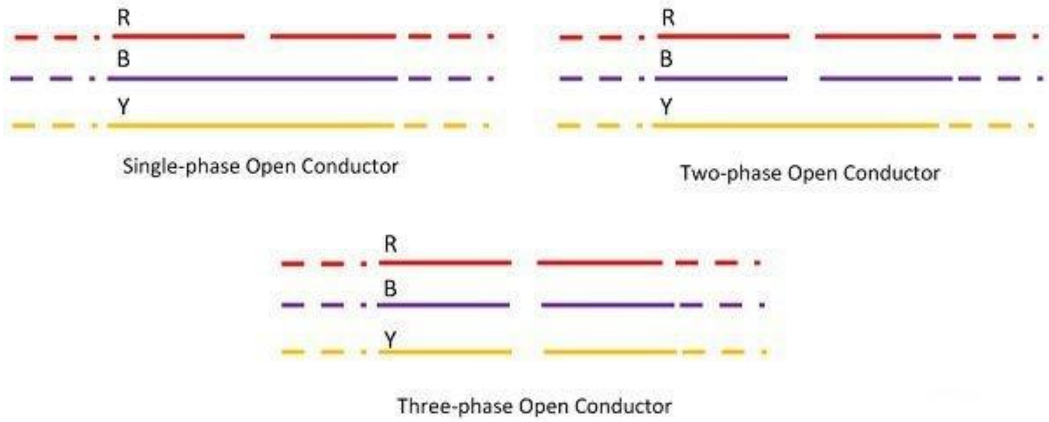

Fig I. 19 open circuit fault

I.4.4. Short circuit faults

This kind of fault occurs when the conductors of different phases unintentionally make contact with each other, either through a power line, power transformer, or any other circuit component. As a result, there is a significant current flow in one or two phases of the system. The short-circuit fault can be classified into symmetrical and unsymmetrical faults.

I.4.4.A. Symmetrical faults

Three-phase symmetrical fault occurs when three equal fault impedances $\bar{Z}_f$ are applied to the three phases, as depicted in (FigI.20). If $\overline{Z}_f = 0$, it is referred to as a solid or bolted fault. These faults can be classified into two types: (a) line-to-line-to-line-to-ground fault (LLLG fault) and (b) line-to-line-to-line fault (LLL fault). Since all three phases are equally affected, the system remains balanced. Therefore, this fault is known as a symmetrical or balanced fault, and the fault analysis is conducted on a per-phase basis. The behavior of LLLG fault and LLL fault is identical due to the balanced nature of the fault. This type of fault is highly severe and, when $\overline{Z}_f = 0$, it is typically the most severe fault that can occur in a system. Fortunately, such faults are infrequent, accounting for only approximately 5% of all system faults are three phase faults.

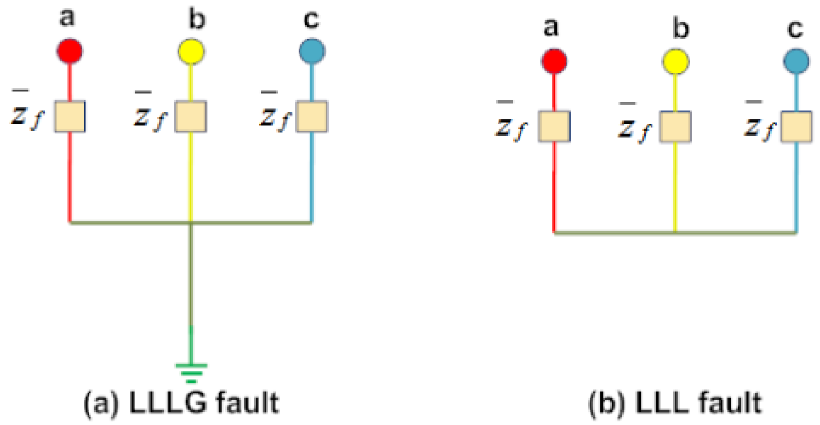

Fig I. 20 Symmetrical Fault

I.4.4.B. Unsymmetrical faults

Unbalanced faults are referred to as faults that disrupt the balanced state of the network. Among unbalanced faults, the most prevalent type in a system is a single line to ground fault (LG fault), accounting for approximately 70 to 80% of all faults. Other types of unbalanced faults include line-to-line faults (LL faults) and double line to ground faults (LLG faults). LLG faults make up about 15 to 25% of faults, while LL faults constitute approximately 5 to 15%. These fault types are illustrated in (FigI. 20).

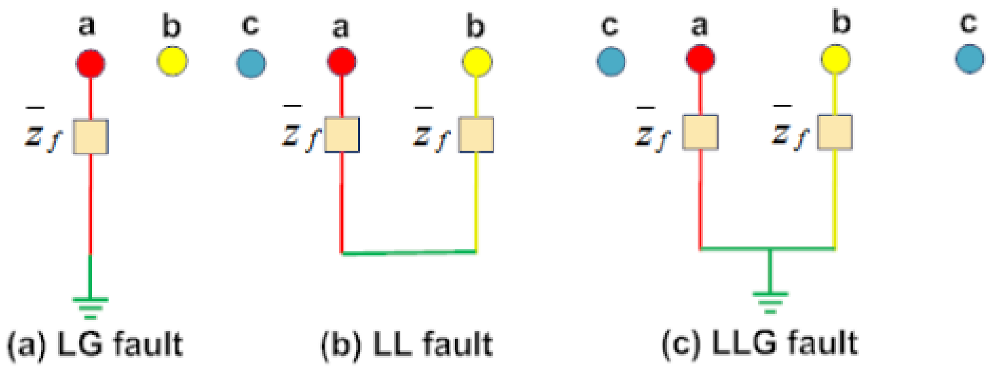

Fig I. 21 Unsymmetrical Fault

The majority of faults occur on transmission lines due to their exposure to external elements. Factors such as lightning strikes, high-velocity winds cause tower failure, ice loading may result in mechanical failure of line, or insulators, and tree branches may cause short circuit. On the other hand, faults on cables, circuit breakers, generators, motors, and transformers are much less common. Fault analysis plays a crucial role in selecting appropriate circuit breaker ratings and determining relay settings and coordination. Symmetrical faults are examined by considering each phase individually, whereas unsymmetrical faults are analyzed by using symmetrical components.

S.No	Type of Faults	Short Form	Symmetrical or Unsymmetrical	Probability of Occurrence
1	Three phase line to ground fault	3LG	Symmetrical	5%
2	Three phase line to line fault	3LL	Symmetrical	5%
3	Single line to ground fault	1LG	Unsymmetrical	70 - 80%
4	Line to line fault	1LL	Unsymmetrical	5 - 15%
5	Double line to Ground fault	2LG	Unsymmetrical	15 - 25%

Table I.1 Symmetrical or Unsymmetrical

1.5. Voltage levels

The new standard defines the AC voltage levels as follows: [9]

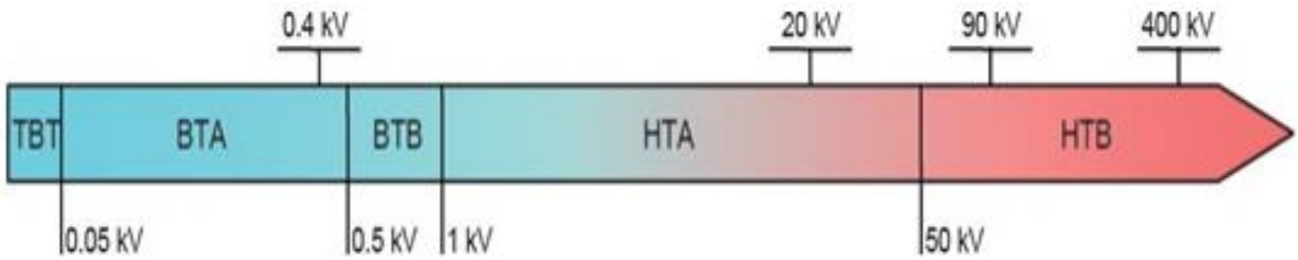

Fig I. 22 Standard voltage levels

- HTB → for a compound voltage greater than 50kV
- HTA → for a compound voltage between 1kV and 50kV
- BTB → for a compound voltage between 500V and 1kV
- BTA → for a compound voltage between 50V and 500V
- TBT → for a compound voltage less than or equal to 50V

1.7. Protection system

A substation is a dormant system, in which almost nothing happens (from time to time a maneuver...) unlike a control unit where the control permanently regulates the voltage and frequency depending on the loads drawn and the set points. But if in the substation or on the parts of the network supervised by the substation a fault occurs, then the protection(s) must (wind) act automatically and quickly according to criteria of safety:

- Security (no untimely order)
- Availability (be operational at all times)
- Selectivity (cause the triggering of the affected area and not another)
- Stability (do not trip on faults that do not concern the protection)

I.8. Conclusion

The main elements of an electrical power system are generators, transformers, transmission lines, loads as well as protections and control equipment To protect the system from any Fault. These elements are connected together in order to allow the production of electricity in sufficient quantity to satisfy customer demand and to provide a good quality of this energy at competitive prices.

Chapter II

The Wavelet Transforms

II.1. Introduction

Wavelet transforms are extensively employed and considered the most powerful tool in the realm of signal processing. They have gained significant attention due to their adaptability to non-stationary image signals and their ability to represent human visual characteristics. The efficiency of wavelet transform in signal representation is notable, enabling multiresolution analysis to extract relevant information from a signal. By dividing a signal into segments corresponding to different frequency bands, wavelet transforms offer a more comprehensive analysis than the Fourier transform. While Fourier transform provides frequency content information, it fails to simultaneously offer good frequency and time resolution. The inability of Fourier transform to determine the timing of specific frequencies in a signal renders it ineffective for analyzing non-stationary signals. The windowed Fourier transform, or short-time Fourier transform, was introduced to address this limitation by providing time information. However, it lacks the multiresolution capability of wavelet transforms. Wavelets solve the multiresolution problem by possessing the crucial property of variable-width sampling windows. Wavelet transforms can be broadly classified into (continuous wavelet transform and discrete wavelet transform). Continuous wavelet transform, although time-consuming for long signals due to integration over all times, was later complemented by the introduction of discrete wavelet transform to overcome time complexity. Discrete wavelet transforms can be implemented by encoding the subband. The advantage of the discrete wavelet transform in signal processing lies in its ability to simultaneously localize signals in both time and scale, unlike the frequency domain localization achieved by DFT or DCT.

The earliest documented literature on wavelet transform dates back to the introduction of Haar wavelet by mathematician Alfrd Haar in 1910. However, the concept of wavelets did not exist during that time. It was in 1981 that geophysicist Jean Morlet proposed the concept, followed by the invention of the term "wavelet" in 1984 by Morlet and physicist Alex Grossman. Prior to 1985, Haar wavelet was the only known orthogonal wavelet, leading many researchers to believe that no other orthogonal wavelet existed. Fortunately, in 1985, mathematician Yves Meyer constructed the second orthogonal wavelet, known as Meyer wavelet. As the field attracted more scholars, the first international conference on wavelets was held in France in 1987. In 1989, Stephane Mallat and Meyer introduced the concept of multiresolution, and in the same year, Ingrid Daubechies developed a systematic method for constructing compact support orthogonal wavelets. Mallat also proposed the fast wavelet transform in 1989, which significantly enhanced the efficiency of wavelet transform computations. The introduction of this fast algorithm led to numerous applications of wavelet transform in the fields of signal and image processing. [11]

History for the Development of Wavelet	
Year	**Devopment**
1910	Haar families
1981	Morlet, wavelet concept
1984	Morlet and Grossman, “wavelet”
1985	Meyer, orthogonal wavelet
1988	Mallat and Meyer, multiresolution
1988	Daubechies, compact support orthogonal wavelet
1989	Mallat, fast wavelet transform

Table II.1 Symmetrical or Unsymmetrical 2 History for the Development

II.2. Wavelet

A wavelet can be described as a wave-like oscillation that is confined to a specific time interval. An example of a wavelet is given below. Wavelets possess two fundamental properties: scale and location. Scale, also known as dilation determines the stretching or compressing of a wavelet which is directly associated with its frequency. Location specifies the position of the wavelet in time (or space). [12]

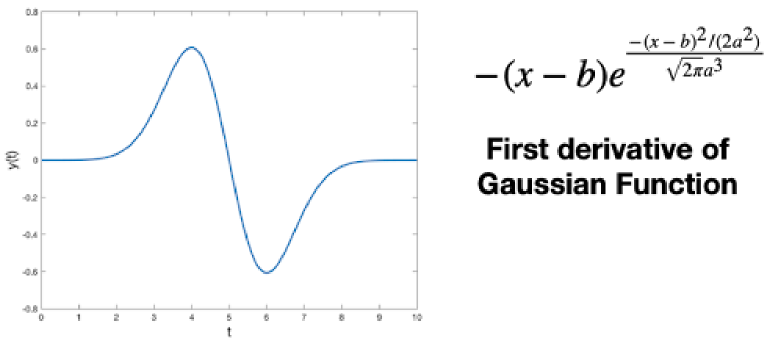

Fig II. 1 Example Wavelets

The parameter "a" in the aforementioned expression controls the scale of the wavelet. By reducing its value, the wavelet becomes more compressed or squished, allowing it to capture high-frequency details. Conversely, increasing the value of "a" stretches the wavelet, enabling it to capture low-frequency information.

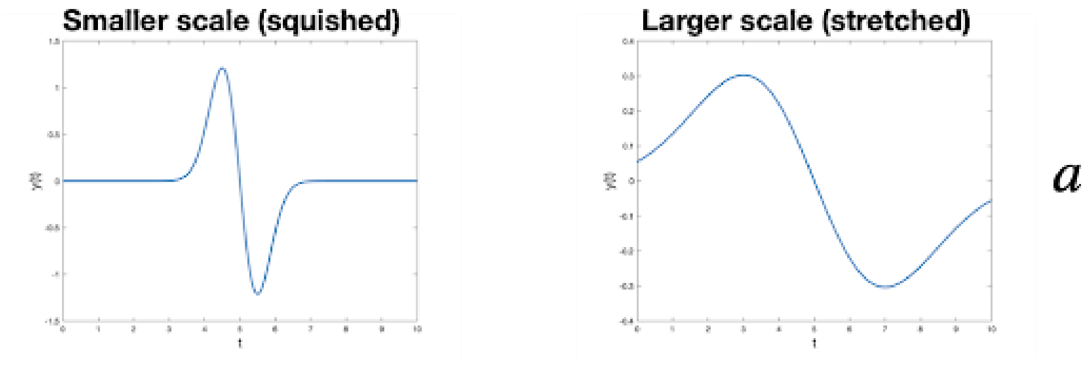

Fig II. 2 Wavelet scale variable

The parameter "b" determines the position of the wavelet. By decreasing "b," the wavelet is shifted towards the left, while increasing "b" shifts it towards the right. The concept of location is crucial because unlike waves, wavelets are only nonzero within a limited interval. Additionally, during signal analysis, it is not only the oscillations that matter but also the specific locations where these oscillations occur.

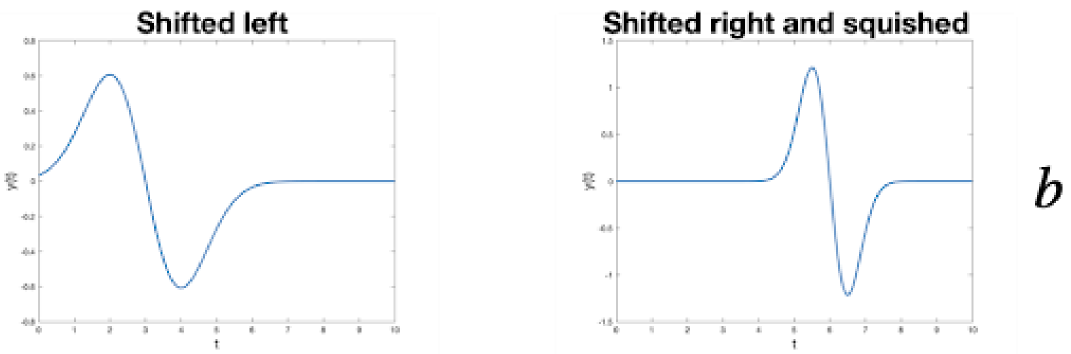

Fig II. 3 wavelet location variable

II.2.1. What is SCALE

Scale is inversely proportional to the frequency of any signal Large scale is used for the analysis of small frequency components presents in any signal Whereas Small scale is used is utilized to analyze the high-frequency components of any signal.

II.2.2. Why Use Wavelets

A couple of key advantages of the wavelet transform are:

The first feature is the Fourier transform. This advantage becomes particularly evident when comparing it to techniques such as the short-time Fourier transform, which necessitates segmenting the signal and applying a Fourier transform to each segment.

The second advantage may appear more technical in nature. However, the key takeaway is that if you have a specific shape or pattern in mind that you want to extract from your signal, the wavelet transform offers a wide range of wavelet options to choose from. These wavelets can be carefully selected to closely match the desired shape, as demonstrated by the various options depicted in the Fig.II. 4

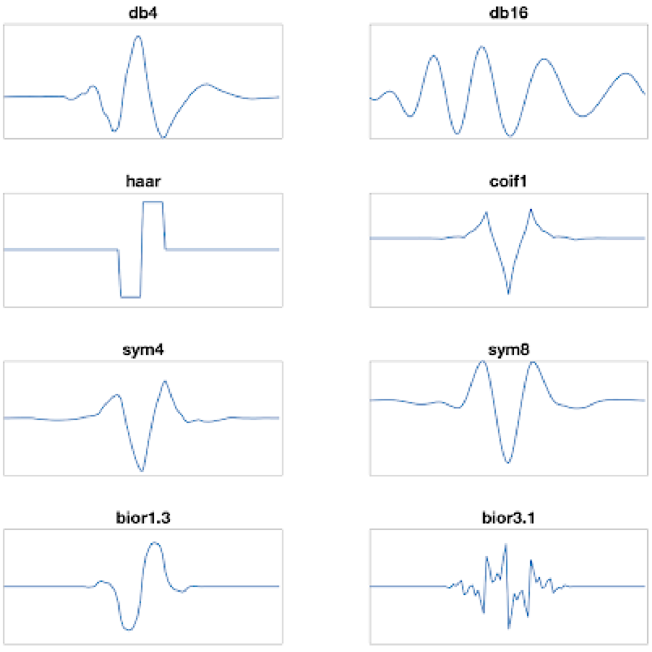

Fig II. 4 wavelet families. Daubechies 4, Daubechies 16, Haar, Coiflet 1, Symlet 4, Symlet 8, Biorthogonal 1.3, & Biorthogonal 3.1.

II.2.3. How Does Wavelet Transform Work

Calculating how much of a wavelet is there in a signal at a given scale and location is the core principle. That is exactly what this is, for those who are familiar with convolutions. at a variety of scales, a signal is convolved with a set of wavelets.

To put it another way, we choose a wavelet with a specific scale, (such as the blue wavelet below). Then, we move this wavelet across the full signal (i.e., change its location), multiplying the wavelet and signal at each time step. we obtain a coefficient. For that wavelet scale at that specific time step. The process is then repeated while increasing the wavelet scale, such as with the red and green wavelets.

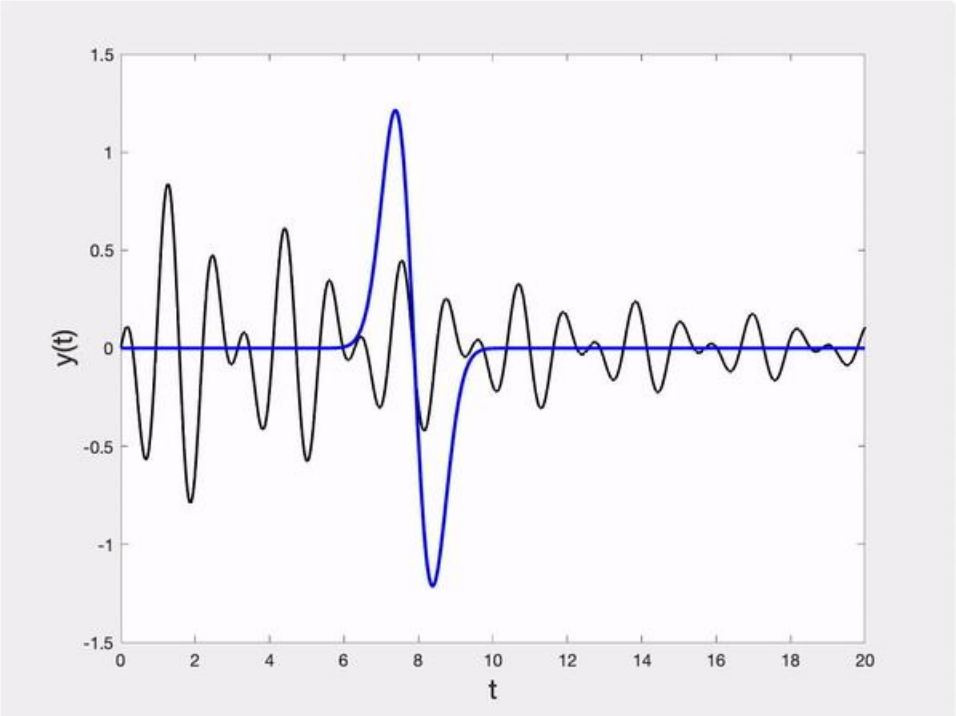

Fig II. 5 How Does Wavelet Transform Work

II.3. Fourier Transform and Analysis

Fourier analysis is a conventional technique employed in signal processing. The expression for the Fourier transform of a function x(t) is presented in Equation (II.1). [13]

$$\hat{x}(\omega) = \int_{-\infty}^{\infty} x(t)e^{-i\omega t}\mathrm{d}t \tag{II.1}$$

The signal to be transformed is denoted as x(t). The calculation of the inverse Fourier transform is performed in the following manner:

$$x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \hat{x}(\omega) e^{i\omega tr} \mathrm{d}\omega \qquad \text{(II.2)}$$

The Fourier series is

$$C_j = \int_{-\infty}^{\infty} x(t) e^{-i,t} \mathrm{d}t \qquad \text{(II.3)}$$

Where

$$x(t) = \sum_{j=-\infty}^{\infty} C_j e^{i\omega jjt} \qquad \text{(II.4)}$$

Discrete Fourier transform (DFT) pairs, which can be efficiently computed using the fast Fourier transform (FFT) algorithm, are also available. However, Fourier methods are suitable only for stationary settings. In the case of non-stationary or transient settings, the short-time Fourier transform (STFT) has emerged as a commonly used technique for signal analysis.

Fig II. 6 Fourier Analysis

II.4. Short-Time Fourier Transform

The definition of the short-time Fourier transform (STFT) for the signal x(t) is given as follows:

$$\hat{x}(\tau, \omega) = \int_{-\infty}^{\infty} x(t) w * (t - \tau) e^{-i\omega t} \mathrm{d}t \qquad (1.5)$$

Where w represents an appropriate window function, w* denotes the complex conjugate of w, and τ is a shift or translation parameter. Equation (II.7) represents a windowed Fourier transform. The STFT process involves applying this transform with translated versions of the window function across the entire duration of the signal. However, the STFT has the following shortcomings.

- The frequency resolution for wavelengths longer than the width of the window, specifically for low frequencies, is significantly inadequate.
- The elongated window causes energy averaging over its width, leading to a considerable difficulty for the STFT to accurately localize high frequencies.
- The Heisenberg inequality (time-bandwidth product bounded by $((4\pi)^{-1})$, i.e., $(\Delta t \cdot \Delta f(4\pi)^{-1}))$, limits the STFT time and frequency resolutions.

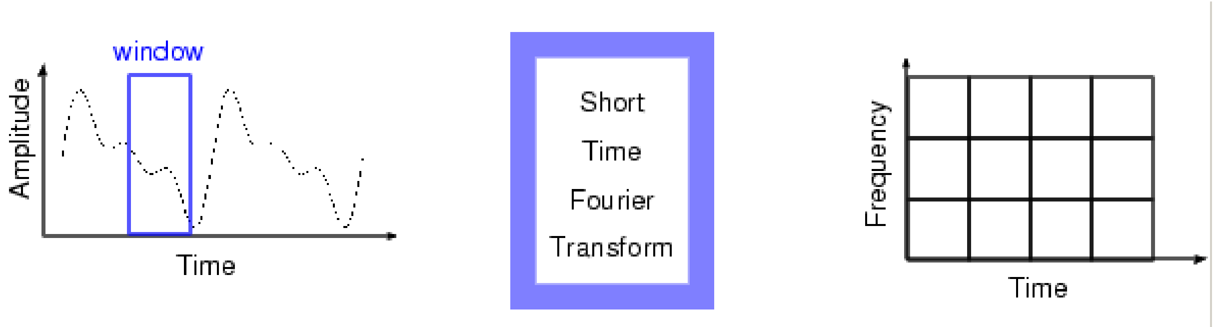

Fig II. 7 Short-Time Fourier Analysis

II.5. Wavelet Transform

To overcome the limitation of the fixed window size in the STFT, the Wavelet Transform has been introduced. Instead of using a fixed width window function, the Wavelet Transform utilizes a wavelet function, often referred to as the mother wavelet. This analysis involves comparing the input signal with scaled and translated versions of the wavelet function. Scaling or dilation of the wavelet function involves stretching or narrowing the analysis function, while translation refers to Shifting the analysis function along the time axis of the input signal. Fig.II. 8 provides an example of the Wavelet Transform analysis of the signal x(t) using a mother wavelet shifted by time τ. [14]

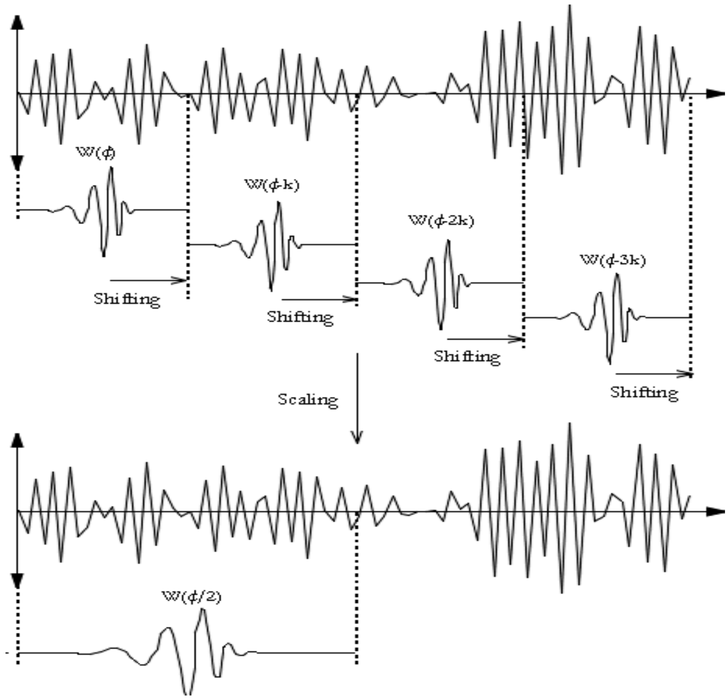

Fig II. 8 Wavelet transform for the signal x(t)

The depicted figure illustrates the adaptive nature of the Wavelet Transform function, which can adjust its width based on the high and low frequency components of the analyzed signal. This characteristic empowers the Wavelet Transform to effectively extract frequency components from fast transient signals.

II.5.1. Types of wavelet transforms

Two types of wavelet transforms, namely the continuous wavelet transform and the discrete wavelet transform, are employed in various applications.

II.5.1.A. Continuous Wavelet Transform

The equation representing the continuous wavelet transform (CWT) of an input signal $x(t)$ is as follows:

$$CWT(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \psi^* \left(\frac{t-b}{a}\right) dt \qquad \text{(II.6)}$$

In the equation, $x(t)$ represents the input signal, $\psi^*(t)$, is the mother wavelet, and the scale parameter is denoted as 'a' while the translation parameter is represented as 'b'. The continuous wavelet transform (CWT) analysis operates by varying the wavelet scaling parameter a and the shifting parameter b and compares it with the signal along the time axis By starting with a small scale parameter (resulting in a narrow wavelet), the CWT captures the high-frequency components of the input signal. As the scale parameter increases (resulting in stretching of the wavelet), the CWT becomes capable of extracting lower-frequency features.

In the given equation, the mother wavelet $\psi^*(t)$, is a wave function of limited duration that satisfies specific mathematical requirements. This wavelet function is normalized, with a magnitude of 1 $\left(\|\psi^*(t)\|^2 = 1\right)$ ensuring that all wavelets at each analysis level possess the same energy as the mother wavelet. Additionally, the wavelet function has a zero average $\left(\int_{-\infty}^{\infty} \psi^*(t)dt = 0\right)$ Various types of mother wavelets exist, such as Haar, Daubechies, Symmlet, among others, each possessing distinct characteristics suitable for different applications, as depicted. Most wavelet functions exhibit time oscillations, and the wavelet order (for example db4) determines its decay rate. The selection of the mother wavelet significantly influences the analysis of the decomposed signal. The choice of wavelet type and order depends on the specific application and the characteristics of the signal, aiming to achieve optimal results.

As indicated by equation II.6, the output of the continuous wavelet transform (CWT) at a specific scale and translation yields a two-dimensional representation that combines time and frequency information of the input signal. Consequently, this introduces a high level of redundancy, where the continuous wavelet transform generates a two-dimensional representation from a one-dimensional time series signal.

II.5.2.B. Discrete Wavelet Transform

The Discrete Wavelet Transform (DWT) is the digital counterpart of the CWT. It is used to analyze a sampled input signal x[n]. The mathematical expression for the DWT applied to the input signal is as follows:

$$DWT(m,k) = \frac{1}{\sqrt{a}} \sum_n x[n]\psi^*\left(\frac{k-b}{a}\right) \tag{II.7}$$

Where k is a particular sample of the input signal.

In discrete signal analysis, the DWT is utilized to decompose the input signal into a sequence of wavelet components that are scaled and translated versions of the mother wavelet. This process involves applying the input signal to multiple stages of lowpass and highpass filter banks. Passing the input signal through a lowpass filter yields the approximation coefficients, while passing it through a high pass filter simultaneously yields the detail coefficients. This procedure is illustrated in Fig II. 9.

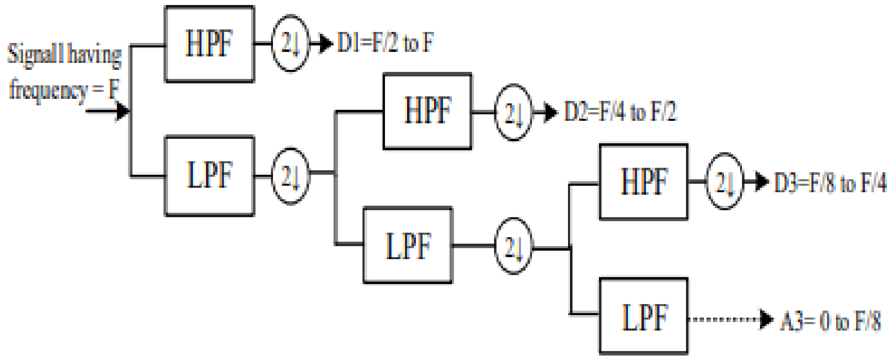

Fig II. 9 The DWT multi-resolution analysis

The output of the lowpass filter, which corresponds to the approximation coefficients, is further processed through additional sets of high pass and lowpass filters. This iterative process continues until the desired level of decomposition is achieved. At each stage, the sampling frequency of the output signal is halved to reduce redundancy. This approach is called multi-resolution wavelet analysis (MRA), as it provides different frequency resolutions at each analysis level. In Fig II. 10 each box represents a specific frequency band (scaled) that exists in the analyzed signal within a particular time window. The dimensions of each box indicate the time-frequency resolution. Starting from the top of the figure with low scale, narrow boxes offer a good representation of time with a wide frequency range (but poor frequency resolution). As the scale increases, the height of the boxes decreases, providing better frequency resolution over a broader time range (but poorer time representation). Ultimately, the final analysis level yields the low-frequency content of the signal.

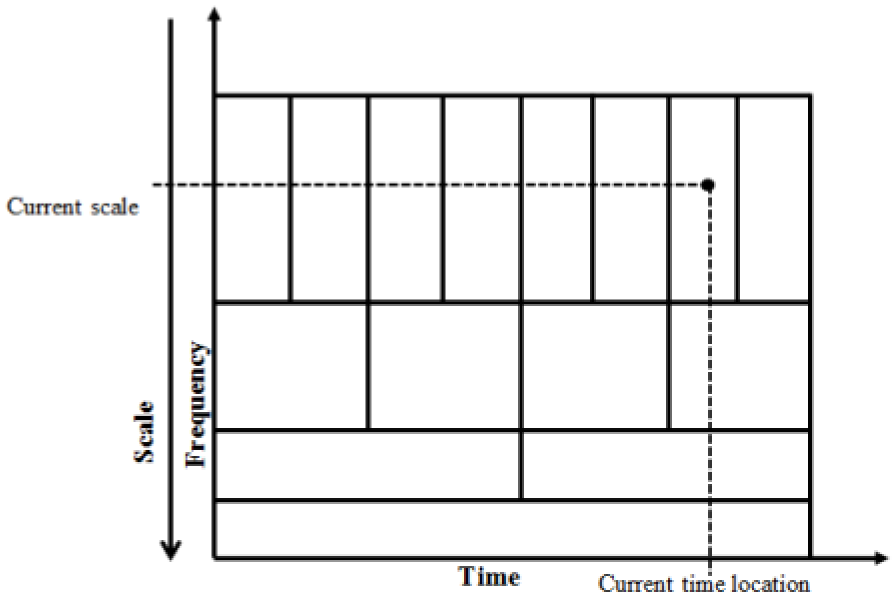

Fig II. 10 frequency and time resolution from the wavelet analysis

As previously mentioned, the filter coefficients are derived from the scaling and wavelet functions, which are based on the chosen mother wavelet. Fig II. 11 provides examples of scaling and wavelet functions, along with their corresponding filter coefficients, for different mother wavelets such as Haar, Daubechies 2, and Daubechies 4

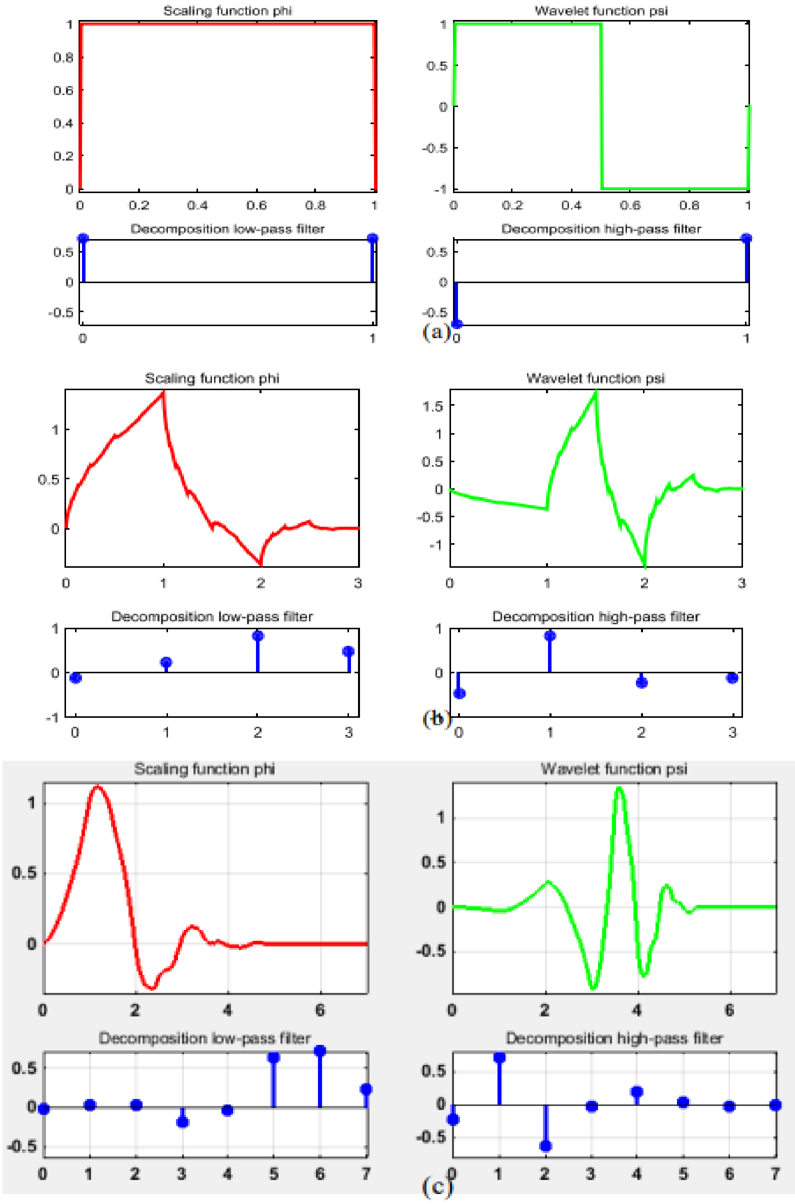

Fig II. 11 Scaling and wavelet functions with associated filters coefficients (a) Haar (b) db2 (c) db4

II.6. Filter Bank

The DWT can analyze a signal at different frequency bands with different resolutions by decomposing the signal into approximate and detail information using scaling and wavelet functions. The MATLAB algorithm for DWT works by convolving the original signal with a high-pass and low-pass filter, then down sampling the signal by keeping the even indexed elements to obtain the level one approximate and detail coefficients. If If additional decomposition is necessary, the level one approximate coefficient will undergo a similar process of passing through the high-pass and low-pass filters and then being down sampled once again to obtain the level two approximate and detail coefficients obtain the level two approximate and detail coefficients.

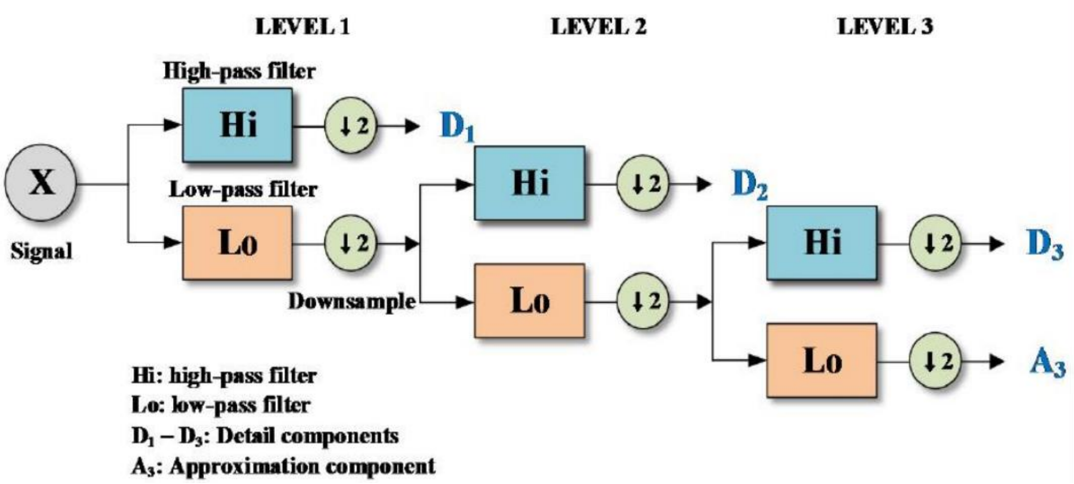

Fig II. 12 Filter Bank as Applied by MATLAB Wavedec Function

II.6. Similarities between Wavelets and Fourier Transforms

The wavelet transform and Fourier transform share certain similarities. Both the discrete wavelet transforms (DWT) and the fast Fourier transform (FFT) They tend to generate data structures that contain log2n segments of various lengths. Usually, they fill and transform them into different data vectors of lengths 2R. Moreover, the matrices involved in these transforms exhibit similar mathematical properties. DWT and FFT inverse transform matrices are transposed is the transpose of the original matrix. Consequently, both transforms can be interpreted as rotations in function space, switching domains. In the case of the FFT, this new domain comprises basis functions such as sines and cosines. A wavelet transform, on the other hand, encompasses more intricate functions known as wavelets, mother wavelets, or analyzing wavelets.

Both the DWT and the FFT exhibit further similarities in terms of their basis functions, which are localized in frequency. This characteristic enables the utilization of mathematical tools such as power spectra, which measure the amount of power within specific frequency intervals, and scale grams, which aid in identifying frequencies and calculating power distributions. These properties make both transforms valuable for analyzing frequency-dependent phenomena. [13]

II.7. Dissimilarities Between Wavelets and Fourier Transforms

The DWT and the FFT possess an intriguing dissimilarity: individual wavelet functions are localized in space, while Fourier sine and cosine functions are not. This localization property of wavelets in both space and frequency leads to sparsity when functions and operators are transformed into the wavelet domain. This sparsity property has enabled the application of wavelets in various domains, including denoising time series, detecting features in images, and data compression.

To appreciate the differences in time-frequency resolution between the wavelet transform and the Fourier transform, it is helpful to consider the coverage of basis functions in the time-frequency plane. In Fig.I. 1, the concept of the windowed Fourier transform (WFT) is illustrated, where a square wave is used as the window. This square wave window truncates the sine or cosine function to fit within a specific window width. Since a single window is employed for all frequencies in the WFT, the analysis resolution remains the same across all locations in the time-frequency plane. In contrast, the advantage of the wavelet transform lies in the variation of windows based on the width of the signal being analyzed.

II.8. Conclusion

wavelet transforms are a valuable tool for analyzing signals and data in various domains. In ower case The Discrete Wavelet Transform (DWT) allows for the decomposition of signals into different frequency bands with varying resolutions, providing detailed information about signal characteristics. By using scaling and wavelet functions, the DWT enables the extraction of both approximate and detailed components of a signal. The process involves filtering the signal with high-pass and low-pass filters, followed by down sampling to obtain different level coefficients. Further decomposition can be performed by repeating this process on the approximation coefficients. Wavelet transforms find applications in diverse fields such as signal processing, approach to understanding and manipulating signals, making them an essential tool for researchers, engineers, and data scientists.

Chapter III

Diagnosis of Transmission Line Fault Using Wavelet

III.1. INTRODUCTION

When a fault occurs on a transmission line, it is crucial to swiftly detect and clear it to prevent damage to power system equipment and avoid potential economic losses for the community. Over the past decade, various techniques have been employed for fault detection on transmission lines. These include impedance, bus impedance, symmetrical component techniques etc. other techniques include the expert systems (machine language, artificial intelligence etc.) and signal analysis techniques.

In a polyphase system different type of faults are categorized as: single line to ground fault (LG), line to line fault (LL), double line to ground fault (LG), triple line fault (LLL) and triple line ground fault (LLLG). Protecting the power system from all these faults categorize concern with the two major task: (a) fault detection (b) fault processing which include fault detection and its distance estimation and consequently involves the fault classification, such that the type of fault is identified, so we can restore power the supply and solve the problems. [16]

III.3. POWER SYSTEM MODEL

In this chapter, simple three-phase power system was simulated in MATLAB SIMULINK for Fault Detection testing using Wavelet Transform. This simple power system consists of Three-Phase Source It works as a generator and Three-Phase Series RLC Branch It acts as a transmission line and block, Three-Phase Series RLC Load to represent pregnancy.

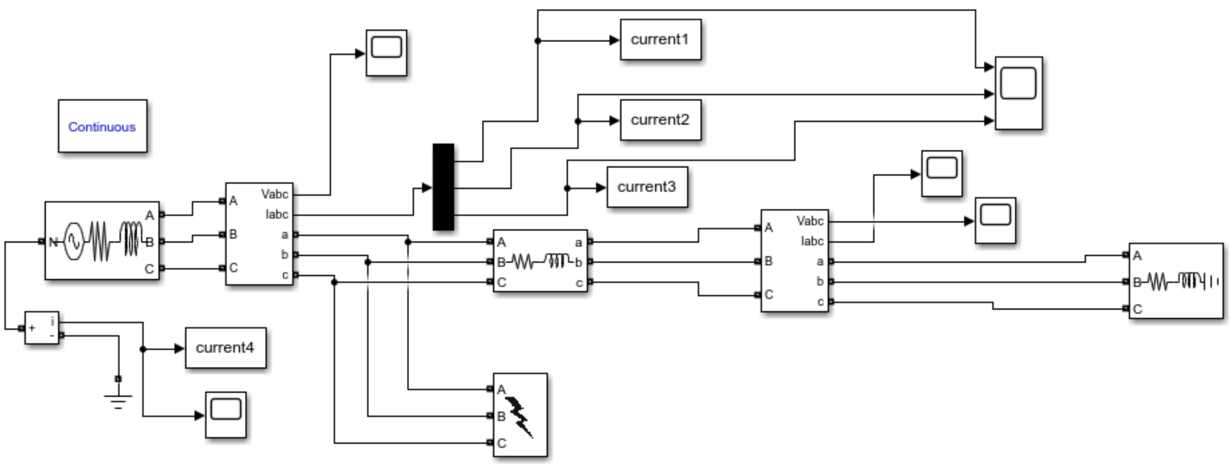

Fig III. 1 Power system simulation model

System Parameters	
Source	250 kV
System Frequency	60 Hz
Load power	304.8 MVA
Number of Phases	3
Line Resistance per phase	0.15 Ohms/km
Line Inductance per phase	1.3263 Mh/Km
Line Shunt capacitance	is negligible
Line length	40 km

Table III.1 System Parameters

III.4. SIMULATION RESULTS

III.4.A. System Normal

The graph shows the nature of voltages and current in all phases. Without error, all phases of current and voltage are in normal condition.

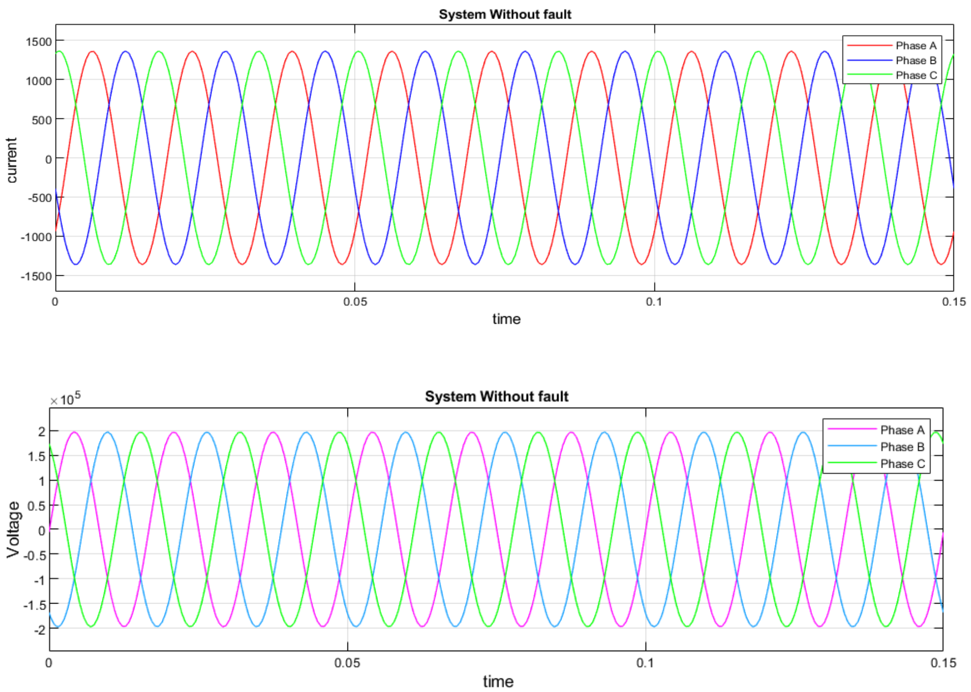

Fig III. 2 Voltage and current waveform of system normal

III.4.B. Three phase to ground Fault

The graph shows the nature of voltages and current in a three phase ground fault. the current is at its highest value, but the voltage to zero.

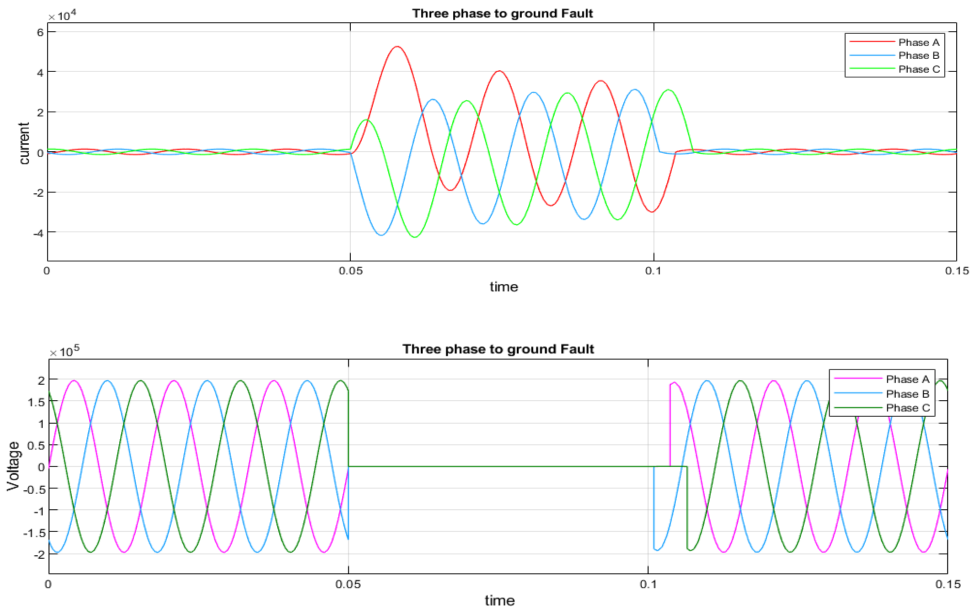

Fig III. 3 Voltage and current waveform during for Three phase to ground Fault

III.4.C. Three phase Fault

The graph shows the nature of voltages and current in a three-phase fault. the current is at its highest value, but the voltage is down to zero.

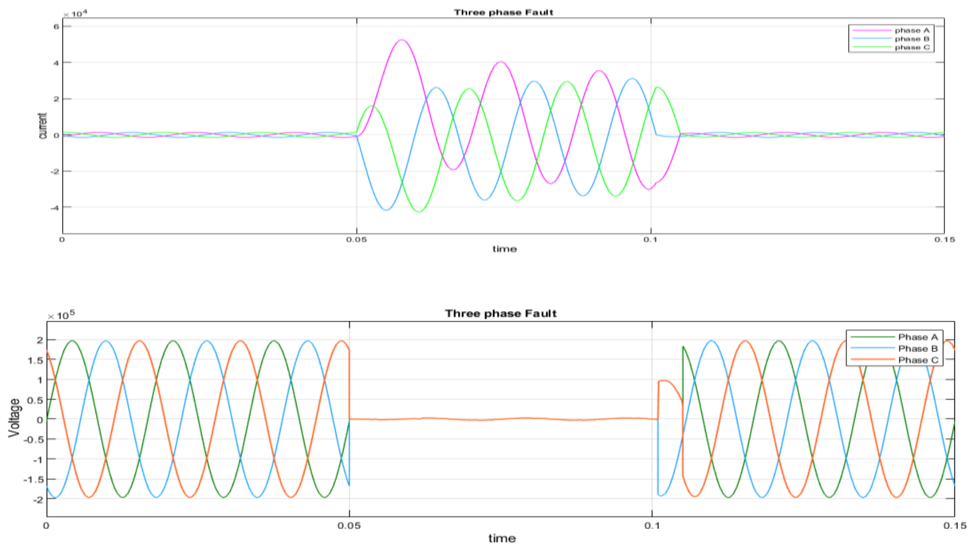

Fig III. 4 Voltage and current waveform during for Three phase Fault

III.4.D. Double Line to Ground Fault (AB-G)

The graph shows the nature of voltages and current in a double line to ground fault (AB-G). the current is at its highest value, the phase C is normal. As for the voltage to zero, phase C is in its normal state.

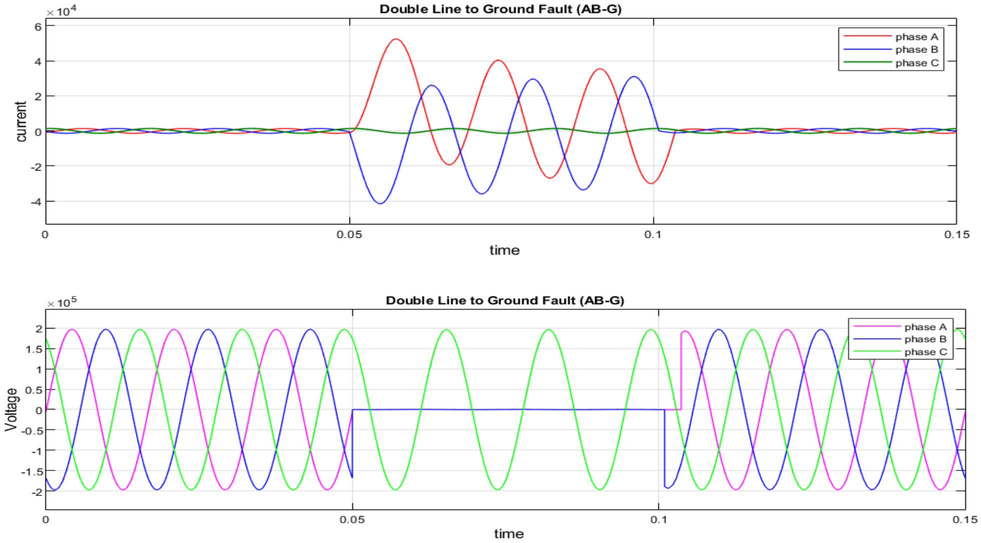

Fig III. 5 Voltage and current waveform during for Double Line to ground Fault (AB-G)

III.4.E. Double Line to Ground Fault (AC-G)

The graph shows the nature of voltages and current in a double line to ground fault (AC-G), the current is at its highest value, the C phase is normal. As for the voltage to zero, phase C is in normal condition.

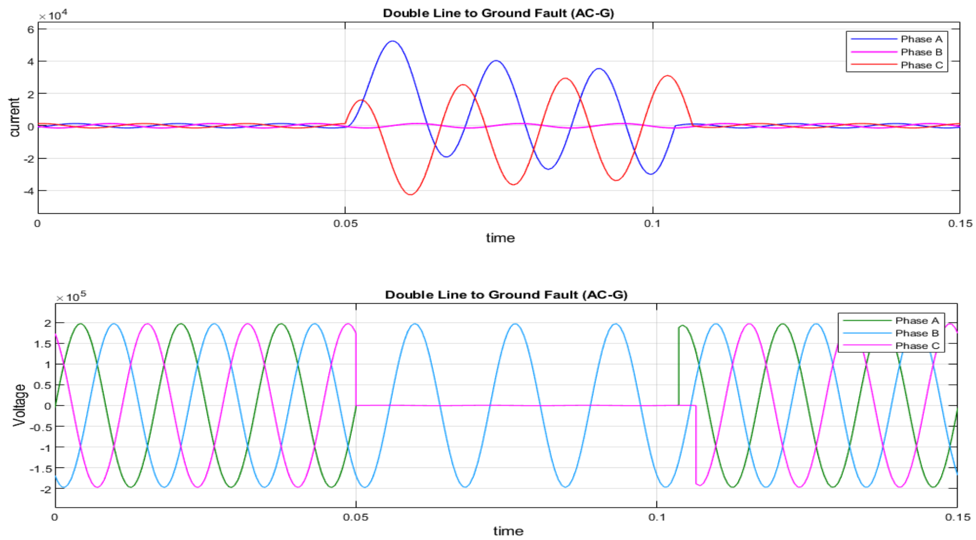

Fig III. 6 Voltage and current waveform during for Double Line to ground Fault (AC-G)

III.4.F. Double Line to Ground Fault (BC-G)

The graph shows the nature of voltages and current in a double line to ground fault (BC-G), the current is at its highest value, phase A is normal. As for the voltage to zero, phase A is in normal condition.

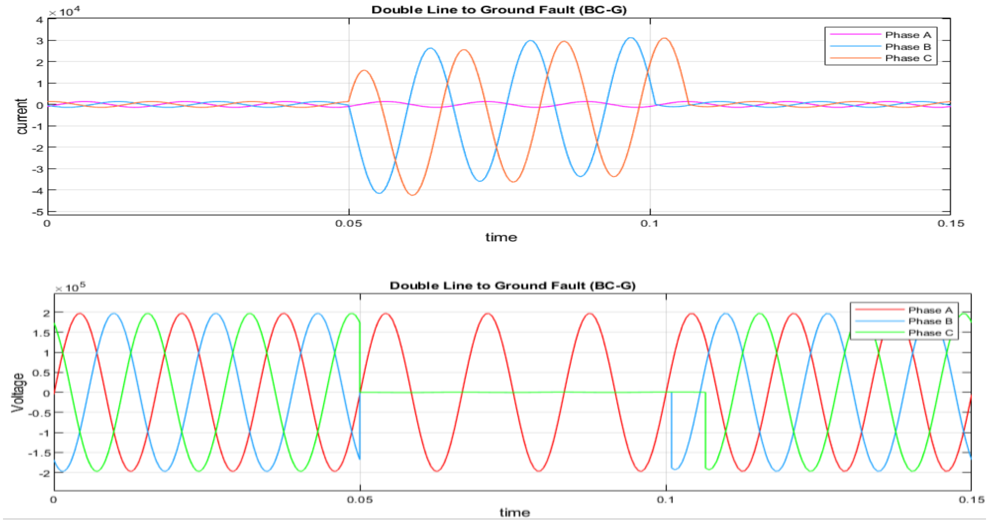

Fig III. 7 Voltage and current waveform during for Double Line to ground Fault (BC-G)

III.4.G. Line to Line (A-B) Fault

The graph shows the nature of voltages and current in a line-to-line (A-C) fault, the current is at its highest value, but the B phase is normal. As for the voltage, it goes up because there is no ground, the B phase is in a normal state.

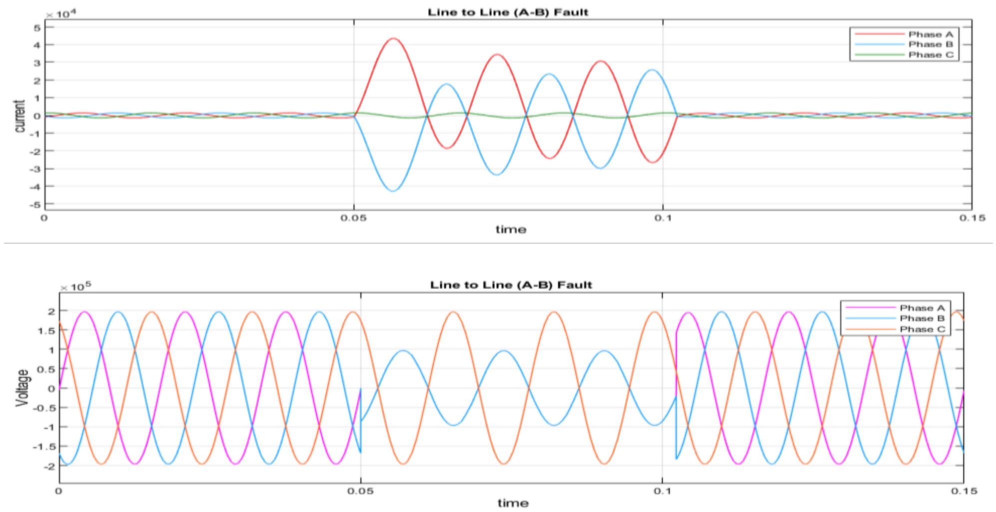

Fig III. 8 Voltage and current waveform during for Line to line Fault (A-B)

III.4.H. Line to Line (A-C) Fault

The graph shows the nature of voltages and current in a line-to-line (A-C) fault, the current is at its highest value, but the B phase is normal. As for the voltage, it goes up because there is no ground, the B phase is in a normal state.

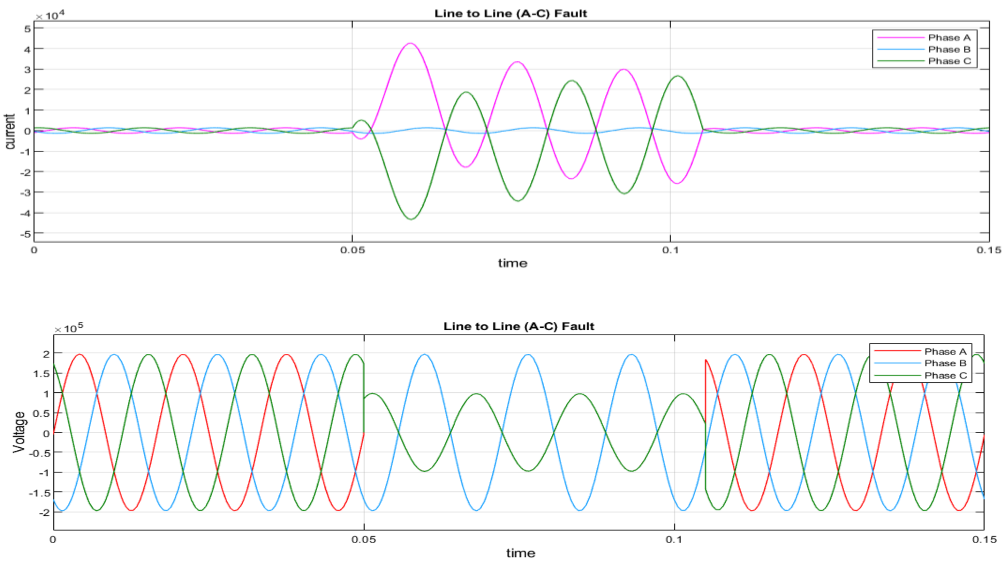

Fig III. 9 Voltage and current waveform during for Line to line Fault (A-C)

III.4.I. Line to Line (B-C) Fault

The graph shows the nature of voltages and current in a line-to-line (B-C) fault, the current is at its highest value, but the A phase is normal. As for the voltage, it goes up because there is no ground, phase A is in normal condition

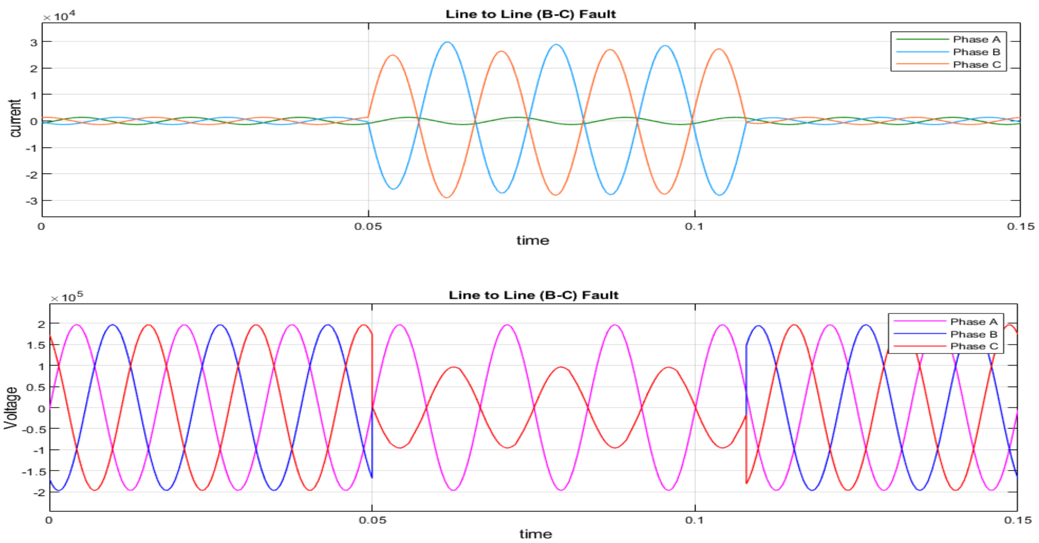

Fig III. 10 Voltage and current waveform during for Line to line Fault (B-C)

III.4.J. Single Line to Ground Fault (A-G)

The graph shows the nature of voltages and current in One line to ground fault (A-G), the current is at its highest value, the rest of the phases are in normal condition. As for the voltage in phase A, it is reduced to zero, and the rest of the phases are in a normal state.

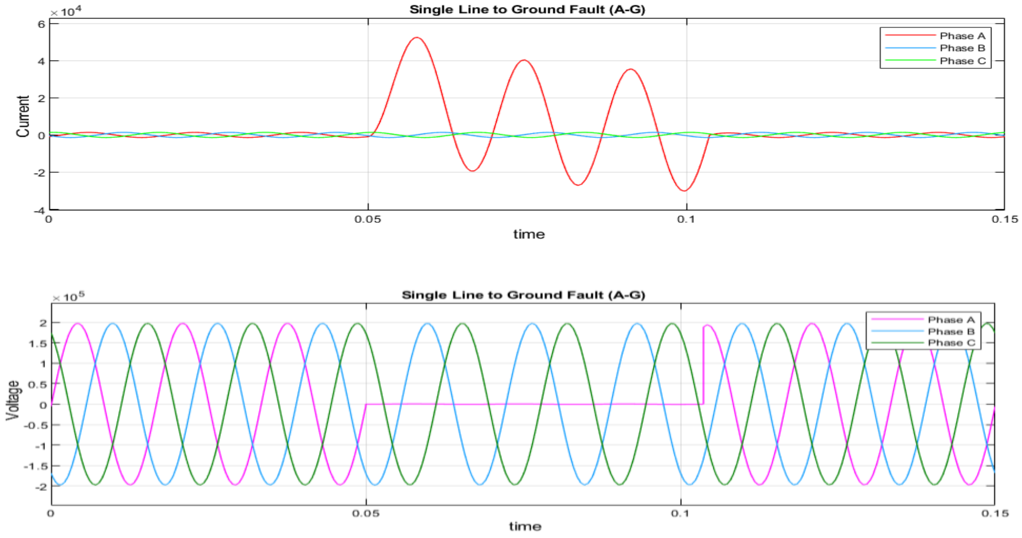

Fig III. 11 Voltage and current waveform during for Line to Ground Fault (A-G)

III.4.K. Single Line to Ground Fault (B-G)

The graph shows the nature of voltages and current in One line to ground fault (B-G), the current is at its highest value, the rest of the phases are in normal condition. As for the voltage in phase B, it drops to zero, and the rest of the phases are in normal condition.

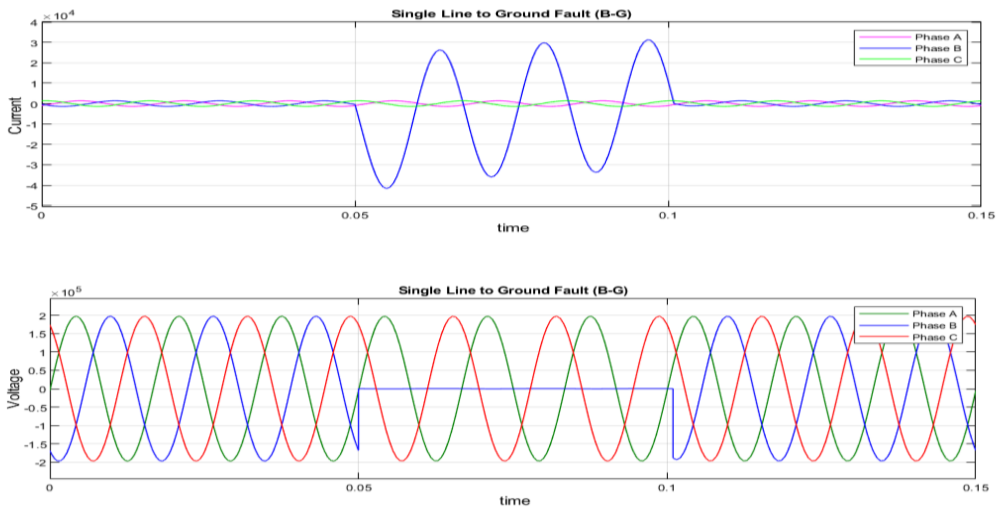

Fig III. 12 Voltage and current waveform during for Line to Ground Fault (B-G)

III.4.L. Single Line to Ground Fault (C-G)

The graph shows the nature of voltages and current in One line to ground fault (C-G), the current is at its highest value, the rest of the phases are in normal condition. As for the voltage in phase C, it drops to zero, and the rest of the phases are in normal condition.

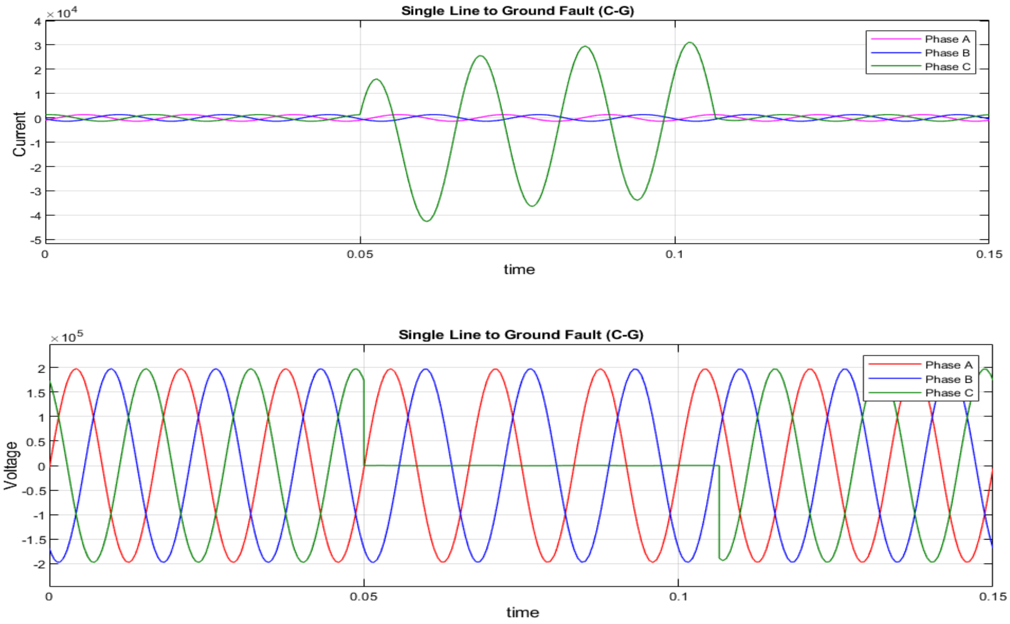

Fig III. Voltage and current waveform during for Line to Ground Fault (C-G)

III.5. How to Apply Wavelet Transform

III.5.1. Wavelet Transform Syntax to Apply on Signal:

- [c,l] = wavedec (x,n,wname)

Where wavedec = function which decomposes the signal

- x = signal,
- n = wavelet layer (default = 4)
- wname = name of the wavelet type (such as haar, Daubechies etc).
- c = Output wavelet decomposition vector
- l = number of coefficients by level.

III.5.2. Wavelet Transform Syntax for detailed coefficients of signal:

- D = detcoef (c,l,n)

Where, detcoef = function which obtains the detailed coefficients of the signal

- c = Output wavelet decomposition vector
- l = number of coefficients by level.
- n = wavelet layer (default = 4)
- D = Extracts the detail coefficients at the coarsest scale from the wavelet decomposition structure [c, l]

III.6. DETECTION METHODOLOGY

With the ability to utilize variable window lengths, the wavelet transform proves valuable in the analysis of transients related to line faults or switching operations. In contrast to the Fourier transform, wavelet analysis offers the advantage of examining localized sections of a signal, enabling the identification of characteristics such as break points and discontinuities. This makes the wavelet transform a useful tool for detecting fault onset and handling non-stationary signals that encompass both low and high frequency components.

Fault detection can be obtained from details of first decomposition level of the measured current signal using db4 wavelet. is employed to analyze the details of the first level decomposition of the measured current signal. This level contains high frequencies associated with faults. Detection of a fault involves monitoring the norm of the DWT coefficient corresponding to these fundamental frequency components. If the norm of the DWT coefficient for the line current falls below a certain threshold, it indicates the lines are in a healthy state. Once the norm of one or more current DWT coefficients exceeds the threshold value, a disturbance is identified. Six levels of decomposition are performed for fault classification.

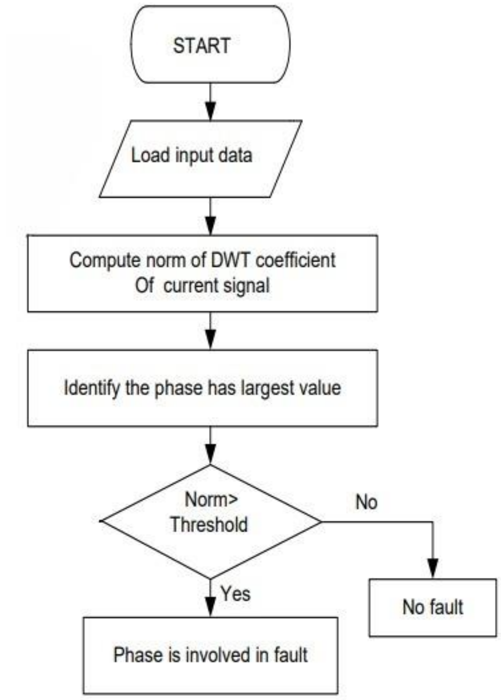

Fig III. 13 Flowchart for fault identification.

III.7. Maximum Value of detailed coefficients of all phases and ground current for different faults

Type of Fault	Max. coefficient of Phase A Current	Max. coefficient of Phase B Current	Max. coefficient of Phase C Current	Max. coefficient of Ground Current
Three phase to ground Fault	3.3831e+03	3.5284e+03	3.4272e+03	3.3377e+03
Three phase Fault	3.3687e+03	3.5370e+03	3.4158e+03	**0.0458**
Double Line to Ground Fault AB-G	3.8739e+03	2.3577e+03	**134.3414**	3.8879e+03
Double Line to Ground Fault AC-G	2.8813e+03	**132.0712**	4.0644e+03	2.1145e+03
Double Line to Ground Fault BC-G	**136.9898**	3.0867e+03	3.2146e+03	2.2729e+03

Line to Line A-B Fault	**2.1284e+03**	**2.6552e+03**	**132.9265**	**0.0092**
Line to Line A-C Fault	1.9934e+03	**106.4068**	1.4577e+03	**0.0183**
Line to Line B-C Fault	**105.8482**	1.8147e+03	1.3760e+03	**0.0041**
Single Line to Ground Fault A-G	3.6783e+03	**106.8074**	**131.1426**	2.4063e+03
Single Line to Ground Fault B-G	**138.0447**	2.8472e+03	**84.8719**	3.2701e+03
Single Line to Ground Fault C-G	**131.7063**	**143.8782**	3.1580e+03	3.4282e+03
System without Fault	**133.2825**	**106.4068**	**131.4976**	**8.2185e-10**

Table III.2 Maximum Value of detailed coefficients of all phases and ground current for different faults

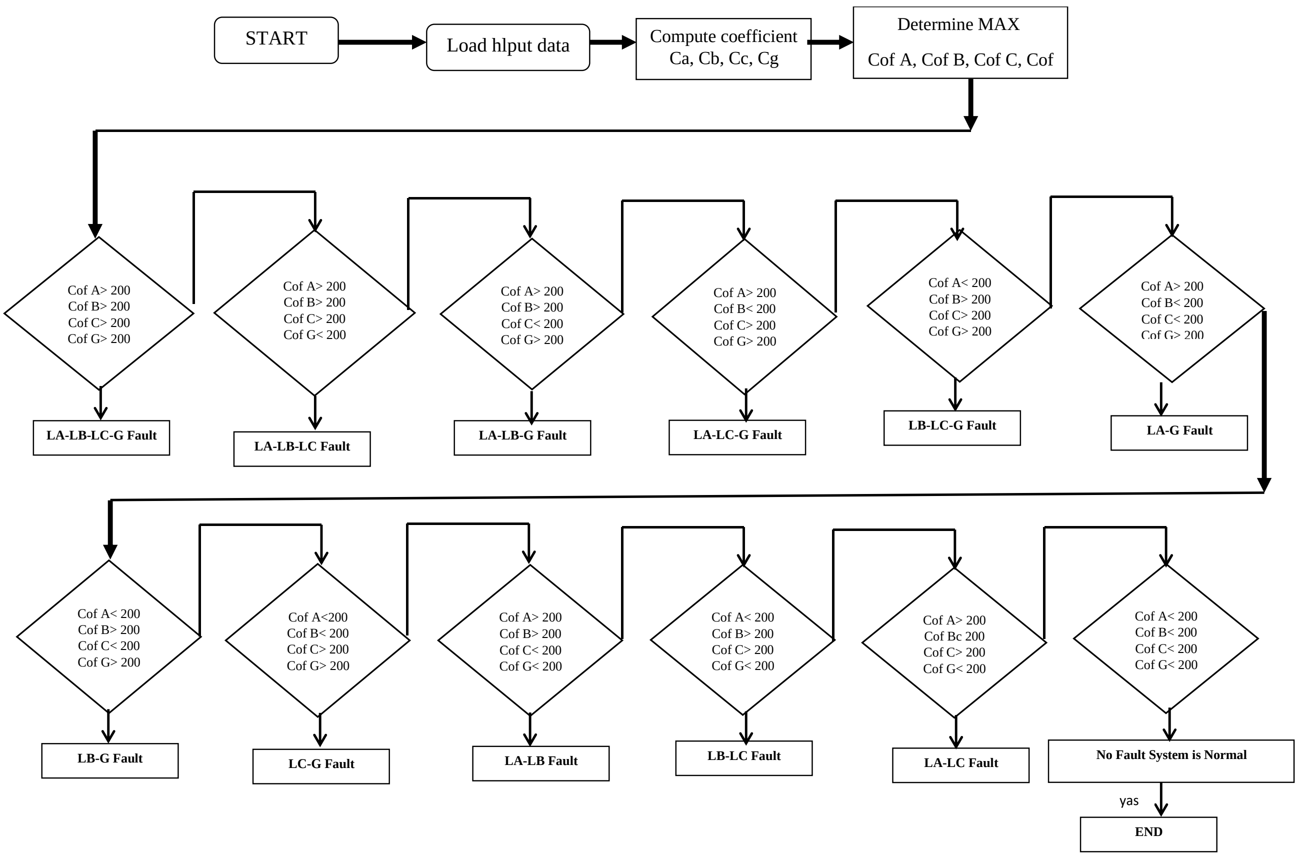

Fig III. 14 Algorithm for fault classification

Conclusion

The simulation results depict the capability of wavelet technique to Identification and Classification a fault. Wavelet transform technique will be an aid to conventional wave analyses used in power station for de-noising transmitted signals. Wavelet transform method is successful in detection of faults in AC networks. Comparing the results obtained, it can be observed that wavelet transform method is capable of distinguishing and Identification and Classification type of fault.

Conclusion General

Wavelet transforms are a valuable tool for analyzing signals and data in various fields. Our case concerns faults in the lines of electrical networks. In the lower case, the discrete wavelet transformation (DWT) allows the decomposition of the line current signals into different frequency bands with varying resolutions, providing detailed information about the characteristics of each signal. Using scaling and wavelet functions, the DWT allows the extraction of both coarse and detailed signal components. The process involves filtering the signal with high-pass and low-pass filters, followed by down sampling to obtain different level coefficients. A further decomposition performed by repeating this process on the approximation coefficients. With wavelet transforms we found very satisfactory results for the detection and classification of all possible faults in power lines, which makes it an essential tool in our case for researchers, engineers and data scientists to used. As a perspective, it is important to expand the application of wavelet transforms for the location of faults in power lines and other components of electrical networks.

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