Chapter 1

# Significance and Basics of Power Systems

## 1.1 Introduction

Modern world heavily depends upon electric grids for critical service capabilities such as healthcare, transportation, household heating and cooling and industrial manufacturing etc. Grid integrity more often effected by many reasons such as energy delivery systems age, natural disasters and man-made mistakes. Urban infrastructure energy delivery systems highly depend on the electric grid, if any vulnerability to electric grid outages becomes a major national concern. Electric power transmission is the bulk movement of electrical energy from power plants, to electrical substations. Essentially an electrical grid is an interconnected network for delivering electricity from producers to consumers. It consists of generating stations that produce electrical power, high voltage transmission lines that carry power from distant sources to demand centres and distribution lines that connect individual customers or businesses. Transmission lines are a vital part of the electrical distribution system, as they provide the path to transfer power between generation and load. Transmission lines operate at voltage levels ranging from 100kV to 1000kV. These transmission lines are interconnected for reliable operation of the electric grid. In recent years many new technologies such as advanced sensors, intelligent automation, communication networks have been integrated into the electric grid to enhance its performance and efficiency.

In recent years, power quality has become the main concern in power systems engineering with major power systems faults occurs on distribution lines. The faults that occur on the transmission lines have a more significant and widespread impact on the consumers. The performance of a power system is affected by faults on the transmission lines, which results in interruption of the power flow. As the power system configuration becomes more complex quick detection of faults and accurate estimation of fault location is critical. The rapid repair, restoration of the power supply is essential for minimizing the local and regional economic impacts, reducing overall power outages and improving customer satisfaction.

When a fault occurs in the transmission line, it initiates a transition condition. Transients produce overcurrents in the power system, which can damage power system equipment’s depending upon fault severity. Transmission protection systems are designed to identify the faults and isolate only the faulted section of the network with compromising the network security of the system with significant accuracy. With the advent of new measurement devices like phasor measurement units (PMU), digital fault recorders (DFR) are often used to provide detailed information about the health of the grid. These operating technologies (OT) in power systems led to a massive amount of data from the monitoring of transmission lines. Using machine learning algorithms with that data opens potential to implement smart and robust fault diagnosis methods.

## 1.2 Basics of Power systems

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| Fig.1 Building Blocks of Electric Power System |

Electric power systems are real-time energy delivery systems. Real-time means power is generated, transported and supplied the moment the switch is turned on. Electric power systems are not capable of storing the generated energy like water systems and gas systems. The generator produces energy as demand calls for it. Fig.1 shows the basic block diagram of the electric power system. The power system consists of three major part generation, transmission and distribution. In the generating stations, electrical energy is produced and then transformed in the power stations to high voltage electrical energy that is more suitable for long-distance transportation. The generating stations transform other sources of energy into electrical energy. For example, thermal, hydraulic, chemical, solar, wind, geothermal, nuclear and other sources of energy are used in the production of electrical energy. High voltage (HV) power lines in the transmission portion of the electric power system will transport the electrical energy from generating stations to long distances to the consumer locations. Finally, the substations at the remote locations are transforming this HV electrical energy to lower high voltage power lines called “feeders” that are most suitable for distribution of electrical energy. This electrical energy is again transformed to even lower voltage services for residential, commercial and industrial consumption.

The power generation and distribution have four stages:

1. *Generation:* Power plants will produce electrical energy that is ultimately delivered to the consumers through transmission lines, substations and distribution lines. Electrical energy must be generated at the same rate as it is consumed. A sophisticated control system is required to ensure that the power generation closely matches with the consumption.
2. *Transmission:* Transmission lines are necessary to carry high-voltage electricity over long distances and connect generators to consumers. Transmission line voltages are typically at above 110kV, with some transmission lines are even operating at 765kV. Power generators, however, produce electricity at lower voltages. The generated voltage is stepped-up to transmission voltages with the help of step-up transformers.
3. *Distribution:* Distribution systems are responsible for delivering electrical energy from distribution substation. Most of the distribution systems in India operates at 11kV. These networks carry power to consumers like a business and residential entities.
4. *Load:* This stage accounts for electrical energy used by various loads on the power system. Electricity is consumed and measured several ways depending on whether the load is residential, commercial, or industrial and whether the load is resistive, inductive, and capacitive.

## 1.3 Power Transmission Networks

High voltage transmission lines transmit power long distances much more efficiently due to two reasons. First, high voltage transmission lines offer less resistive loses over distribution lines. Secondly, raising the voltage to lower the current one to use lower conductor size, or have more conductor capacity available for growth. Transmission lines systems relay the power from production sites to the users. Failure of these structures can lead to power cuts and therefore disrupt the day to day life of people as well as the industries dependent on electricity.

The power system is a network of power stations, transmission lines and substations. Energy is usually transmitted within the system with three-phase AC. Transmission lines are either overhead power lines or underground cables. Overhead transmission lines are not insulated and are vulnerable to weather but can be less expansive to install than underground cables.

Typically, there are three types of line configurations used in the transmission network. These line configurations include (a) radial (one-terminal), (b) two-terminal, and (c) multi-terminal of which three-terminal is possibly the most prominent multi-terminal type. It should be noted that "terminals" in this context, refers to source terminals and not-tapped transformer terminals or stations. The two-terminal line configuration is the most dominant type followed by radial, and the three-terminal lines are the exceptions.

## 1.4 Problem Statement

Transmission lines or transmission network is a crucial part of the electric grid as it carries high voltage power from generating site to the substations where the voltage stepped-down for end-use consumption transported via distribution lines. Though the frequency of faults is much higher in distribution lines, faults on transmission lines have more widespread impact and faults in buried transmission lines take longer to locate and repair. The voltage level of the transmission line is very high if any fault occurred in the line leads to unsafe conditions. Therefore, safeguarding against exposed fault is the most critical task in the protection of the power system. The protection schemes or mechanisms for the transmission lines become challenging as configurations of the transmission lines become increasingly complex.

Faults on transmission lines and the varying environmental conditions present a complex classification and detection problem. With the advent of new machine learning methods and supervised and unsupervised learning methods, these challenges may be more effectively addressed. Machine learning methods are based on the idea that systems can learn from data, identify patterns and make decisions with minimal human intervention. The ability to automatically apply complex mathematical calculations to big data – over and over, faster and faster give these algorithms potential to identify insights in the data which would be otherwise an impossible task for humans. The availability of high-resolution/high-volume data, due to the proliferation of intelligent electronic devices in smart grids, paves ground to implement more accurate and intelligent machine learning methods for fault classification and location identification on the transmission lines.

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| Fig. 2. The studied system with sources at both ends |

In this thesis, we had considered a simple three-phase system as shown in fig. 2 for analysis. The length of the transmission line is 200 km and the operating frequency is 50 Hz. The line voltage of the transmission line is 220 kV. The transmission line connects two sources and has positive impedance *Z1* = 4.76 + *j*59.75 Ω and zero sequence impedance *Z0* = 77.70 + *j*204.26 Ω.

Chapter 2

# Background and Related Work

## 2.1 Introduction

Electrical power gird is most complex power system consisting of power plants, transmission lines, and distribution lines. Fault classification, location identification is necessary to improve the protection mechanism and have a reliable supply. Most of the electrical faults result in mechanical and material damage to the lines and the equipment, which must be repaired before returning the line to service. As we know repairing and restoration is extremely important for maintaining critical and societal services. The restoration process can be delayed if the location estimation cannot do accurately. Various fault classification and location estimation methods have been over the years, and each method has its own advantages and disadvantages.

## 2.2 Faults on Transmission Lines

The fault is an abnormal condition in the electrical systems. The faults in the electric transmission lines are short circuit faults and open circuit faults etc. Open circuit faults are very rare in the transmission lines but the short circuit faults are very common these faults are may be due to natural climatic conditions and mis-operation.

### 2.2.1 Series Faults

Series faults represent open conductor and take place when unbalanced series impedance conditions of the lines are present. These faults disturb the symmetry in one or two phases and are therefore unbalanced faults. Series faults are characterized by an increase of voltage and frequency and fall in current in the faulted phases.

### 2.2.2 Shunt Faults

There are two types of shunt faults which can occur on transmission lines; balanced faults and unbalanced faults also known as symmetrical and unsymmetrical faults as shown in fig.3. The shunt faults are the most common type of fault taking place in the field. They involve power conductors or conductor-to-ground or short circuits between conductors. In shunt faults increment, the current suffers fall in voltage and increase frequency.

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| Fig. 3. Classification of Short Circuit faults |

#### a) Symmetrical Faults:

Symmetrical faults are most severe faults and rarely occurs in the power system. These faults are balanced. These faults are of two types LLL fault and LLL-G faults, when ground involves in the fault then that is called as LLL-G fault else called as LLL fault. The analysis can be done by using per phase. Fig.4 describes balanced faults in the transmission lines.

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| Fig.4 Symmetrical Faults |

#### b) Unsymmetrical Faults:

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| Fig. 5 Unsymmetrical Faults |

These faults are very common and less severe than the symmetrical faults. These faults are classified as the line to ground (L-G), line to line (L-L), double line to ground fault (LL-G) faults. These faults are unbalanced in nature and cause unbalanced currents to flow in the phases.Fig.5 describes unbalanced faults. The study of un-symmetrical faults can be done by using symmetrical components.

1. Single line to ground fault:

When one phase of transmission line comes in contact with the ground either by ice, wind, falling tree or any other incident results in L-G fault. About 70% of the faults in the transmission lines comes under this category. It causes the conductor to make contact with earth or ground.

1. Line to line fault:

During heavy winds, one phase could touch another phase which results in line-to-line fault. Approximately 15% of all transmission lines faults are line-to-line faults. The line to line faults occurs when two conductors make contact with each other mainly while swinging of lines due to winds. These are also called unbalanced faults since their occurrence causes unbalance in the system.

1. Double line to ground fault:

When two phases come in contact with the ground it will lead to this type of fault. Two phases will be involved instead of one in the line-to-ground fault condition. 15 to 20 % of faults in the transmission lines are double line to ground faults.

## 2.3 Causes of Electrical Faults

#### a) Climatic conditions:

It includes lighting strikes, heavy rains, heavy winds, salt deposition on overhead lines and conductors, snow and ice accumulation on transmission lines, etc. These environmental conditions interrupt the power supply and also damage electrical installations.

#### b) Failure of equipment:

  Electrical equipment like [generators](https://www.elprocus.com/working-of-generators/), motors, transformers, reactors, switching devices etc. causes short circuit faults due to malfunctioning, ageing, insulation failure of cables and winding. These failures result in high current to flow through the devices or equipment which further damages it.

#### c) Human errors:

Electrical faults are also caused due to human errors such as selecting improper rating of equipment or devices, forgetting metallic or electrical conducting parts after servicing or maintenance, switching the circuit while it is under servicing, etc.

#### d) Fires:

Ionization of air, due to smoke particles, surrounding the overhead lines results in spark between the lines or between conductors to the insulator. This flashover causes insulators to lose their insulating capacity due to high voltages.