

ANALYSIS OF ELECTRIC FIELD STRENGTH PROPAGATING  
UNDERNEATH THE 132 kV OVERHEAD POWER LINE

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## ABSTRACT

This research presents the electric field strength propagating of 132 kV overhead power lines. In the calculation of the electric field with the charge simulation method it is difficult to judge the magnitude of the field strength in the area, especially the accuracy of the field strength. One of the applications of electric field strength is its implementation in radio planning process as an accurate estimation of propagating power loss. This provides a way for determination of the electric field strength carrier-to-interference (C/I) ratio and all other parameters necessary for proper radio design, to know the effects of electric field on human health. 132 kV overhead lines have selected to be the case of study in this project because this type used to be in the area which near the residential area that nowadays mostly being occupied with commercial, offices, building, housing estates etc. The objectives of this study to define the possible method enabling calculating the electric field strength underneath the 132 kV line, another objective is to calculate the electric field strength propagated by the 132 kV line at some points above the ground level, and analysis the finding results with the guideline electric limits public and occupational exposure as defined in the international standard. The work in this project has used Excel and Visio to discuss the analysis before getting results it has done calculate the conductor sag, conductor clearance and conductor distances for each level. The study has divided to three cases the first case analysis the electric field for single conductor, the second case analysis the electric for two conductors, the third case analysis the electric field for all six conductors, all those analyse are on 1 m and 2 m above the ground and its vicinity on 30 m left and 30 m right from the centre line. This research has compared the finding results with the EMF exposure standards with general public and occupational exposure limits the results were less than standard limits for both cases of study 1m and 2m above the ground on 30m form center the line. The results of this research shown the electric field in area on 1m and 2m above the ground at 30m left and right from center the line is enough safe.

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## LIST OF SYMBOLS AND ABBREVIATIONS

C/I	Carrier-to-interference
ELF	Extremely low frequency
ICNIRP	The international commission on non-Ionizing radiation protection
HV	High Voltage
kV/m	Kilovolt per meter
C	Coulomb
N	Newton
F	The magnitude of the force
Q	Positive or negative Charge
k	Proportionality constant
m	Meter
$\epsilon_0$	Permittivity of free space
F/m	Farads per meter
$\vec{E}$	Electric Field direction
E	Electric Field
V	Voltage
ACSR	Aluminium Conductor Steel Reinforced
NGT	National Grid Technical
EHV	Extra High Voltage
EMF	Electric and Magnetic Field
r	Conductor radius
L	Conductor High
C	Capacitance
N/C	Newton/Coulomb
v	Volt

# CHAPTER I

## INTRODUCTION

### 1.1 Background

Electric power transmission is the bulk transfer of electrical energy from generating power plants to electrical substations located near demand centres. Besides the power transmission line is one of the most important components of electrical power system. It is the main function to transfer the electric energy with minimal losses from the power source to the load centres, usually separated by long distance.

An electric field surrounds electrically charged particles and time-varying. The electric field depicts the force exerted on other electrically charged objects by the electrically charged particle the field is surrounding. The concept of an electric field was introduced by Michael Faraday. [1]. Electrical discharge that always occurs from a space might be responsible for the electrostatic hazard such as the explosion of a super tanker and gasoline tank. Meanwhile, So many phenomena can be explained in terms of the electric field, but not nearly as well in terms of charges simply exerting forces on each other through empty space, that electric field is regarded as having a real physical existence, rather than being a mere mathematically-defined quantity. For example when a collection of charges in one region of space move, the effect on a test charge at a distant point is not felt instantaneously, but instead is detected with a time delay that corresponds to the changed pattern of electric field values moving through space at the speed of light.



That electric field strength submitted is the ratio of the force on a positive test charge at rest to the magnitude of the test charge in the limit as the magnitude of the test charge approaches zero. It has a special unit of volts per meter ( $Vm^{-1}$ ) [2].

Furthermore, several critical parameters may affect the operability and availability of power lines. Due to temperature and aging effects, the sag of the conductor changes and may extend to a critical state which is the minimum distance to objects in the environment that may not be guaranteed with adequate safety margins. Another important aspect is icing of the power line as it constitutes additional weight and may further increase the sag.

Moreover, for electric power transmission, high voltage overhead power lines play an important role as the costs for power transmission are comparatively low. Also, the environmental conditions in many geographical regions can change over a wide range. Due to the high voltages, adequate distances between the conductors and objects in the environment have to be ensured for safety reasons as shown in figure

1.1.

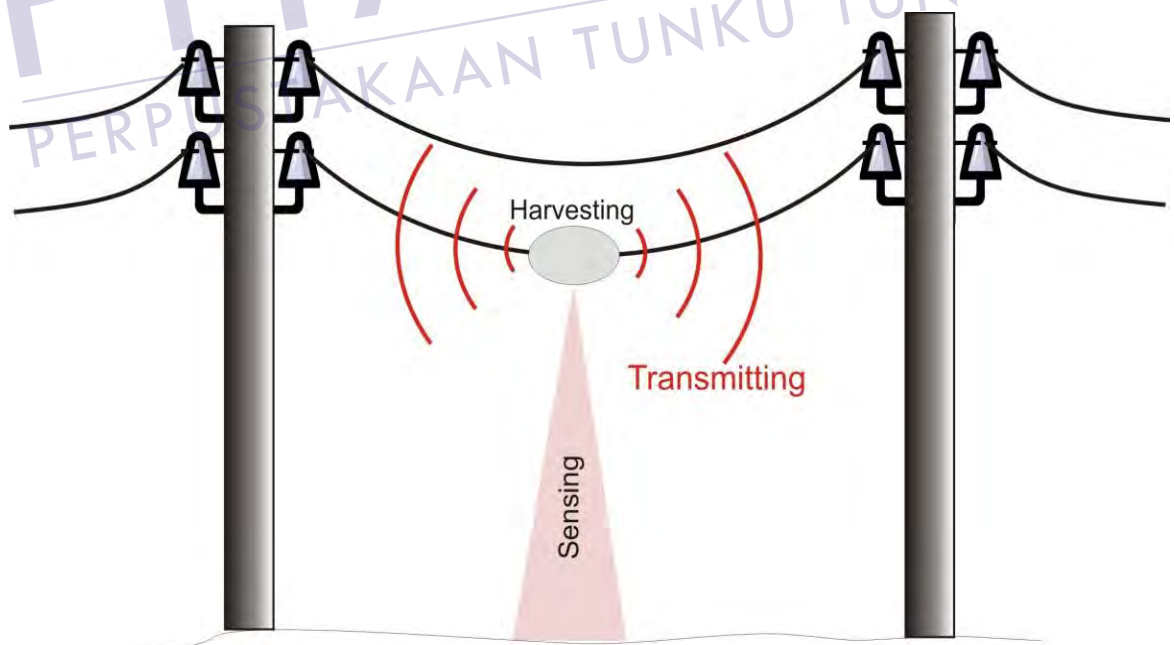


Figure.1.1: principle of overhead monitoring system [3].

In other word, sag of the conductors due to temperature variations or aging, icing of conductors as a result of extreme weather conditions may increase safety margins and limit the operability of the power lines.

Heavy loads due to icing or vibrations excited by winds increase the risk of line breakage. With online condition monitoring of power lines, critical states or states with increased wear for the conductor may be detected early and appropriate counter measures can be applied[3,4].

## 1.2 Project Questions

This research will be conducted to answer the following questions:

- i. What is the existing method of analyzing or measuring electric field strength?
- ii. Have researches been done on the electric field strength in underneath overhead power lines?
- iii. What are the requirements needed to analysis the electric field strength underneath overhead power lines?
- iv. What is the significance of analyzing electric field strength underneath overhead power lines?

## 1.3 Problem Statement

One of the applications of electric field strength its implementation in radio planning process as an accurate estimation of propagating power loss. This provides a way for determination of the electric field strength, carrier-to-interference (C/I) ratio and all other parameters necessary for proper radio design [5].

Researchers have done that for measuring the electric-field intensity in the near field, the characteristics of the top-loaded short dipole antenna is studied theoretically and applied to an electric field measurement system [6].

However, there have been lesser researches on the analysis of electric field strength propagating in the overhead power lines. Thus, this research intends to analysis the electric field strength that is propagating underneath overhead power lines.

To know the effects of electric field for human health, and let the people know how much effect of electric field. 132 kV overhead line has selected to be the case of study in this project because this type used in the area which near the building.

#### 1.4 Project Objectives

The primary objective of this study is to analysis the electric field strength propagating underneath 132 kV overhead power line. In line with this primary objective the secondary objectives are as following.

- i. To define the possible method enabling calculating the electric field underneath the 132 kV line.
- ii. To calculate the electric field strength propagated by the 132 kV line at some points above the ground level.
- iii. To analysis the finding result with the guideline limits such public and occupational exposure as defined in the international standard.

## 1.5 Project Scope

In order to achieve the objectives, the scopes have been highlighted such as:

- i- To analyses the standard 132 kV overhead tower designs.
- ii- To determine the correct method for analyzing or measuring electric field strength.
- iii- To validate of the results with researches have been done on electric field strength underneath overhead power line.
- iv- To analysis the outcomes result with the guideline limit set by international standard appropriate simulation software.



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## CHAPTER II

### LITERATURE REVIEW

#### 2.1 Previous Study

R. Amiri, H Hadi, M. Marich from department of electrical engineering, faculty of genie electric, university of sciences and technology of Oran, Mohamed Boudiaf, has presented work for the influence of sag in the electric field calculation around high voltage overhead transmission lines. Precise analytical modeling and quantization of electric field produced by overhead power lines is important in several research areas. Considerable research and public attention is concentrated on possible health effects of extremely low frequency (ELF) electric field .In annual report conference on electric insulation and dielectric phenomena in 2006 [7].

During the last 25 years, electric fields have been considered more and more as environmental factors. The international commission on non-Ionizing radiation protection (ICNIRP) published in 1998 the guidelines Analytical calculation of the electric field produced by Single-circuit power lines has presented in IEEE transactions on power delivery vol, on 3 July 2008 by A.E. Tzinevrakis [8].

Today electromagnetic environment has become the critical factor which determines the construction of power transmission lines. Therefore, it is necessary to analysis the distribution of electric field under the HV overhead lines especially in the

residential area. In June 2009, Zhujinglin and Mengyu from Shanghai electric power design Institute Co Ltd they have studied the analysis of power frequency electric field for the buildings under the high voltage overhead lines [9].

S.S. Razavipour, M. Jahangiri, H. Sadeghipoor in 2012 has studied electrical field around the overhead transmission lines. In today's world, an increasing level of sensibility to health and ecological problems is seen. High-voltage overhead lines generate electric and magnetic fields in their neighborhood. The electric field is caused by the high potential of the conductors [10].

## 2.2 Electric Field

Electric field strength,  $E$ , is a function of voltage change around the line, expressed in units of kilovolt per meter ( $kVm^{-1}$ ). These fields can be felt near transmission lines through the coupling of voltages and current on motor vehicles or other metallic objects. Increasing the voltage level will increase electric field strength [11].

An electric field is said to exist in a region of space if an electrical charge, at rest in that space, experiences a force of electrical origin (i.e. electric fields cause free charges to move). Electric field is a vector quantity that has both magnitude and direction the direction corresponds to the direction that a positive charge would move in the field. Sources of electric fields are unbalanced electrical charges (positive or negative). Transmission lines, distribution lines, house wiring, and appliances generate electric fields in their vicinity because of the unbalanced electrical charges associated with voltage on the conductors.

The spatial uniformity of an electric field depends on the source of the field and the distance from that source. On the ground under a transmission line the electric field is nearly constant in magnitude and direction over distances of several feet (1 meter).



However, close to transmission or distribution line conductors, the field decreases rapidly with distance from the conductors. Similarly near small sources such as appliances, the field is not uniform and falls off even more rapidly with distance from the device. If an energized conductor (source) is inside a grounded conducting enclosure, then the electric field outside the enclosure is zero, and the source is said to be shielded.

Electric fields interact with the charges in all matter, including living systems. When a conducting object, such as a vehicle or person, is located in a time-varying electric field near a transmission line, the external electric field exerts forces on the charges in the object, and electric fields and currents are induced in the object. If the object is grounded, then the total current induced in the body (the "short-circuit current") flows to earth. The distribution of the currents within, say, the human body, depends on the electrical conductivities of various parts of the body: for example, muscle and blood have higher conductivity than bone and would therefore experience higher currents.

At the boundary surface between air and the conducting object, the field in the air is perpendicular to the conductor surface and is much, much larger than the field in the conductor itself. For example, the average surface field on a human standing in a 10 kV/m field is 27 kV/m; the internal fields in the body are much smaller: approximately 0.008 V/m in the torso and 0.45 V/m in the ankles [12].

### **2.2.1 Transmission line Electric Field**

The electric field created by a high-voltage transmission line extends from the energized conductors to other conducting objects such as the ground, towers, vegetation, buildings, vehicles, and people. The calculated strength of the electric field at a height of 3.28 ft. (1 m) above an unvegetated, flat earth is frequently used to describe the electric field under straight parallel transmission lines. The most important transmission-line parameters that

determine the electric field at a 1-m height are conductor height above ground and line voltage [12].

Calculations of electric fields from transmission lines are performed with computer programs based on well-known physical principles. The calculated values under these conditions represent an ideal situation. When practical conditions approach this ideal model, measurements and calculations agree. Often, however, conditions are far from ideal because of variable terrain and vegetation. In these cases, fields are calculated for ideal conditions, with the lowest conductor clearances to provide upper bounds on the electric field under the transmission lines. With the use of more complex models or empirical results, it is also possible to account accurately for variations in conductor height, topography, and changes in line direction. Because the fields from different sources add vector ally, it is possible to compute the fields from several different lines if the electrical and geometrical properties of the lines are known. However, in general, electric fields near transmission lines with vegetation below are highly complex and cannot be calculated. Measured fields in such situations are highly variable [13].

There are standard techniques for measuring transmission-line electric fields (IEEE, 1987). Provided that the conditions at a measurement site closely approximate those of the ideal situation assumed for calculations, measurements of electric fields agree well with the calculated values. If the ideal conditions are not approximated, the measured field can differ substantially from calculated values. Usually the actual electric field at ground level is reduced from the calculated values by various common objects that act as shields.

Maximum or peak field values occur over a small area at mid span, where conductors are closest to the ground (minimum clearance). As the location of an electric-field profile approaches a tower, the conductor clearance increases, and the peak field decreases. A grounded tower will reduce the electric field considerably by shielding.

For traditional transmission lines, such as the proposed line, where the right-of-way extends laterally well beyond the conductors, electric fields at the edge of the right-of-way are not as sensitive as the peak field to conductor height. Computed values at the edge of the right-of-way for any line height are fairly representative of what can be expected all along the transmission-line corridor. However, the presence of vegetation on and at the edge of the right-of-way will reduce actual electric-field levels below calculated values [13].

### 2.2.2 Theory of the Electric Field on Transmission Lines

They are also called force lines.

- ❖ The field lines are originated from the positive charge.
- ❖ The field lines end up at the negative charge.

A positive charge exerts out and a negative charge exerts in equally to all directions, it is symmetric. Field lines are drawn to show the direction and strength of field. The closer the lines are, the stronger the force acts on an object. If the lines are further each other, the strength of force acting on an object is weaker [14]. Figure 2.1 shown the positive charge, negative charge and two point different charges

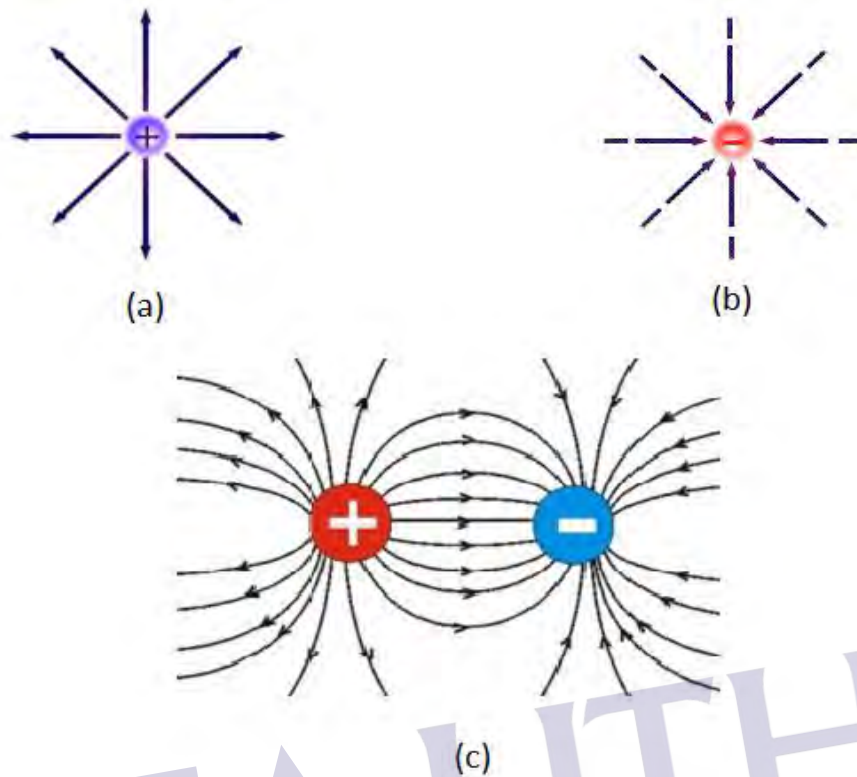


Figure 2.1: (a) Electric field line for positive point charge. (b) Electric field line for negative point charge. (c) Electric field line for two point different charges. [14].

Field lines start on positive charges and end on negative charges, and the direction of the field line at a point tells you what direction the force experienced by a charge will be if the charge is placed at that point. If the charge is positive, it will experience a force in the same direction as the field; if it is negative the force will be opposite to the field.

When there is more than one charge in a region, the electric field lines will not be straight lines; they will curve in response to the different charges. In every case, though, the field is highest where the field lines are close together, and decreases as the lines get further apart.

### 2.3 Electrostatic Field

Electricity is an essential part of our lives. It powers our appliances, office equipment and countless other devices that we use to make life safer, easier and more interesting. Use of electric power is something many of us take for granted. Some have wondered whether long-term public exposure to electric and magnetic fields produced through the generation, transmission and use of electric power might adversely affect our health [14].

An electrostatic field is an electric field produced by static electric charges. The charges are static in the sense of charge amount it is constant in time and their positions in space charges are not moving relatively to each other. Due to its simple nature, the electrostatic field or its visible manifestation electrostatic force - has been observed long time ago. Even ancient Greeks knew something about a strange property of amber that attracts under certain conditions small and light pieces of matter in its vicinity. Much later this phenomenon has been understood and explained as an effect of the electrostatic field. From this historical viewpoint, it would be logical to start the presentation of electromagnetic field theory with electrostatic field. Another reason, as it will be later clear, is its simplicity but also applicability. Namely, electrostatic field plays an important role in modern design of electromagnetic devices whenever a strong electric field appears. For example, an electric field is of paramount importance for the design of X-ray devices, lightning protection equipment and high-voltage components of electric power transmission systems, and hence an analysis of electrostatic field is needed. This is not only important for high-power applications. In the area of solid-state electronics, dealing with electrostatics is inevitable. It is sufficient to mention only the most prominent examples, such as resistors, capacitors or bipolar and field-effect transistors. Concerning computer and other electronic equipment, the situation seems to be similar: cathode ray tubes, liquid crystal display, touch pads etc. [12, 13].

### 2.3.1 Electric Charge

The phenomena of two objects sticking together can be explained by the notion that friction between objects can gain a net electric charge as illustrate in Figure [2.2]. There are two types of charge, called positive (+) and negative (-) with the following basic property

- ❖ Like-charged objects repel each other.
- ❖ Opposite-charged objects attract each other



Figure 2-2: (a) to gain charges positive by rubbing a plastic rod with fur.  
 (b) To gain charges negative by rubbing a grass rod with silk [14].

Detailed experiments have established following fundamental characteristic charge

- ❖ Charge is never created nor destroyed
- ❖ Charge always comes in an integral multiple of a basic unit

The unit of charge is called the Coulomb (C),  $e=1.062 \times 10^{-19}$  Coulomb (C)

### 2.3.2 Coulomb's Law

The electric interaction between two charged particles is described in terms of the forces they exert on each other. Charles Augustin de Coulomb (1786-1803) using an invented tension balance to determine quantitatively the force electric exerted between two objects where each having a static charge of electricity. He states that the force between two charged particles separated in a vacuum or free space by a distance is directly proportional to the product of charges and inversely proportional to the square of the distance between them. The magnitude of the force of attraction or repulsion is given by Coulomb's Law as standard in equation (2.1).

$$F = \frac{k \cdot |Q_1 \cdot Q_2|}{R^2} = \frac{Q_1 \cdot Q_2}{4\pi \epsilon_0 R^2} \quad \text{(Newton)} \quad [14] \quad (2.1)$$

Where  $Q_1$  and  $Q_2$  are the positive or negative quantities of charge,  $R$  is the separation and  $k$  is proportionality constant. If SI unit is used  $Q$  is measured in coulombs(C),  $R$  is meters (m) and force should be Newton (N). This will be achieved if the constant of proportionality  $k$  as is written as

$$k = \frac{1}{4\pi\epsilon_0} m^2 C^{-2} \quad [14] \quad (2.2)$$

$$k = 8.987 \times 10^9 m^2 C^{-2} \text{ N}$$

$$k = 9 \times 10^9 N m^2 C^{-2}$$

The constant  $\epsilon_0$  is called the permittivity of free space and has magnitude measured in farads per meter F/m;

$$\epsilon_0 = 8.854 \times 10^{-12}$$

$$\epsilon_0 = \frac{1}{36\pi} 10^{-9} F/m \quad [14] \quad (2.3)$$

Figure 2.3 shown the direction of the force  $F$



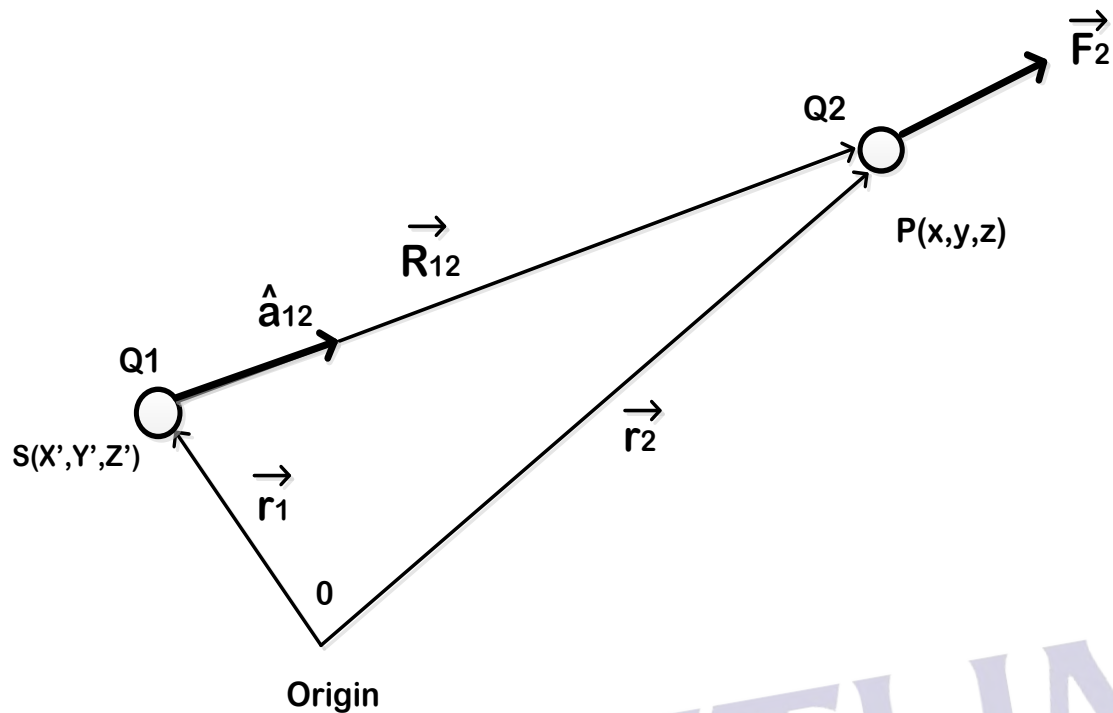


Figure 2.3: If  $Q_1$  and  $Q_2$  have like signs, the vector force  $F_2$  on  $Q_2$  is in the same direction as the vector  $\hat{a}_{12}$ .

Consider  $Q_1$  and  $Q_2$  are two charges particles located  $S(x', y', z')$  and  $P(x, y, z)$  with vector  $\vec{r}_1 = x'\hat{x} + y'\hat{y} + z'\hat{z}$  and  $\vec{r}_2 = x\hat{x} + y\hat{y} + z\hat{z}$  respectively. The vector  $\vec{R}_{12} = \vec{r}_2 - \vec{r}_1$  respectively the directed line segment  $Q_1$  to  $Q_2$  as shown in figure 2.2 The vector  $\vec{F}_2$  is the force on  $Q_2$  and is shown for the case where from  $Q_1$  to  $Q_2$  have the same sign. The vector from Coulomb's law is [14].

$$\vec{F}_2 = \frac{Q_1 Q_2}{4\pi \epsilon_0 R^2} \hat{a}_{12} \quad [14] \quad (2.4)$$

Where:

$$\hat{a}_{12} = \frac{\vec{R}_{12}}{|\vec{R}_{12}|} = \frac{\hat{r}_2 - \hat{r}_1}{|\hat{r}_2 - \hat{r}_1|}$$



### 2.3.3 Potential Difference and Potential

Potential difference is defined as work done in moving a unit positive charge from one point to other in an electric field. It is a location dependent quantity which expresses the amount of potential energy  $DW$  per unit charge

$$dV = \frac{dW}{q} = -\vec{E} \cdot d\vec{l} \quad [21] \quad (2.5)$$

The potential difference between points A and B in a circuit is commonly referred as voltage calculated as integration the path taken from B to A.

$$V_{AB} = -\int_B^A \vec{E} \cdot d\vec{l} \quad (V \text{ or } \frac{J}{C}) \quad [21] \quad (2.6)$$

$V_{AB}$  is positive if work is done in carrying the positive charge from B to A. The SI unit of potential difference is the volt (V) or joules per coulomb. Consider the potential difference between point A and B in the field of a point charge Q placed at the origin as shown in the figure 2.4.[21].

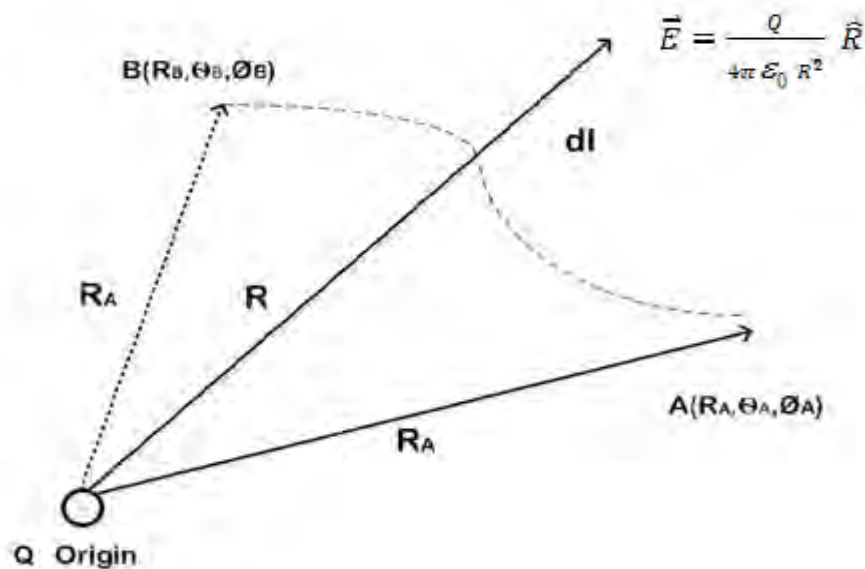


Figure 2.4 A path between points B and A in the field of point charge at origin [21].

Point charge Q produce electric field  $\vec{E} = \frac{Q}{4\pi \epsilon_0 R^2} \hat{R}$ . The difference element  $\vec{dl}$  chosen

in cylindrical coordinate,  $\vec{dl} = dR\hat{R} + Rd\theta\hat{\theta} + r \sin \theta d\phi\hat{\phi}$  and  $d\theta$  and  $d\phi$  is zero after dot product.

$$V_{AB} = - \int_B^A \vec{E} \cdot \vec{dl} \quad [21] \quad (2.7)$$

$$V_{AB} = - \int_B^A \left( V \text{ or } \frac{J}{C} \right) \cdot (dR\hat{R} + Rd\theta\hat{\theta} + r \sin \theta d\phi\hat{\phi})$$

$$V_{AB} = - \frac{Q}{4\pi \epsilon_0 R^2} \oint \frac{dR}{R^2}$$

$$V_{AB} = - \frac{Q}{4\pi \epsilon_0 R^2} \left( \frac{1}{R_A} - \frac{1}{R_B} \right)$$

$$V_{AB} = V_A - V_B \quad [21] \quad (2.8)$$

Where  $V_A$  and  $V_B$  have the same zero reference point. In electrostatics, the potential difference between points A and B is independent of the integration path. If we move from point A to B by path C1 and then back from B to A by C2, it forms a closed contour and the potential difference becomes zero. In fact, the line integral of the electrostatic field  $\vec{E}$  around any closed contour is zero [21].



### 2.3 4. Potential of Point Charges

Figure 2.5 shown the potential at point charge, which represented with three dimension of, coordinates system (x, y, z) axis.

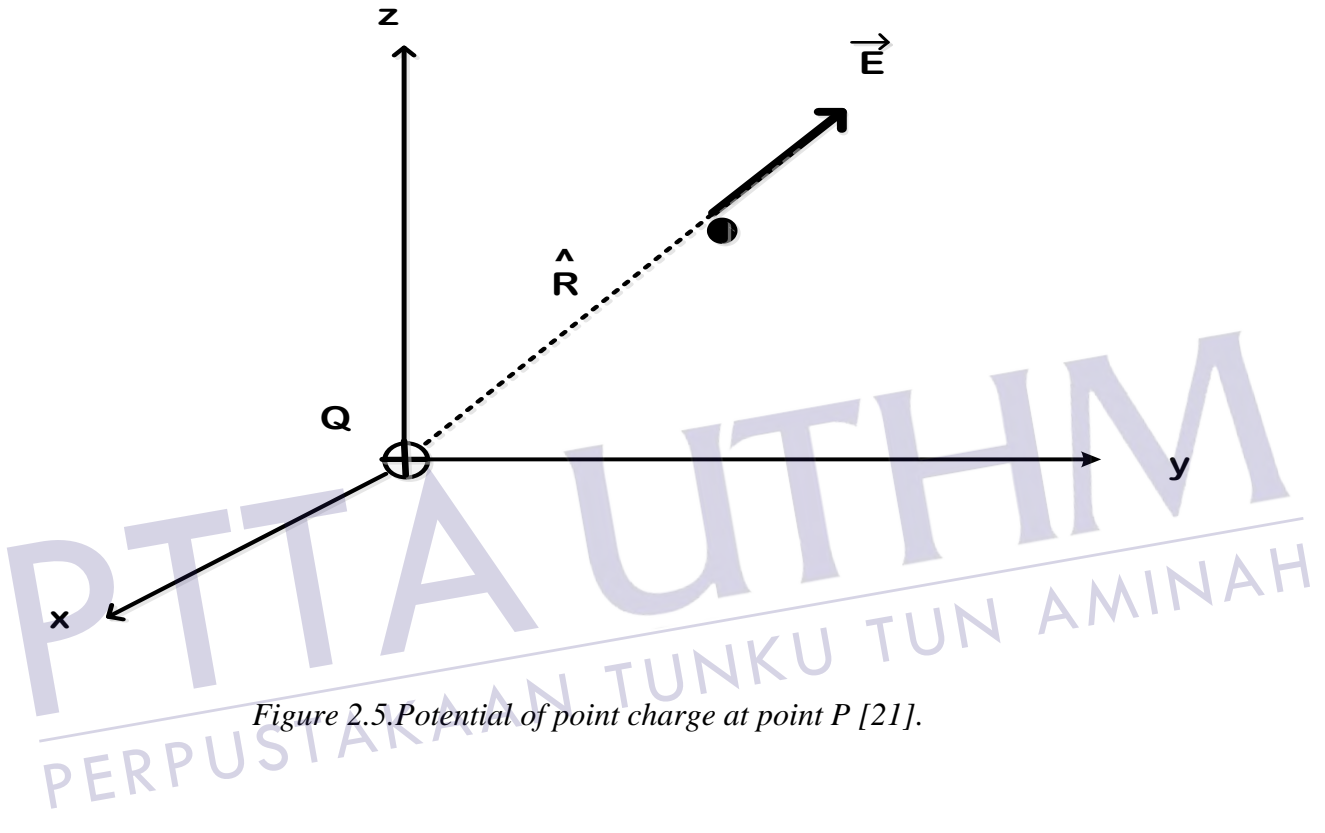


Figure 2.5. Potential of point charge at point P [21].

Electric field at point P of a positive point charge Q located at origin is

$$\vec{E} = \frac{Q}{4\pi \epsilon_0 R^2} \hat{R} \quad [21] \quad (2.9)$$

Where:  $\vec{E}$  is the electric field, Q is the charge, R is the distance, the constant  $\epsilon_0$  is called the permittivity of free space and has magnitude measured in farads per meter F/m.

The potential at point P of a positive point charge located at the origin is the work done in bringing a test charge from infinity to point P.

$$V_P = - \int_{\infty}^P \vec{E} \cdot d\vec{l} \quad [21] \quad (2.10)$$

$$V_P = - \int_{\infty}^P \left( \frac{Q}{4\pi \epsilon_0 R^2} \right) \cdot (dR \hat{R})$$

$$V_P = - \int_{\infty}^R \frac{Q}{4\pi \epsilon_0 R^2} dR$$

$$V_P = - \frac{Q}{4\pi \epsilon_0 R^2} (V) \quad [21] \quad (2.11)$$

If the charge  $Q$  is at a location other than the origin, specified by a source position vector  $\vec{R}_1$ , then  $V$  at observation position vector  $\vec{R}$  becomes

$$V(\vec{R}) = - \frac{Q}{4\pi \epsilon_0 |\vec{R} - \vec{R}_1|} \quad [21] \quad (2.12)$$

where  $|\vec{R} - \vec{R}_1|$  is the distance between the observation point and the location of the charge  $Q$ .

For  $N$  discrete point charges  $Q_1, Q_2, \dots, Q_N$ , we use the principle of superposition and add the potentials due to the individual charges.

$$V(\vec{R}) = - \frac{1}{4\pi \epsilon_0} \sum_{i=1}^N \frac{Q_i}{|\vec{R} - \vec{R}_i|} (V) \quad [21] \quad (2.13)$$

For continuous charge distribution, we use the principle of integral. The general expression for potential of continuous distribution is

$$V_P = \int \frac{dQ}{4\pi \epsilon_0 R}$$

$$V_P = \frac{1}{4\pi \epsilon_0} \int \frac{dQ}{R} \quad [21] \quad (2.14)$$

The concept of continuous charge distribution can be applied to determine potential due to line, surface and volume charge distribution [21].

The expression assistant

$$V_P = \frac{1}{4\pi \epsilon_0} \int \frac{P_l dl}{R} \quad (\text{Line charge distribution}) \quad [21] \quad (2.15)$$

$$V_P = \frac{1}{4\pi \epsilon_0} \int \frac{P_s dQ}{R} \quad (\text{Surface charge distribution}) \quad [21] \quad (2.16)$$

$$V_P = \frac{1}{4\pi \epsilon_0} \int \frac{P_v dQ}{R} \quad (\text{Volume charge distribution}) \quad [21] \quad (2.17)$$

### 2.3.5 Equipotential Surface

Filed lines help us to visualize electric fields. In a similar way the potential at various in an electric field can be described by equipotential surface where each corresponds to a different fixed value of the potential.

An equipotential surface is surface each the every point in the surface has the same potential. The equipotential surface through any point must be perpendicular to the direction of the field at the point. Field lines and equipotential surface are always mutually perpendicular. If a charge moves along an equipotential line, no work done; if a charge moves between equipotential lines, work is done [14].figure 2.6 shown Equipotential surface for point charge.



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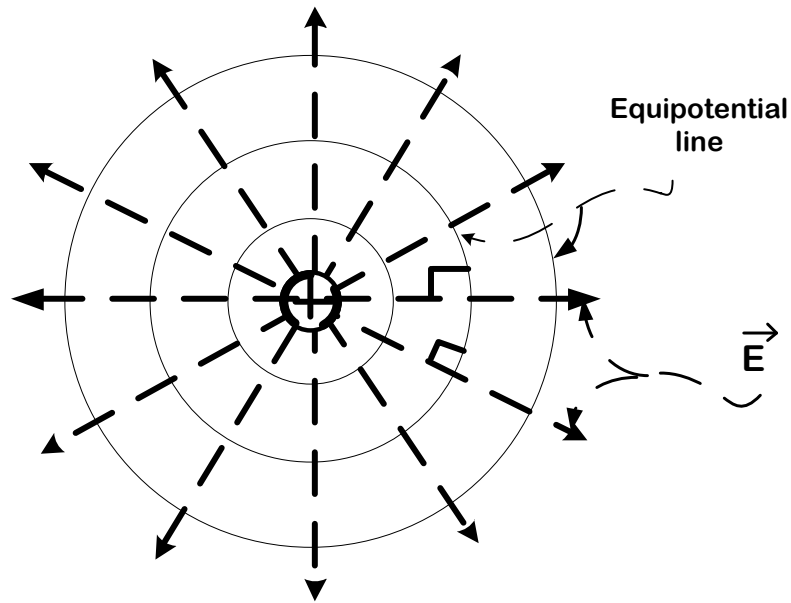


Figure 2:6. Equipotential surface for point charge [14].

### 2.3.6 Potential Gradient

There are two methods of determining potential, one directly from the electric field intensity by means of a line integral and another from the basic charge distribution itself by a volume integral.

Both methods are not helpful in determining the fields in most practical problems because neither the electric field intensity nor the charge distribution is very often known so we need simple methods of finding the electric field intensity from the potential. The operation on  $V$  by which  $-\vec{E}$  is obtained is known as the gradient. From definition potential.

$$V = - \int \vec{E} \cdot d\vec{l} \quad [21] \quad (2.18)$$

$$dV = -\vec{E} \cdot d\vec{l} \quad [21] \quad (2.19)$$

$$dV = -E_x \hat{x} - E_y \hat{y} - E_z \hat{z} \quad [21] \quad (2.20)$$

Equation  $dV$  equivalent with

$$dV = \frac{\partial V}{\partial x} dx + \frac{\partial V}{\partial y} dy + \frac{\partial V}{\partial z} dz \quad [21] \quad (2.21)$$

Compare equations (2, 20) and (2, 21)

$$E_x = -\frac{\partial V}{\partial x}$$

$$E_y = -\frac{\partial V}{\partial y} \quad E_z = -\frac{\partial V}{\partial z}$$

$$\vec{E} = -\frac{\partial V}{\partial x} \hat{x} - \frac{\partial V}{\partial y} \hat{y} - \frac{\partial V}{\partial z} \hat{z}$$

or

$$\vec{E} = -\nabla V \quad [21] \quad (2.22)$$

Where  $\vec{E}$  is opposite with gradient  $V$ . Negative sign show that direction of  $\vec{E}$  is opposite with direction of increasing  $V$ , which is  $\vec{E}$  direct from maximum to minimum potential. That gradient may be expressed in term of partial derivatives in Cartesian, Cylindrical, or spherical coordinate systems [21].

$$\nabla V = \frac{\partial V}{\partial x} \hat{x} + \frac{\partial V}{\partial y} \hat{y} + \frac{\partial V}{\partial z} \hat{z} \quad (\text{Cartesian}) \quad [21] \quad (2.23)$$

$$\nabla V = \frac{\partial V}{\partial r} \hat{r} + \frac{1}{r} \frac{\partial V}{\partial \phi} \hat{\phi} + \frac{\partial V}{\partial z} \hat{z} \quad (\text{Cylindrical}) \quad [21] \quad (2.24)$$

$$\nabla V = \frac{\partial V}{\partial R} \hat{R} + \frac{1}{R} \frac{\partial V}{\partial \theta} \hat{\theta} + \frac{1}{R \sin \theta} \frac{\partial V}{\partial \phi} \hat{\phi} \quad (\text{Spherical}) \quad [21] \quad (2.25)$$

## 2.4 Configuration 132 kV Tower (case of study)

The work is based on the analysis of a 132 kV tower as used on the National Grid system. This is one of the most common tower types and was therefore selected for analysis, this type of the tower is can be found in the area which near from the building in cites, dimensions and scales for 132 kV overhead line as shown in Figure 2.7.

The 132 kV L4 overhead lines composed of the tower body which made of steel the tower high is 26 meters above the ground. The 132 kV L4 has six conductors the Aluminium Conductor Steel Reinforced (ACSR) used in this type of tower. One of the most important and yet one of the most vulnerable links in transmission and distribution is insulators. Porcelain and toughened glass are the materials principally used for supporting conductors on overhead lines, and although these materials are relatively brittle and inelastic, they have proven service experience and are still widely used. The poles carry 3-phase conductors (cables) in a single circuit network with an under slung earth wire, which incorporates a fibre optic cable for protection signalling and communication purposes, The minimum ground clearance distance for a 132kv overhead line is 6.7m (including the lower earth wire) and the overhead line is designed to ensure this distance is maintained at all times and in all conditions.132 kV has three cross-arms are steel construction made [15].





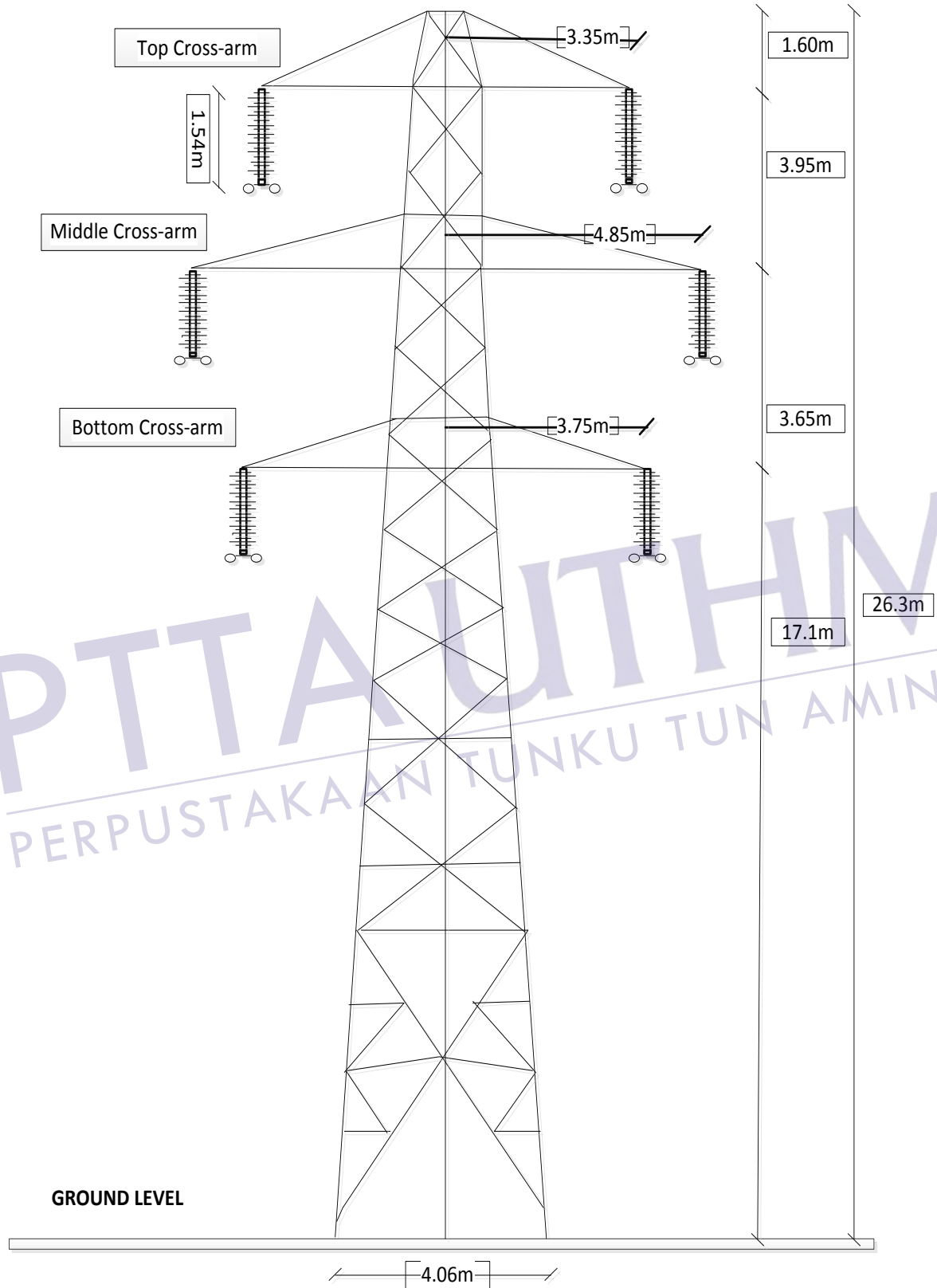


Figure 2.7: Standard 132 kV L4 tower design [18]

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