VOLTAGE UPRATING OF EXISTING 275kV OVERHEAD TRANSMISSION LINE TOWER FOR INCREASING POWER TRANSFER CAPABILITY

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ABSTRACT

This project presents a methodological approach, suggestions and information in uprating the existing 275kV transmission overhead line. The work also calculate and analyses the effect of conductor swing angle on L3 tower top geometrics and keep the probability of flashover at low state. In this project, the insulator length and clearances of swing conductor to tower body, top cross-arm, bottom cross-arm and conductor to conductor are considered. The purpose of this work is to determine the clearances necessary to insulator withstand for 400kV line. In addition, it is also important to make sure that conductors have to maintain the clearances under TOV (temporary over-voltage), switching and lightning overvoltages. The work in this project have used Excel and Smart Draw to analyze the results and plot the clearance distances of swing conductor, also the phase to phase rms voltage and redrawing the existing overhead tower. Therefore, voltages rating for the L3 tower can be determined through the available clearances. Firstly, the voltage rating is determined with standard 400kV specification of insulator length. Then, the insulator is being shorted to do the analysis to the voltage rating and lastly, the overall cross-arm is changed to fully insulate such as composite cross-arm. As the result, by using standard insulator length, the tower only carried 351kV rather than composite cross-arm that carry 450kV. The standard L3 tower will be increase the power transfer capacity to 400kV in term of voltage by changing the steel cross-arm to composite cross-arm.

ABSTRAK

Projek ini menerangkan pendekatan metodologi, cadangan dan maklumat dalam meningkatkan voltan talian penghantaran 275kV sedia ada. Kajian ini juga mengira dan analisis kesan sudut pergerakan konduktor pada geometri pencawang L3 dan mengekalkan kebarangkalian percikan (*flashover*) di peringkat yang terendah. Dalam projek ini, panjang penebat dan jarak sudut konduktor kepada badan menara, ke atas silang lengan (*cross-arm*), ke bawah silang lengan dan konduktor ke konduktor di ambil kira. Tujuan kajian ini adalah untuk menentukan kelegaan yang perlu untuk menampung talian 400kV. Di samping itu, ia juga penting untuk memastikan bahawa penebat perlu untuk bertahan di bawah voltan lebihan sementara (*TOV*), menukar dan kilat voltan lebihan. Di dalam projek ini, perisian *Excel* dan *Smart Draw* digunakan untuk menganalisa keputusan dan menentukan jarak yang selamat bagi pergerakan penebat (*insulator*) dan konduktor, juga fasa untuk voltan rms dan merangka semula menara penghantar mengikut saiz sebenar. Oleh itu, penarafan voltan untuk menara L3 boleh ditentukan melalui kelegaan yang tersedia. Pertama, kadar voltan ditentukan dengan spesifikasi asal 400kV panjang penebat. Kemudian, penebat di pendekkan untuk membuat analisis rating voltan dan akhir sekali, keseluruhan silang lengan diubah sepenuhnya dan berfungsi sebagai penebat seperti silang lengan komposit. Hasilnya, dengan menggunakan panjang penebat asal, menara L3 hanya boleh membawa 351kV, manakala apabila menggunakan silang lengan komposit akan membawa 450kV. Menara L3 asal akan meningkatkan keupayaan pemindahan kuasa kepada 400kV dalam jangka voltan dengan perubahan silang lengan keluli ke silang lengan komposit.

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LIST OF ABBREVIATIONS

kV	-	kilovolt
kA	-	Kilo Amperes
HTLS	-	High Temperature Low Sags
ACCR	-	Aluminum Conductor Composite Reinforced
ACSR	-	Aluminum Conductor Steel Reinforced
ACAR	-	Aluminum Conductor Alloy Reinforced
AAAC	-	All Aluminum Alloy Conductors
AACSR	-	Aluminum Alloy Conductor Steel Reinforced
LV	-	Low Voltage
MV	-	Medium Voltage
HV	-	High Voltage
EHV	-	Extra High Voltage
UHV	-	Ultra High Voltage
µs	-	Microseconds
ms	-	Milliseconds
s	-	Second
p.u	-	Per-unit
Hz	-	Hertz
TOV	-	Temporary Overvoltages
SFO	-	Slow Front Overvoltages
FFO	-	Fast Front Overvoltages
VFFO	-	Very Fast Front Overvoltages
VAr	-	Volt Ampere Reactive
Um	-	Maximum voltage operation
Eq	-	Equation
°C	-	Temperature in Celsius
m	-	Meter

mm^2	-	Millimeter square
NGC	-	National Grid Company
CRIEPI	-	Central Research Institute of Electric Power Industry
Kg	-	Gap Factor
Ka	-	Atmospheric factor
d or D	-	Distances
$U50_{pe\_pf}$	-	50% of probability of flashover of phase to earth of power Frequency overvoltage
$U50_{pe\_sf}^{+ve}$	-	50% of probability of flashover of phase to earth of positive Switching overvoltage
$U50_{pe\_sf}^{-ve}$	-	50% of probability of flashover of phase to earth of negative Switching overvoltage
$U50_{pp\_sf}^{+ve}$	-	50% of probability of flashover of phase to phase of positive Switching overvoltage
$U50_{pe\_ff}^{+ve}$	-	50% of probability of flashover of phase to earth of positive Lightning overvoltage
$U50_{pe\_ff}^{-ve}$	-	50% of probability of flashover of phase to earth of negative Lightning overvoltage
U_{max_sf}	-	Highest voltage of switching impulse
n/a	-	Not Applicable
cdr	-	Conductor
CWF	-	Critical Wave Front

CHAPTER 1

INTRODUCTION

1.1 Project Background

Nowadays, the developments in technology are increase slightly to improve quality of life and consequently a growing demand of electrical power. The world total energy demand for electricity increase 2.3 percent per year from 2008 to 2035 and continues to outpace growth in total energy use throughout the projection period that shown in Figure 1.1 [1].

Since population increasing and urban expansion rapidly today, the construction of new transmission line is limited due to environmental difficulties concern and lack of investors interested in such projects. Therefore the option to cope with an increasing load demand is by increasing transmission line capacity.

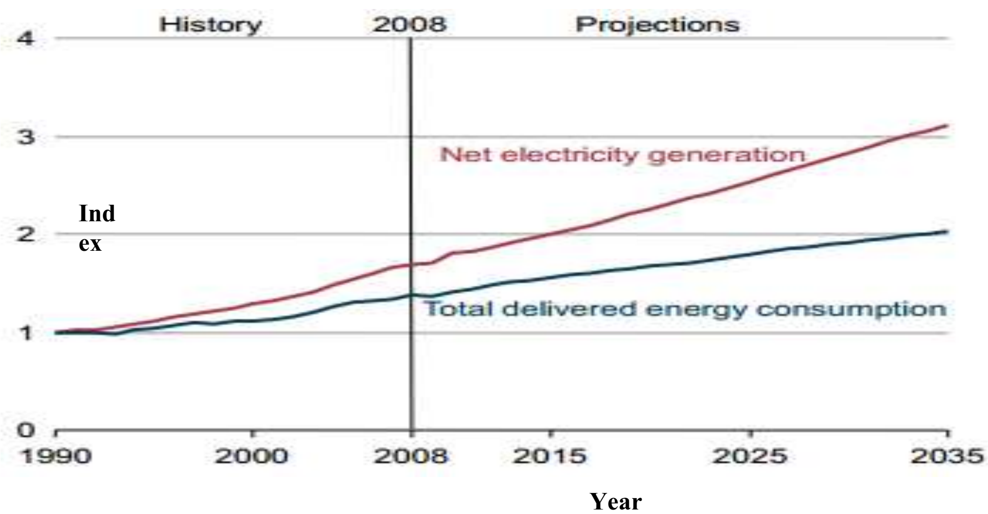

Figure 1.1: Growth in world electricity generation and total delivered energy consumption from year 1990 to 2035 [1]

While there is increase in generation capacity of system, the growth of transmission line capacity has been limited due to environmental constraints resulting in transmitting electrical power through the existing transmission overhead line that are normally more than 50 years. Therefore, the only way to solve this problem is either by construct with new lines or increase transmission lines capacity by carrying more current or uprating the voltage.

There are various techniques used throughout the world to increasing power transfer capability of the transmission lines. Since the power is the multiplying of current square with voltage ($P=I^2V$), all the techniques of current and voltage uprating would increase the power capability.

1.2 Problem Statement

Increasing of population and technologies needs a lot of electricity power in order to fulfill human necessary. However, environmental and economic issues make a limitation to building new transmission lines. Utilities would have to overcome various obstacles such as difficulty in obtaining permission for new lines, right of way, the change in land use, the impact on ecological systems and other environmental of line construction and maintenance.

There are very few cases of uprating by increase in voltage capability of a line are found rather than current uprating. Compared to the current uprating, voltage uprating would results much higher potential for power transfer capability with reduced electrical losses [2]. Thus voltage uprating is more suitable than current uprating since uprating the current would increase the temperature of the conductor. However, the solution is only re-conductoring such as increasing the conductor cross-section, higher thermal rated cable and increasing number of conductor per phase [3, 4].

Utilities companies all around the world are using different techniques in voltage uprating as analyzed in published literature. The issues such as conductor air clearances, insulation electrical strength, overvoltages and increasing conductor height are a part of methodology for uprating the line to 400kV.

This project gives the suggestions and information to uprating voltage for increasing the power transfer capacity of an existing 275kV line with the L3 structure. Two area of study is required to uprating voltage of existing transmission line. First to identify the availability of required air clearances for the 400kV and the second is to access the insulation level required for withstand transient overvoltages especially lightning and switching overvoltages.

1.3 Objectives

The objective of this project is to increase the power transfer capability of existing 275kV overhead tower line by voltage uprating method.

Its measurable objectives are as follows:

1) To determine the characteristics tower of existing 275kV overhead transmission component lines.
2) To identified the required minimum clearances necessary to withstand overvoltages for 400kV.
3) To determine the voltage rating of the L3 tower.

1.4 Project Scopes

In order to achieve the objective, several scopes of work proposed such as:

(a) Literature review covering related issues such as overvoltages, clearances, insulator, overhead line tower, etc.

(b) To determine either 275kV can be uprate the voltage up to 400kV without changing much to the physical structure in-term of safe and economical.

(c) To design the simulation tools for data collecting of voltage uprating parameters using appropriate software such as Excel, Matlab and etc.

(d) Analysis of data and summarize them in the thesis.

Through this, the National Grid 275kV L3 tower is used as the framework for the analysis.

1.5 Limitation

Other aspects of interest of voltage upgrading that are not included in this thesis are location of surge arrestors, corona noise, conductor selection etc.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The overhead transmission lines is the most important elements of today's applications and has been used long time ago also would continue along the year. In designing any of transmission lines, the probabilities method needs in order to achieve the minimum requirements in designing or improving the existing transmission line for right of way, environmental impact and human safety.

The planning studies take a leading role in the definitions of an electric system or in the expansion. Due to the several variables involved in the process, the planning activities had been start several years before expansion of an existing transmission line can be implemented. However, all those activities had done by researcher all over the world especially and at this chapter would provide the work had done for few researchers around the world and summarize them at section 2.2 with other researchers.

An example of voltage uprating using the cross-arm modification and re-conductoring can be found in a paper by K. Kopsidas, M.N.R. Baharom et al (2010) [5], reporting work to investigate the possibility of uprating L3 towers from 275kV to 400kV. In this work, the composite cross-arms has the potential benefits such as it allows voltage uprating to 400kV without infringing the required clearances to the tower and ground that dominate the design, also there is no swing angle. Therefore, the only way to increase its power transfer capacity is by re-conductoring. By using the novel technologies High Temperature Low Sags (HTLS) conductors of Aluminum Conductor Composite Reinforced (ACCR) with its equivalent size diameter 18.4mm, the better mechanical and electrical performance can be achieved at normal operating temperatures which cannot be realized with the existing system. The use of this HTLS can provide power uprating up to almost 150% compared to the existing capability. Even when voltage uprating is not an option for the operator a simple increase of maximum conductor temperature is feasible due to increase in maximum permitted sag. The outline diagram of this work can be view at Figure 2.1 which shows the clearances of the 275kV L3 type and modified with composite cross-arm.

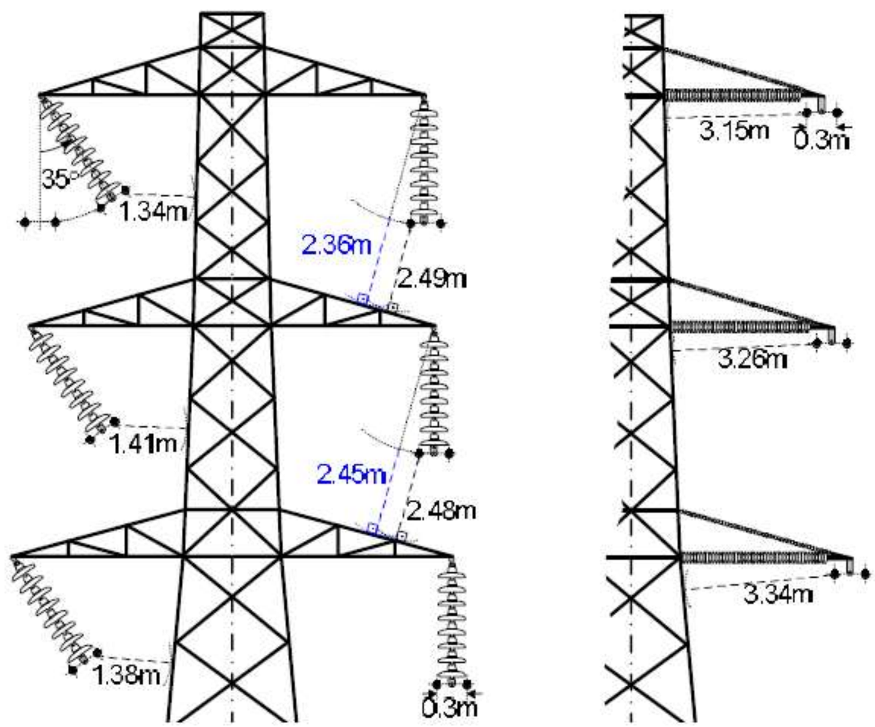

Figure 2.1: Clearance observed on an L3 tower with normal suspension set (left) and the modified with composite cross-arm (right) [5].

Haddad, H. Griffiths et al. (2009) in [6] said while uprating an overhead line to a higher voltage level, normally the required clearance level is difficult to achieve for uprated structure. By using transmission line arresters is an effective technique in controlling overvoltages and thereby the required clearance margin can achieved. In this paper, a case study of existing 275kV is investigated to uprating voltage to 400kV and a lot of configuration locations of arresters are investigate. However, when the arresters are present at every alternate line sections, the highest overvoltage could be reduced down to 1.7 p.u (per-unit) in every nodes such as Node 1, Node 3, Node 5 (Tower conductor 1, tower conductor 3 and so on). Therefore an optimum number of arresters could be more suitable by putting at alternate line section rather than at the line ends or at line ends with at the middle of the line.

In 2010, a similar concepts was produced by R.Bhattarai et al. (2010) in [7] that voltage uprating of overhead transmission lines can be achieved by applying line surge arresters along the line to controlling overvoltage since phase to earth clearance is a key issue for voltage uprating; therefore the minimum required clearance for 400kV system is reducing. From this paper, the application of line surge arresters can effectively control overvoltages due to lightning and switching was demonstrated. The detailed consideration of developed overvoltages under direct strike and backflashover can help optimize, hence reduce the number of surge arresters deployed along the line. Therefore, arresters placed at the top phases only would be sufficient to control overvoltages due to shielding failure. But in very rare cases, if the strike hits a middle or bottom phase conductor, the arresters in top phases also can help to control overvoltage in striking phase.

Another example is done by S. Narain, D. Muftic et al. (2006) in [8] for Eskom Lethabo power station which uprating of 275kV lines to 400kV as part of a contingency plan for generation integration. From this paper, there are many types of compacted existing overhead line and by changing the insulator from existing U120 type to U160 type glass insulator disc and assemblies with Delta VVV that shows at Figure 2.2. Re-insulation provide the opportunity to optimize clearances and insulator creepage which this two parameters crucial for the successful operation at 400kV. But in various study, this V-string type mostly suitable for current uprating not for voltage uprating.

Figure 2.2: V-V-V assembly on 433B tower after re-insulation [8].

Figure 2.3 shows an alternative solution in voltage upgrading of existing L3 towers employing with the V-string concept where for this type can be consider as V-string style 2. By summarizing S.Venkatesan, R. Bhattarai et al. (2010) in [9] works, the use of a V-string insulator of shorter vertical length (3.2m) could provide 2.63m clearance. Therefore it can prevent the insulator from swinging and this combination would result in meeting the required clearance. However the insulation level of the shorter string would need to be established for this case since replacement with 400kV insulator has confirmed that standard replacement of the same length would not result in sufficient clearance levels.

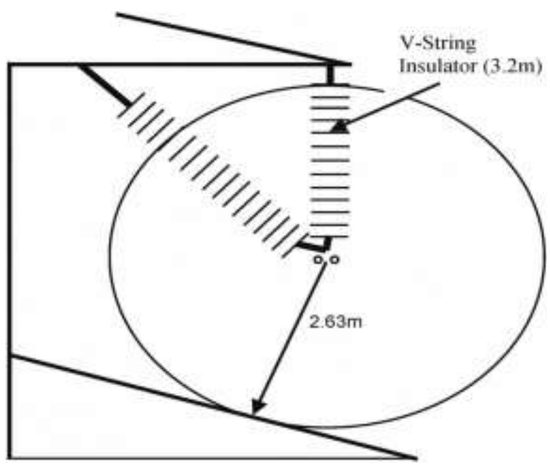

Figure 2.3: V-string style 2 insulator to restrict insulator swing [9].

2.2 Summary of previous work

Table 2.1: Summary of previous work

Author	Title	Method and Outcome comparison
I, Albizu, A.J. I. Zamora [3]	Methods for Increasing the Rating of Overhead Lines	- 132kV tower and 275kV tower - Increase of conductor templating temperature and low sag conductor (Reconductoring)
K. Kopsidas, owland et. al.	Power Transfer Capacity Improvement of Existing Overhead Line Systems	- Increase 275kV tower to 400kV - Cross-arm modification and Reconductoring with High Temperature Low Sags (HTLS), Aluminum Conductor Composite Reinforced (ACCR)
S. Venkatesan, lad et. al. [6]	Reducing Air Clearance Requirements for Voltage Uprating of Overhead Line by use of Line Surge Arresters	- Increase 275kV tower to 400kV - Voltage uprate by using surge arrester at line conductor to reduce air clearances, also control overvoltages.
R. Bhattarai, dad et. al. [7]	Voltage Uprating of Overhead Transmission Lines	- Increase 275kV tower to 400kV - Applying surge arrester along the line to control overvoltages
S. Narain, D. et. al. [8]	Uprating of 275kV lines to 400kV as Part of a Contingency Plan for Generation Integration	- Increase 275kV tower to 400kV - Changing type of insulator to 400kV and assembly I-string to V-string insulator.
S. Venkatesan, tarai et. al. [9]	A case study on Voltage Uprating of Overhead Lines-Air Clearance Requirements	- Clearance requirement on 275kV tower - Short the standard insulator and apply V- string style 2 to prevent swinging.

2.3 Transmission Overhead line

Transmission overhead lines mainly consist of three parts which is tower, conductor and insulator. Structure (tower) for overhead lines take a variety of shapes depending on the type of the line. Conductor is a material which contains movable electric charges in metallic conductors usually uses copper type. Insulators are non-conducting materials with fewer mobile charges, which resist the flow of electric current. Insulator is a material contains unmovable electric charge and it use for hold and support the conductors and maintain sufficient distance between conductor and tower structure [10, 11].

Since transmission lines power losses are proportional to the square of the load current ($P_{loss}=I^2R$), high voltages are used to minimize losses. Thus as high voltage at overhead line, the losses to transfer voltage can be minimizing. Overhead line power of transmission lines can be classified by range of voltages in Table 2.2 [10, 11].

Table 2.2: Overhead transmission lines classification [10, 11]

Voltage Classes	**Voltage range(kV)**	**User**
Low voltage (LV)	<1kV	Residential, small commercial areas
Medium voltage (MV)	1kV-33kV	Distribution in urban and rural areas, factories.
High voltage (HV)	33kV-230kV	Sub-transmission and transmission
Extra high voltage (EHV)	230kV-800kV	Long distance and very high power transfer
Ultra high voltage (UHV)	800kV-1600kV	

2.4 Types of Overvoltages

Overvoltage is the disturbances superimposed on rated voltage circuit [12]. There are two classes of overvoltage which is low frequency and transient. For the transient type, there are three overvoltage types such as lightning overvoltages, switching overvoltages and very fast front overvoltages, while the frequency class had only the temporary overvoltages. Overvoltage types are usually classified according to their waveform shape, term and damping or magnitude. Table 2.3 shows the characteristics of the various overvoltage types according to the IEC 60071-4 standard [13].

Table 2.3: Characteristics of the various overvoltage types

Overvoltages types	per unit (p.u) voltage	Term or Duration
Lightning overvoltages	>6	1-10μs (very short)
Switching overvoltages	>4	1ms (short)
Temporary overvoltages	2 to 4	≥1s (long)
Power frequency overvoltages	≤√3	>1s (very long)

2.4.1 Power Frequency Voltages

The frequency of the grid system that used in Malaysia nominally at 50Hz rated frequency but most systems are specified to work within some tolerance on small increases and decreases in the system. Table 2.4 gives the statutory of frequency values as defined by the National Grid [14].

System voltage is the rms, phase to phase power frequency voltage of an electric system. The system usually designed by a nominal system voltage to which certain operating characteristics of the system are related. Generally, most systems are specified for operating near the nominal system voltage. But some systems are required to operate near or at the maximum system voltage which is usually 5 to 10% higher or lower than the nominal. Highest system voltage is the highest rms phase to phase system voltage that occurs under normal operating conditions continuously. Table 2.5 gives the statutory of voltage value as defined by the National Grid code [4, 13-14].

Table 2.4: System frequency for all plant and equipment [4, 14].

Frequency range	Requirement
50 Hz	Rated frequency operation of plant
47 Hz to 47.5 Hz	Minimum frequency operation for a period at least 10seconds is required each time the frequency is below 47.5 Hz
50.5 Hz	Maximum frequency and continuously

Table 2.5: System voltages for all transmission lines [4, 14].

Rated voltage	420 kV	300kV	145kV
Nominal system voltage (phase to phase)	400kV	275kV	132kV
Maximum continuous system voltage	420kV	303kV	145kV
Minimum continuous system voltage	360kV	247kV	119kV

2.4.2 Temporary Overvoltage

Temporary overvoltages (TOV) are of oscillatory nature at a given location or defined as phase to phase or phase to ground oscillating overvoltages normally of relatively long duration and which are un-damped or weakly damped. Usually, TOV originate from switching operation, such as load rejection or resonant conditions and TOV usually not considered for determining electrical clearances for a line [15].

TOVs are classified as internal overvoltages, since they are principally determined by the system configuration and its parameters [4]. In general, the principal causes of temporary overvoltages can be classified into four groups [16]:

- Phase to earth faults-on normal system it may assumed that the temporary overvoltages will not exceed:

  1.4 pu for solidly earthed networks.

  1.7 pu for resistance earthed networks.

  2.0 pu for reactance earthed networks.

- Load rejection (supplying capacitive current through a large inductive reactance, e.g. a small generator connected to a long cable or overhead line).

- Ferro resonance (interchange of stored energy for series or parallel combinations of inductive and capacitive reactance).

- Ferranti effect (receiving end voltage greater than sending end voltage under no load or for lightly loaded lines).

Temporary overvoltages are normally eliminated by careful system design and correct neutral earthing. At distribution voltage levels (below than 145kV) the method of earthing will normally determine the level of temporary overvoltage rather than at transmission lines [16].

2.4.3 Switching Overvoltage

Switching overvoltage also defined as slow front overvoltages (SFOs) are classified as internal overvoltages and depend basically on system parameters, system configuration and system condition, e.g. load release, improper opening, closing circuit breaker, isolator etc. However, switching overvoltages may attain different value even for the same system and the same switching operation. The overvoltages of this type in an overhead line are mainly produced by energize or by reclosing operations of the line [15].

Switching overvoltages are of short duration, of irregular or impulse form and highly damped [16]. A typical switching overvoltages standard form wave shape is the 250/2500 μs, as it can be seen in Figure 2.4 [15]. From this figure the value of overvoltages depend on the relative timing of the switching event with respect to the power frequency system voltage sine wave. Generally, the closing time of the breaker is not synchronized with the power frequency voltage wave shape. It is random and each switching operation will result in a different overvoltage. Overvoltages due to switching phenomena become important at the higher transmission voltage levels (above 245kV) [16].

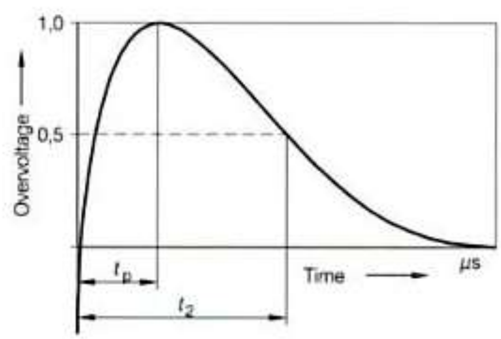

Figure 2.4: Standard slow front impulse voltage, t_p=250 μs: t_2=2500 μs [15].

2.4.4 Lightning Overvoltage

Lightning overvoltages which also defined as fast front overvoltages (FFOs) are mainly caused by a lightning strikes [4]. These overvoltages happen due to lightning are considered as an external overvoltages and dependent on the system voltages. Lightning overvoltages are important for insulation coordination design at system voltages below than 300kV [4]. Such overvoltages are usually unidirectional and of very short duration. The standard lightning impulse has a front time of 1.2 μs and a time to half value of 50 μs as it can see in Figure 2.5 [15]. Lightning overvoltages can be generated on transmission lines in three different ways that can be described below [4, 16]:

- Lightning directly strikes on an overhead line support tower. The potentials along the current path will rise to very high values due to even the smallest inductive and resistive impedance to true earth. If the effective impedance to true earth is high enough to break down the insulation then a flashover will take place either from the earth wire or tower to the phase conductors, usually across the insulator strings. This type of lightning fault is known as a 'back flashover'.

- Lighting directly strikes on shielding conductors (shielding failure). The short duration is usually insufficient to present temperature rise problems but sufficient strike magnitude may result in a flashover across an insulator. A voltage surge then travel along the line an impact on substation equipment. Figure 2.5 shows the real time examples of direct strike on conductors [17].

- Lightning strikes to nearby ground induce voltages in overhead lines but this significant only for the distribution lines. To prevent these phenomena, the function of the overhead earth wire shield or shielding towers can be applied to divert itself a lightning discharge which might otherwise strike the phase conductors or substation plant.

Impulse rise times are of the order of 10 microseconds for the common negative flow from cloud to ground (considerably longer for strikes from a positive part of the cloud to ground) together with a relatively slow decay time of approximately 100 microseconds or less. For design purpose, the most severe peak lightning current and rate rise of 200kA.per microsecond may be considered [16].

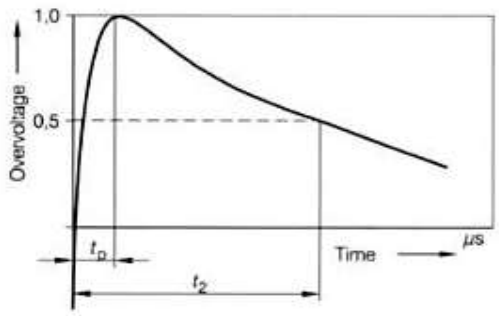

Figure 2.5: Standard fast front impulse voltage, t_p=1.2us:t_2=50us [15]

Figure 2.6: Direct strikes to the upper conductor (1988) [17].

2.4.5 Very Fast Front Overvoltage

Very fast front overvoltages (VFFO) can originate from fault within gas insulated substations (GISs) due to the switching operations of fast breakdown of the gas gap circuit breakers. The adjacent transition points in the same GIS is very short below than 0.1 µs and the duration of very fast front overvoltages would be less than 2-3 ms. Furthermore, they may occur several times during the switching operations of opening and closing of equipment. The maximum amplitude to 2.5p.u can be assumed to be achievable. Thus, VFFO are normally not considered in overhead line design [4, 16].

2.5 Ferranti Effect

The Ferranti effect are defined when medium or long transmission lines are operated at no load or light load, the receiving end voltages becomes more than the sending end voltages. The charging current produces a voltage drop in the series reactance of the line. This voltage drop is in phase opposition of receiving end voltage; hence the sending end voltage becomes smaller than receiving end voltage [18].

For long transmission lines, shunt reactors or shunt capacitive VAr are provided to absorb a part of the charging current under no load or light load conditions to prevent from overvoltages [18].

2.6 Clearances

The overhead line tower generally provide with some clearances requirements between the energized conductors with other objects or obstacles to avoiding flashover that caused by overvoltages that describes above. There are about three types of clearances that need to be considering which is phase to ground clearances, phase to phase clearances and conductor / insulators to towers clearances.

The phase to ground or phase to earth clearances is the external clearances needed since the consequence of flashover could loss of human life. This clearance requirement mostly determined as switching overvoltages [4, 19].

The phase to phase clearances is the internal clearances that need considered mostly than other part since this phase to phase must withstand a higher level voltages, since the vibration of the electric flow in the conductor need to be considered. This clearance requirement mostly determined as switching overvoltages [4, 19].

The conductor / insulator to tower clearances is the internal clearances and any horizontal movement toward to the tower basically the conductor through the conductor swing that produced by wind motion. This clearance requirement mostly determined as switching overvoltages [4].

In TOV condition that described above, the per unit level of 1.4 pu is the reasonable maximum limit for the temporary overvoltages when an earth fault of solidity network occurs. Therefore the temporary overvoltages limit to withstand overvoltages can be determined by the following formula Eq. (1) to express the maximum limit [4, 16, 19].

$$TOV = \frac{U_m}{\sqrt{3}} x\sqrt{2}\ x\ per\ unit(pu)\ x\ 1.4\ p.u$$

(1)

Where Um is the maximum voltage operation for each nominal system or rated voltage (Ur). Values of 300 kV and 480 kV were considered here when phase to earth fault for the 275kV and 400kV transmission lines respectively by using formula Eq. (1)..

M.N.R Baharom (2009) in [4] had improve the statement about this clearance requirements for those types that mentioned above and he defined the standard maximum values of switching overvoltages and lightning overvoltages for 275kV and 400kV which is according from IEC 60071-1 standard requirement. Table 2.6 shows the maximum allowable switching and lightning overvoltages in most cases of tower. However, 1.5 pu is needed for phase to phase fault which is higher than phase to earth fault condition standard [4, 19].

Table 2.6: Maximum allowable lightning and switching overvoltages from IEC 60071-
1 [4, 19].

System voltage, kV	275	400
Switching Overvoltage (Phase to Earth), kV	750 850	850 950 1050
Switching Overvoltage (Phase to Phase), kV	1125 1275	1275 1425 1575
Lightning Overvoltage, kV	850 950 1050	1050 1175 1300 1425

For transmission system voltages greater than 245kV, switching overvoltages are the deciding factor for specifying system air clearance requirements. However, the tower line insulation is subjected not only to switching surges, but also to lightning and power frequency voltages and need put into account. The requirement of these overvoltages clearance can be idealized as described in Figure 2.7 [9].

These clearance envelopes are affected by the nature of back-flashover and the effect of wind on insulator swing angles. However the electrical clearances for lightning not take account on wind swing angles since the probability swing angle during lightning stroke is very low rather than switching overvoltages and power frequency voltage [9].

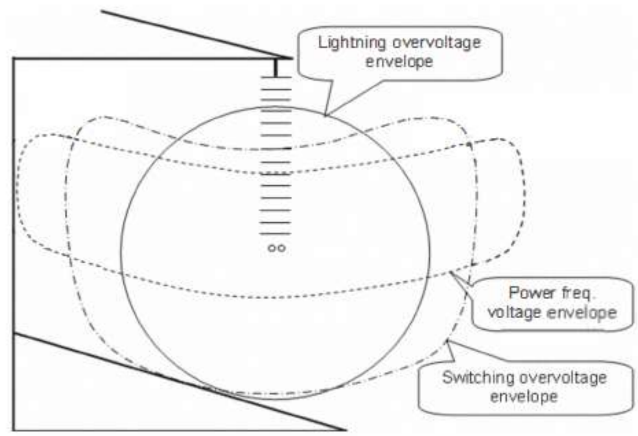

Figure 2.7: Clearances envelopes for various overvoltages [9].

2.6.1 Safety Distances Clearance

Safety distances clearance is defined as the minimum distance clearance between a person and a live conductor to avoid the risk of flashover. This safety distances is important for a person when working on a tower without endangering themselves. Table 2.7 shows the safety distances clearance with different system voltages [12].

Table 2.7: Safety distances requirement [12].

System Voltage (kV)	Safety Distance (m)
132	1.4
275	2.4
400	3.1

2.6.2 Clearances to Ground, Roads and Obstacles

In overhead line design, Table 2.8 shows the minimum clearances must not be infringed at the specified maximum conductor temperature with the line conductors and suspension insulators hanging vertically or deflected to any angle up to 45% from vertical [12].

Table 2.8: Statutory clearances to ground [12].

Description of Clearance	**Minimum Clearance (m)**		
	System Voltage (kV)		
	132	**275**	**400**
Line conductor at any point not over road	6.7	7.0	7.6
Line conductor, wire or cable to ordinary road surface	6.7	7.4	8.1
Line conductor, wire or cable to road surface designated 'high load' route	7.5	8.5	9.2
Line conductor to motorway road surface where 'Skycradle' is used	.8.8	9.8	10.5
Line conductor to motorway road surface where scaffolding is used: (i) Normal motorway (ii) Elevated motorway	14.6 11.6	15.6 12.6	16.3 13.3

2.7 Insulator

Insulator is used to give electrical isolation between the conductor and tower to provide mechanical support to the conductor. Normally, insulator is made to have enough strength to support the weight of conductor bundles and other additional loads from pollution such as snow, smoke from industrial, dust, wind load and other aspect. Moreover, this insulator must have a long life in order to stand for long years under any pollution or weather impact.

Commonly, insulator are classified either pin type or suspension type but normally suspension type is used at higher overhead transmission lines. Insulators are made from either ceramic or glass materials with using the cap and pin type or tongue and clevis type insulator strings. Typically 400kV system voltage tend to use the polymeric insulator and both ends of the insulator are fitted with a grading ring for corona discharge control, also protect its surface from stress due to transient overvoltages [4].

2.7.1 Creepages and Insulator String Length

The overall length of the insulator string shall be measured from the bottom of the ball of the last insulator to the bottom of an imaginary ball fitted into the socket of the first insulator. In the case of a composite unit the length is measured from the bottom of the ball fitted into the socket end fitting. The statutory creepage and insulator length of the insulator string specified for tower overhead line 400kV tower used by the National Grid is shows at Table 2.9 [20].

Table 2.9: Overhead line 400kV insulator length requirement tower [20].

Insulator Type	Minimum Creepage Distance (m)	Minimum Insulator Length (m)
Tension	7.2	3.4
Suspension	10 or 12.5 (polluted area)	3.4

2.8 Conductor

Conductor is a material to carry the electric charges [22]. There are many type of conductor such as gold, copper, aluminum etc., but in transmitting power for overhead line, aluminum is a good selection since aluminum are good conductor, low cost and light compare to other types. Therefore the usage of aluminum would enhance the performance of transmission system. There are four type of conductor:

- ACSR- Aluminum Conductor Steel Reinforced.
- ACAR- Aluminum Conductor Alloy Reinforced.
- AAAC- All Aluminum Alloy Conductor.
- AACSR- Aluminum Alloy Conductor Steel Reinforced.

All Alloy Aluminum Conductor have been used all over the networks in early 1990’s by National Grid Company (NGC) program since AAAC type has higher thermal rating up to 75 °C, lower resistance, lighter and less sag ambient temperature rather than ACSR type. Table 2.10 shows the standard conductor used by NGC for 275kV L3 and 400kV L2U transmission line [23].

Table 2.10: Preferred conductor bundles for NGC's overhead line tower [23].

Tower Design	**Bundle Designation**	**Conductor System**	**Nominal Rated Temperature (°C)**
275 kV	L3	1 x 700mm² AAAC 'Araucaria'	50
		2 x 300mm² AAAC 'Upas'	50
400 kV	L2U	2 x 500mm² AAAC 'Rubus'	75
		2 x 570mm² AAAC 'Sorbus'	75

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