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

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DEDICATION

This project is dedicated to my father,
Mat Yamin Bin Long,
who sparked a young boy's interest in engineering.

To my mother,
Shamshiah Binti Abdullah,
who made it all possible.

To all of my family members especially my brothers and sisters,
and not to forget my housemate, also all my friends
who had give a lot of support.

Lastly for those scientist and researcher,
Who love to learn science and technology from the Islamic perspective,
Insya-ALLAH!

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In the name of Allah, the Most Beneficent, the Most Merciful.

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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.

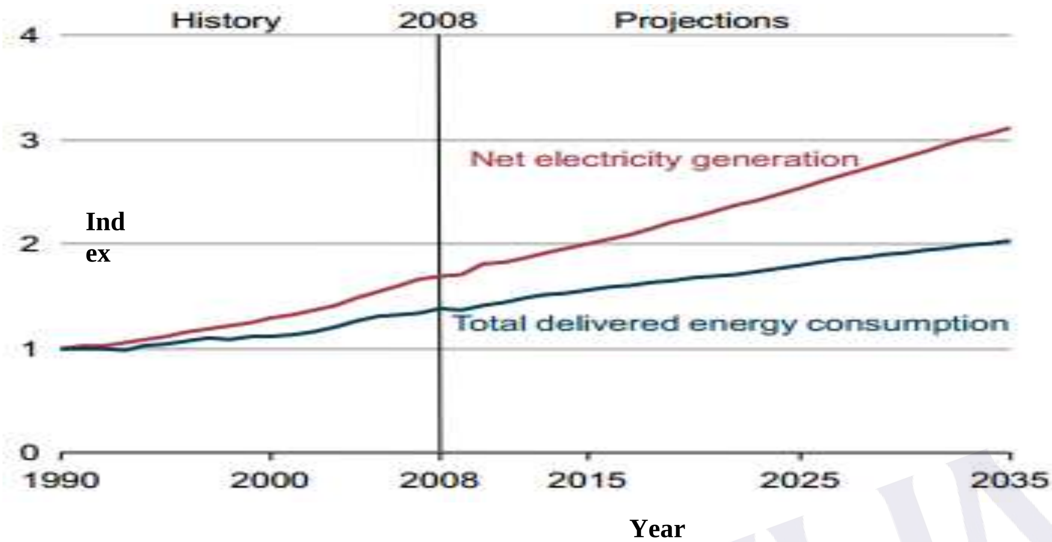

Figure 1.1: Growth in world electricity generation and total delivered energy consumption from year 1990 to 2035 [1]

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.

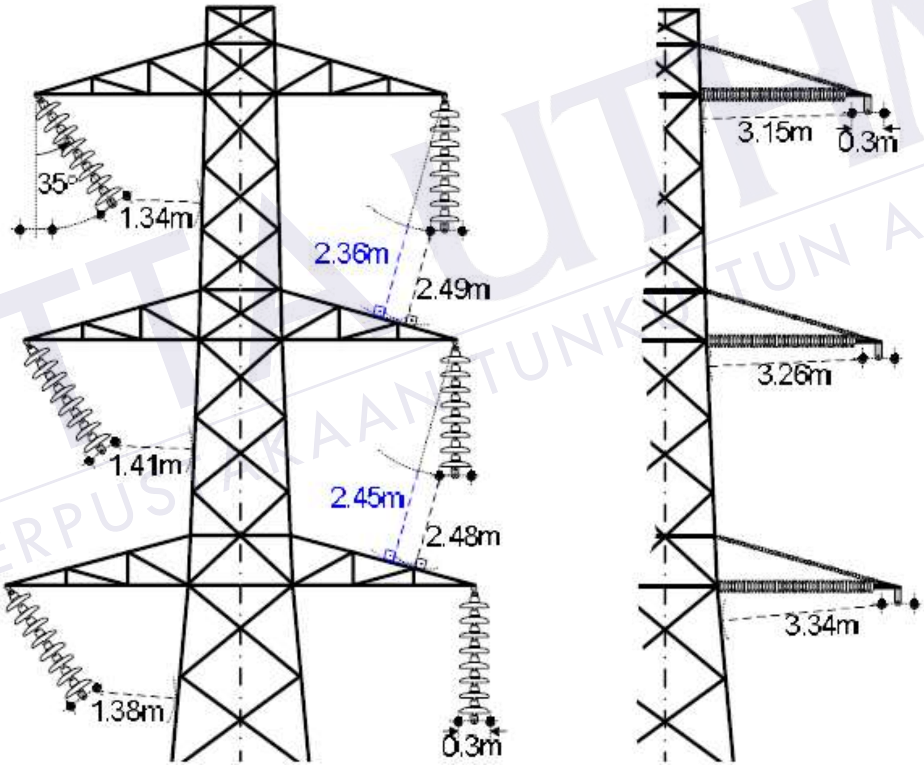

Figure 2.1: Clearance observed on an L3 tower with normal suspension set (left) and the modified with composite cross-arm (right) [5].

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.

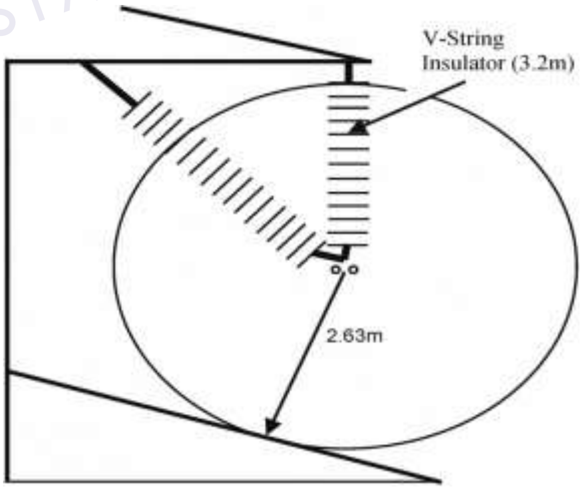

Figure 2.3: V-string style 2 insulator to restrict insulator swing [9].

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	

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