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Issues and Challenges in Voltage Uprating for Sustainable Power Operation: A Case Study of a 132 kV Transmission Line System in Malaysia

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Abstract: Ageing grid infrastructure is a critical issue that is currently faced by electrical utilities worldwide, resulting in crucial decisions that must be made for the replacement, repair, or refurbishment of assets under constrained budgetary conditions, as well as other factors. As one of the fastest-developing countries globally, Malaysia is steadily growing in terms of its cumulative population, large industries, and advanced transportation sector, leading to an increasing electricity demand and, consequently, putting stress on electric utility providers to meet these tremendous demands. Significant concerns in the new development of transmission in Malaysia are the environmental issues, which involve exploration in gazetted areas and forest reserves. This paper describes the issues and challenges in developing a new transmission line system in Malaysia. In recent years, uprating existing transmission line systems has been one of the best asset management decisions for electric utility operators in order to meet such a demand for capacity. This paper assesses the technical issues and conventional methods of uprating the voltage of an existing transmission line system. The initial study found that the phase-to-Earth clearance does not fulfil the electrical clearance envelope. The study on the existing 132 kV transmission line system further analysed these issues and proposed an appropriate technique for uprating to a 275 kV transmission line system. Finally, the results indicate that the voltage uprating of the 132 kV transmission line system to 275 kV is able to satisfy the electrical clearance requirement envelope.

Keywords: transmission line system; power transfer capability; voltage uprating; upgrading; asset management decision; electrical clearance

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1. Introduction

A power system is a network that involves generation, transmission, and distribution systems. A transmission line system is an essential means of bringing energy from various generation sources in different locations into the distribution system. In peninsular Malaysia, the transmission line system is made up of three typical transmission levels: 500, 275, and 132 kV.

In recent years, the growth of technologyies and cumulative populations and the increase in the quality of life experienced by industrialised and developed countries in the world have led to an increasing demand for electricity [1–7]. As of 2018, the Malaysian National Grid consisted of a domestic transmission line system of approximately 23,082 km and 443 domestic transmission line system substations. According to the TNB's annual reports, the growth of Malaysia's National Grid's maximum demand for the year 2009 was by 14,245 MW, which slightly increased to 18,338 MW for the year 2018, as shown in

Table 1. It clearly shows that the percentage increment in the maximum demand over ten years was 22.32%.

Table 1. Maximum demand in the Malaysian National Grid.

Year	Maximum Demand (MW)
2018	18,338
2017	17,790
2016	17,788
2015	16,822
2014	16,901
2013	16,562
2012	15,826
2011	15,476
2010	15,072
2009	14,245

Electric utility providers have already planned, built, and commissioned various sources of generation to meet the ever-increasing demand for electricity. As a consequence of the increase in the generation capacity, the tremendous power transfer capabilities of the existing transmission line system are commonly limited by the thermal, voltage, and systemic capabilities. Increases in the generation of electricity lead to the existing transmission line system being gradually congested. Primarily, it was reported that most of the electrical infrastructures were constructed in the 1950s and 1960s, which means that they have already been in service for about 60 years [8–11]. There are issues associated with this, as most of the old instruments have already exceeded their life cycles or are nearing the end of their lives [5,7,12–14]. Hence, current transmission line systems are loaded with a sizeable number of ageing assets.

Therefore, among the possible mechanisms for accommodating the electricity demand are either constructing a new transmission line system or increasing the utilisation of the existing transmission line system. However, there are issues associated with the development of new transmission line systems. The challenges faced in developing a new transmission line system are complexities in obtaining new rights of way (ROWs) for constructing it and the high cost of development; these have caused tremendous stress for providers of utilities in an effort to establish alternative strategies that are intended to extend the current infrastructures [15–17].

Thus, the increased utilisation of existing transmission line systems has become of interest for electric utility providers throughout the world in order to cater to the increasing electricity demand. According to [18], there are several options available for the management of assets in deciding on increasing the utilisation of existing transmission line systems; these include uprating, upgrading, refurbishing, and life extension or expansion. Uprating is the best option for utilising an existing transmission line system [19]. It is defined as the process of increasing the power transmission capacity of a transmission line system. Many studies have been conducted on the increase in power transmission capabilities by using the method of uprating existing lines, which is associated with the implementation of thermal and voltage uprating mechanisms [20,21]. Previous work revealed that thermal and voltage uprating methods associated with different techniques and processes have been employed all over the world to meet the ever-increasing electricity demand [22–26]. For this reason, the present research was carried out in order to gain a better picture and understanding of the uprating and upgrading of an existing 132 kV transmission line system, with a focus on the situation in Malaysia.

The main contribution of this study is in addressing the issues and challenges faced by electrical utilities providers in developing a new transmission line system in Malaysia. In addition, this study has proposed a mechanism to upgradethe existing 132 kV transmission line system in Malaysia in order to cater to thetremendous demand for power transfer. In this work, the voltage uprating method associated with techniques and processes is applied, where the proposed model is then evaluated by fulfilling the required electrical clearances for the 275 kV transmission line under still air and windy conditions.

2. Voltage Uprating Issues and Challenges in Malaysia

In recent years, Malaysia's population has been steadily growing, reaching 32.37 million people in the year 2020. The growth of large industries and the high-tech transport sector have been steadily contributing to the increasing demand for electricity. Thus, this leads to pressure on electric utility providers in Malaysia to provide sufficient electricity year on year.

Therefore, developing a new transmission line system (i.e., 500 kV and 275 kV) is one of the options for Malaysia's electric utility provider in continuing to meet and stabilise the country's rapid demand. However, the development of a new transmission line system should take into consideration many aspects, particularly technical, environmental, and financial feasibility aspects [1,8,27–31]. In Malaysia, environmental aspects are major issues concerning any new development of a transmission line system (i.e., 500 kV and 275 kV) as such developments mainly involve exploration into gazetted areas and forest reserves. Some of the concerns that can be critically relevant in the planning process are the visual impact of the transmission line system, property devaluation, suspected health effects from the electromagnetic field (EMF), impact on land use, impact on ecological systems, and environmental impact during transmission line construction and maintenance [4,32–34].

Hence, the increased utilisation of existing transmission line systems has been identified as a possible alternative to accommodate the extraordinary demand for electricity. Several studies have been carried out on different methods of uprating, including increased conductor rating, increased conductor temperature, increased thermal rating by active line rating system, probabilistic rating, high surge impedance, and increased electrical clearances [35–44]. The studies cover different techniques such as conductor replacement, conductor tension, line thermal, conductors bundling, and increased conductor attachment height [18,45–51]. A number of studies have been carried out on power transfer capability through voltage uprating, which has reduced line losses and voltage drops compared to current uprating [2,32]. Several studies have been carried out on voltage uprating with a different combination of crossarm length and insulator string length where the performance of the voltage uprating transmission line system was evaluated based on trip-out rates under transient overvoltages [52–55]. However, electric utility providers all around the world utilise different mechanisms based on their capabilities to resolve technical, environmental, and financial issues.

There are several aspects of voltage uprating that can be assessed prior to practical considerations, including its phase-to-earth clearances, insulation coordination statutory clearances (i.e., phase-to-ground), and insulation at the tower (i.e., suspension string insulator length and its creepage distance). In Malaysia, the potential line for voltage uprating is the 132 kV transmission line system. Before this transmission line system voltage uprating can be further applied, several feasibility issues need to be considered:

1. Considerations on the importance of electrical clearances for insulation safety design; it is essential to examine the requirement of electrical clearances of the voltage uprating transmission line system.
2. Considering that increasing the level of voltage would affect electrical parameters (i.e., electric field, magnetic field, audible noise, and radio interference), the acceptance minimum available clearances must be adequate for practical considerations.
3. Since the suspension string insulator is one of the crucial components, it is important to examine appropriate insulator length and its creepage distance for satisfying 275 kV transmission line requirements including insulation coordination requirements for power frequency magnitude and transient overvoltages.
4. On the other hand, electrical clearances (i.e., phase-to-phase, phase-to-earth, and phase-to-ground) under wind conditions are among the crucial parameters for trans-

mission system uprating. It is also essential to ensure that the requirements of electrical clearances under wind conditions are fulfilled.

3. Asset Management Decision and Its Definition

The importance of transmission line systems for both current and future transmission line systems has been established. Therefore, there have been rigorous works and research projects dedicated to increasing the transmission line system components. In this regard, four major asset management decisions, as illustrated in Figure 1, are normally taken into consideration. However, the main concerns to be assessed for increasing the utilisation of existing transmission lines systems are economic and technical factors. According to CIGRE Technical Brochure 353, the guidelines to increase the utilisation of existing transmission lines will be influenced by the asset life expectancy, the load growth forecast, the planning horizon, the value of capital, cost–benefit analysis, economic optimisation, and other project constraints. As summarised in Table 2, Malaysia's national grid maximum demand showed an increment trend annually, and thus, it leads to an increase in load growth in the future.

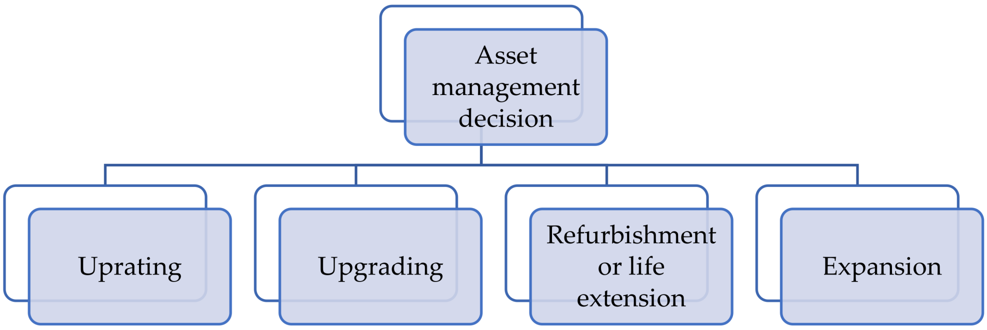


Figure 1. Asset management decision.

Uprating is defined as increasing the electrical characteristics of a transmission line system in, for example, a requirement for higher electrical capacity or larger electrical clearances [52]. Meanwhile, upgrading is defined as increasing the original mechanical and or electrical strengths for increased applied loads in increment weather and extremities such as wind, ice, and any load case combination, or improving electrical performance in conditions such as pollution or lightning performance. On the other hand, refurbishment is defined as the extensive renovation or repair of an item to restore the intended design's working life. Life extension is an option of refurbishment, which does not result in the complete restoration of the originally designed working life [56]. Finally, expansion is defined as increasing the functionality of transmission lines.

There are several uprating methods implemented throughout the world by either increasing the current carrying of its conductor or by increasing its operating voltage level, namely thermal uprating and voltage uprating [57,58]. According to [18], it was revealed that thermal uprating techniques including installing higher capacity of conductors, additional conductors, and redesign led to high surge impedance; meanwhile voltage uprating techniques, for instance by increasing electrical strength and conductor attachment, involved an increase in the power transfer capability. In this study, voltage uprating is chosen, due to it being one of the most effective solutions and strategic approaches to asset management decisions. Previous work in [2] revealed that voltage uprating delivered significantly higher power transfer capability, which occured due to it occuring less electrical losses rather than thermal uprating. In addition, it could be completed at a substantially lower cost than the new development of transmission lines, and it is considered to have a shorter lead time [2,15].There are numerous voltage uprating methods associated with techniques and processes that have been implemented all over the world. Generally, increasing voltage level will ultimately increase the transmission line capacity, potentially also increasing the consequences of a failure [18]. However, the typical limiting and practical considerations of the voltage uprating method might be best considered on a case-by-case basis and will depend upon the location, environment, characteristics, and performances of the existing transmission line.

4. Mechanism for Voltage Uprating

The variety and number of methods and techniques adopted and implemented throughout the world to uprate transmission line systems are directly influenced by the considerable variation of transmission line system designs and construction methods employed [59,60]. Nevertheless, the uprating of the transmission line system generally fell into either increasing voltage capacity or thermal capacity. Table 2 provides a list of the most common voltage uprating mechanisms, the associated methods, techniques, and processes, respectively. According to [18,61], there are two common techniques commonly used by electric utility operators to increase the voltage rating, either by increasing insulation strength or improving conductor air clearance.

Table 2. Transmission line uprating mechanism [18,61].

Mechanism	Method	Technique	Process
Increased voltage rating	Increased electrical clearance	Increasing insulation electrical strength	• Adding/substituting insulator • Crossarms modification
		Improving conductor air clearance	• Structure body extension • Interspaced structures • Conversion of two to one circuit

The decision to increase the existing transmission line system will affect components and electrical parameters, as summarised in Table 3. Techniques that comprise electrical insulation strength could affect electrical parameters such as lightning performance, EMF, radio, and audio interference [62].

Table 3. Affected components and parameters [18].

Component and Parameters		Insulation Electrical Strength	Conductor Air Clearance
Component	Structure	O	X
	Foundations	O	X
	Conductors	O	O
	Insulators	X	O
	Fittings	X	O
Electrical parameter	Earthing	-	-
	Earth wire	-	-
	Earth potential rise	-	-
	Lightning performance	X	O
	Induction	-	-
	Electromagnetic field	X	X
	Radio interference	X	X
	Audio interference	X	X
	Pollution performance	O	O

X = Affected, O = Not affected, - = Not changed.

The selection of the appropriate method in uprating varies from case to case and is subject to the existing line's location, characteristics, and performance [2]. Utility operators around the world have chosen different techniques to increase the voltage capability of their transmission line systems. There are several studies associated with power transfer capability by implementing voltage uprating as the mechanism, summarised in Table 4. As a result, the implemented techniques accomplished voltage uprating either by increasing conductor air clearance or by improving the electrical insulation strength of the existing transmission line system.

Table 4. Voltage uprating studies in various countries.

Reference	Country	The Original Level of Voltage (kV)	The New Level of Voltage (kV)	Technique
[63]	Norway	300	420	• Reinsulation (different types of insulator)
[2]	UK	275	400	• Adjusting insulator length
[64]	Japan	66	154	• Insulator supported jumper devices and compact phase-to-phase spacers
[53]	USA	41.6	115	• Reinsulation, pole-top bracket, midspan spacers, and reconductor
[65]	South Africa	275	400	• Reinsulation (phase assembly insulator)
[66]	Norway	300	420	• Rearrangement of insulator string and additional insulator discs

5. Electrical Clearances Requirement

The nature of the voltage stresses that a transmission line system had experienced power frequency, lightning, and switching overvoltages [67–74]. Both transient and power frequency voltage stresses appear in all shapes and with different amplitudes. Each type of transient and power frequency overvoltage may occur during most types of meteorological conditions, leading to differences in the flashover strength [75].

Those overvoltages must be considered separately in identifying any possibility to assess the feasability of voltage uprating, which is necessary verification of the availability of electrical clearance. Therefore, the fundamental breakdown voltage characteristics were derived in order to evaluate the electrical clearance requirement for particular voltage levels that determine the required clearance envelope for power frequency, lightning, and switching overvoltages. According to [75], the voltage which the transmission line system can withstand are strongly influenced by the weather. In the case of lightning activities, its clearance envelopes are affected by the nature of the back flashover. There is a low possibility for the insulator swing angles to be prominent during the lightning activities. Thus, the electrical clearances for lightning activities could be neglected in favour of wind swing angles. Hence, the clearance envelope for lightning overvoltage is circular, as shown in Figure 2 [57,76]. However, the geometry of electrical clearance envelopes is influenced by the insulator swing angle due to wind conditions, in the case of both power frequency and switching activities [57].

According to [75], a switching surge is an overvoltage occurring on the power system as the result of a perturbation caused by switching activities. Therefore, a switching surge voltage could travel a long distance along with the transmission line system, leading to slight attenuation. Thus, it contributes multiple stressors at the towers on the transmission line system [57,76]. There is a possibility that wind conditions and the resultant deviation swing angle and affect flashover can be significant. Hence, it could influence the electrical clearance envelope. This leads to a switching overvoltage envelope of elliptical shape, as shown in Figure 2.

Power frequency voltage controls the design of insulation strings in contaminated conditions. It is essential to examine the decrements of insulation strength that may occur due to extreme swing angles and accumulation of contamination conditions. Additionally, the magnitude of power frequency voltage is much lower as compared with transient overvoltages. However, the electrical clearance between the phase and the tower structure once the phase and insulator string swing in conditions of extreme winds toward the tower structure or other phases may cause flashover due to reduction of clearance envelope [77].

Therefore, the power frequency voltage clearance envelope is highly elongated to account for extreme wind swing angles, as shown in Figure 2.

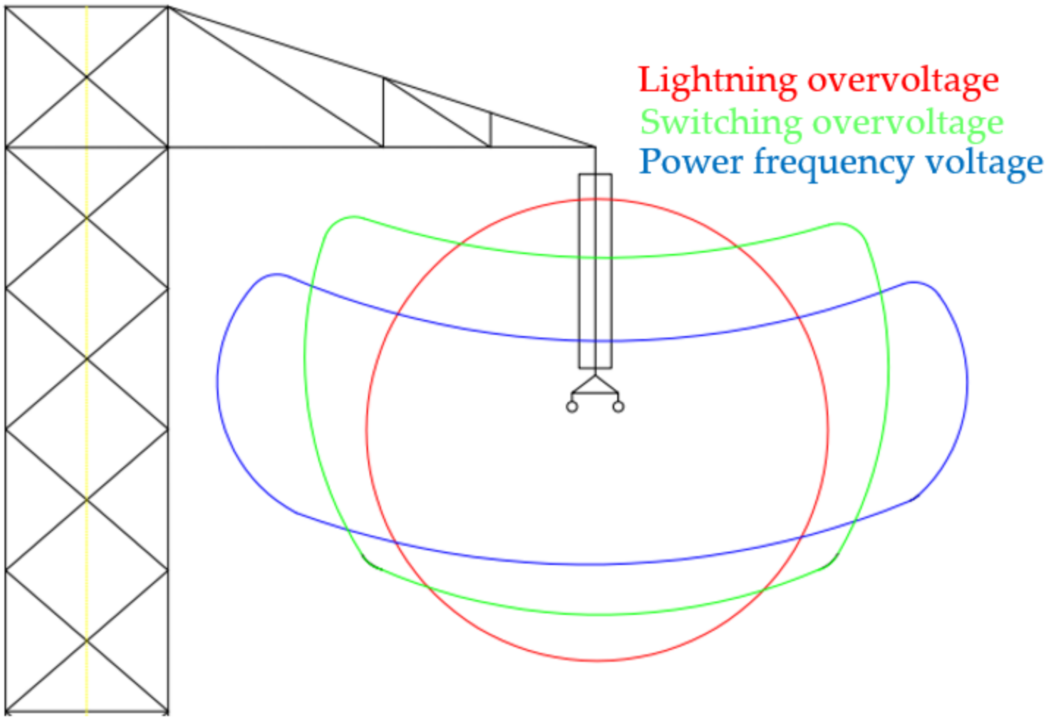


Figure 2. Clearance envelopes for various overvoltages [76].

Figure 3 shows that the measurement is taken for phase-to-phase, phase-to-earth, and phase-to-ground. For clearance measurement, the phase-to-phase defines the distance between the phase conductor and another phase conductor, while phase-to-earth defines the distance between phase conductor and the body of a structure or steel crossarm, and phase-to-ground defines the distance between the lowest phase conductor and the structure base. The minimum air clearances required for each voltage level are given in IEC60071. In this study, the minimum electrical clearances during still air and wind conditions for the 275 kV transmission line system can be seen in Tables 5 and 6.

Table 5. Requirement of electrical clearance under still air condition [2,78–80].

Clearance Type	Power Frequency (300 kV)	Switching Impulse (850 kV)	Lightning Impulse (1050 kV)
Phase-to-earth (m)	0.51	1.80	1.90
Phase-to-phase (m)	0.83	2.60	2.10
Phase-to-ground (m)		7.00	

Table 6. Requirement of electrical clearance under (**a**) normal and (**b**) extreme wind condition [76,79–81].

(a)

Condition	Clearance Type	Power Frequency (300 kV)	Switching Impulse (850 kV)	Lightning Impulse (1050 kV)
Normal wind	Phase-to-earth (m)	0.51	1.80	1.90
	Phase-to-phase (m)	0.83	2.60	2.10
	Phase-to-ground (m)		7.00	

Table 6. *Cont.*

(b)		
Condition	**Clearance Type**	**Power Frequency (300 kV)**
Extreme wind	Phase-to-earth (m)	0.51
	Phase-to-phase (m)	0.83
	Phase-to-ground (m)	7.00

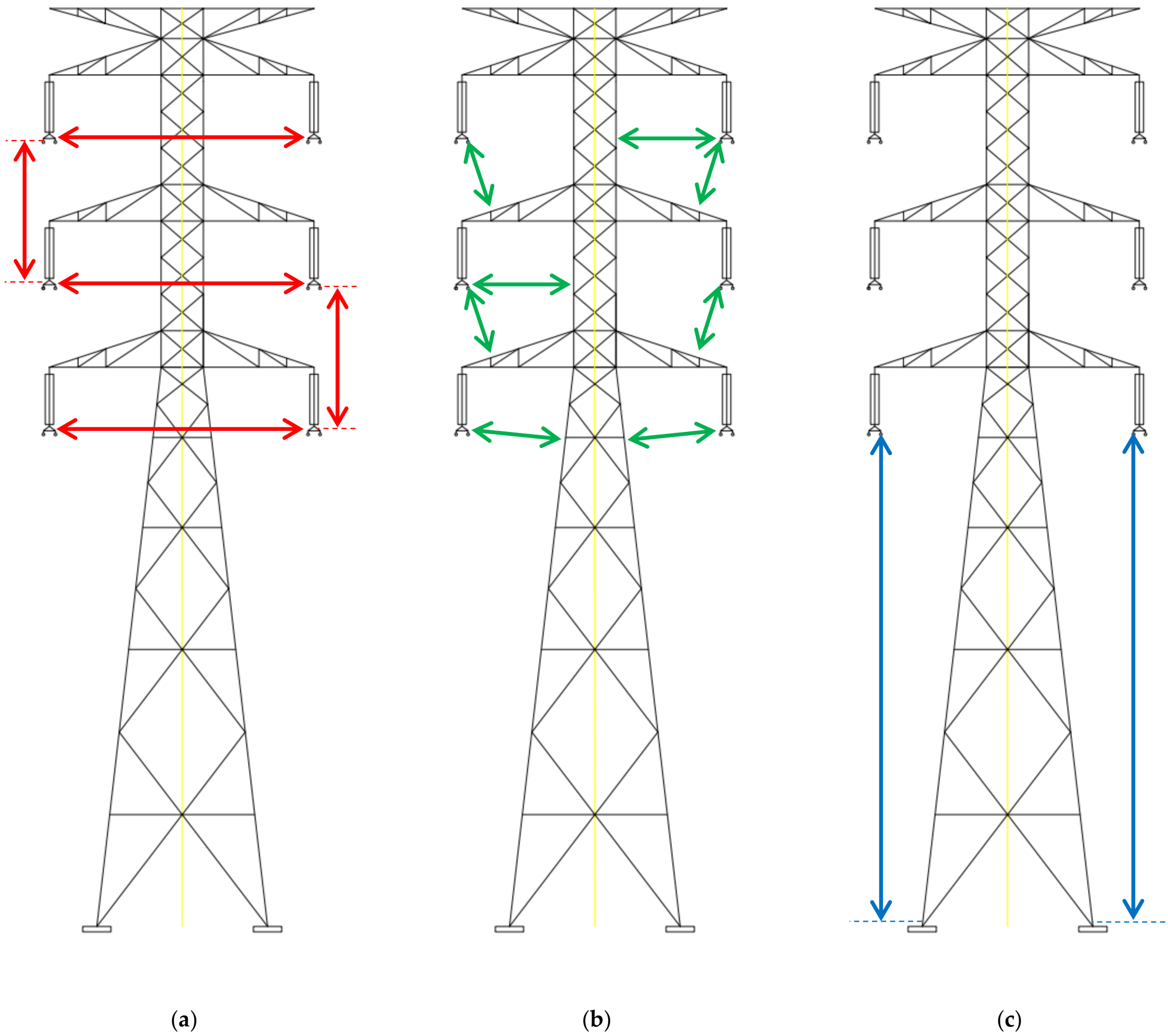


Figure 3. Clearance measurement for (**a**) phase-to-phase, (**b**) phase-to-earth, and (**c**) phase-to-ground.

6. Methodology of Voltage Uprating

Figure 4 depicts the overall workflow in this voltage uprating for the transmission line system in Malaysia. The transmission line system chosen for this study involved was a 132 kV transmission line system. In order to achieve voltage uprating, associated techniques and processes against electrical clearance requirements were used in this study. The proposed techniques of voltage uprating for existing transmission were divided into two parts. The first proposed technique functioned by increasing insulator strength, while the second proposed technique worked by improving conductor air clearance. All proposed techniques and processes were measured to fulfil electrical clearances requirements under still air and windy conditions.

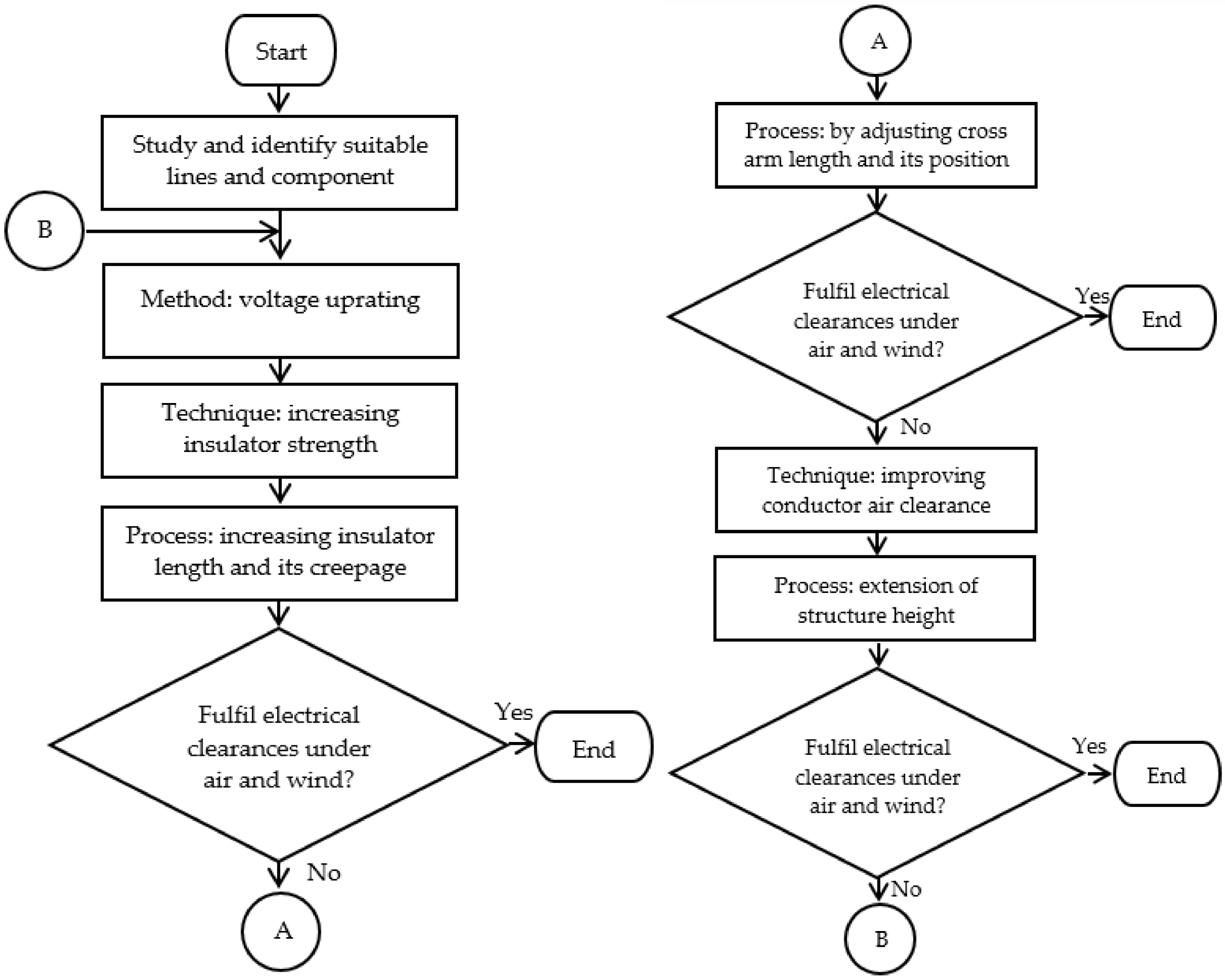


Figure 4. Workflow of voltage uprating and upgrading for existing 132 kV transmission line system in Malaysia.

7. Descriptions of the 132 kV Transmission Line System in Malaysia

A 132 kV transmission line system (denoted as Line A-B) in Malaysia was chosen as the case study in this work. This line has experienced high ground flash density and recorded the most power supply trippings in peninsular Malaysia. The details of the transmission line under the case study are shown in Table 7.

Table 7. Details of 132 kV transmission line under case study [82].

Description	Detail
Type of line	Double circuit line
Starting substation	A
Ending substation	B
Number of tower	295
Line length	112.81 km
Phase arrangement	Circuit 1 (Blue—Red –Yellow) Circuit 2 (Yellow—Blue—Red)
Conductor type	1 × 300 mm^2 Batang
Insulator	14 discs × 146 mm
Line sag (max)	8.89 m
Average ground flash density	4 flashes/km^2/year
Number of tripping (Jan ’04–July ’07)	13
Backflashover rate	4.19 flashes/100 km/year
Tower footing resistance	2—558 Ω

The transmission line system under the case study is a 112.81 km medium line with a double circuit 132 kV transmission line system. Figure 5a shows a typical 132 kV transmission tower construction model in Malaysia, known as type 23L steel lattice. The height of this lattice tower is 28.22 m, and the transmission line system is assumed to be located on flat terrain with a typical span length of 300 m. The line is strung with twin 300 mm^2 Aluminium Conductor Steel Reinforced (ACSR) code-named 'Batang', its outside diameter is 24.16 mm, and bundled conductors are separated at 400 mm each. Meanwhile, the earth wire is a single 160 mm^2 Optical Ground Wire (OPGW) for each circuit, and its outside diameter is 12.20 mm.

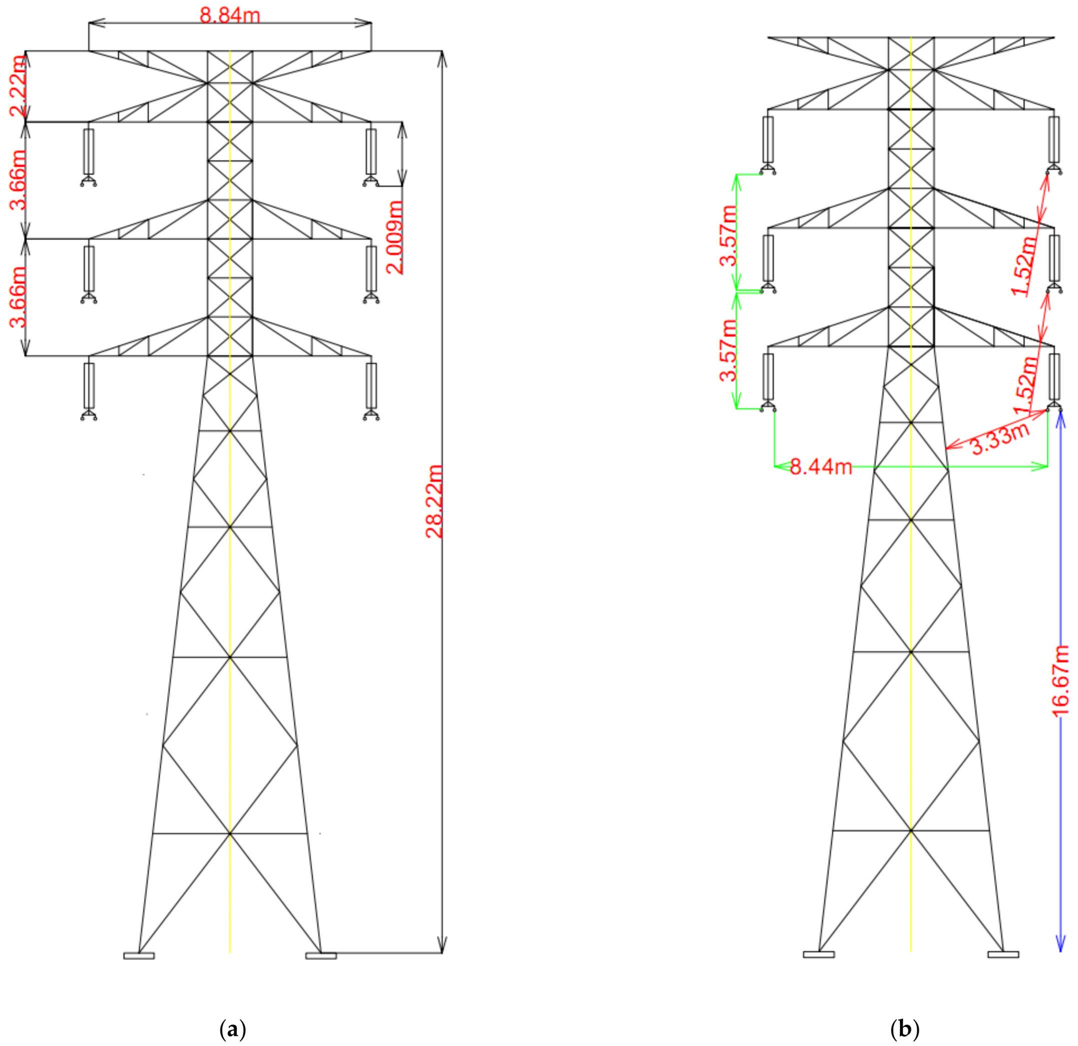


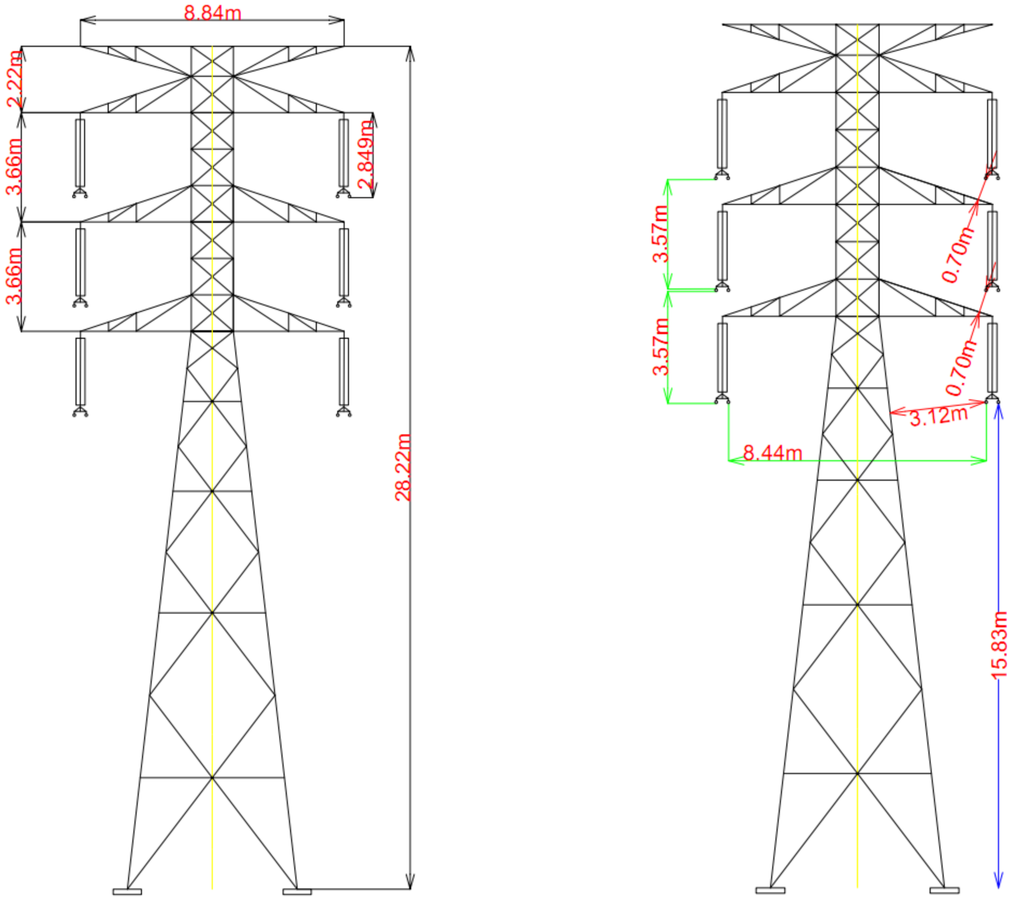
Figure 5. (**a**) The typical 132 kV tower geometry in Malaysia and (**b**) available electrical clearances under still air.

Typical suspension insulator string has ten toughened glass insulator discs and an overall string length of 2009 mm including fittings at the top and bottom of the string. The minimum electrical clearances for phase-to-phase, phase-to-earth, and phase-to-ground are 3.57 m, 1.52 m, and 16.67 m, respectively. Figure 5b shows the details of electrical clearance under evaluation for a typical 132 kV transmission line system.

8. Voltage Uprating of the Existing 132 kV Transmission Line and Its Processes

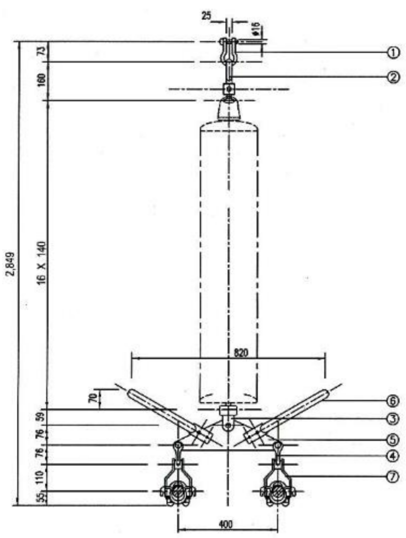
8.1. Analysis Process—Preliminary

Figure 6 shows the 132 kV steel lattice tower with 275 kV suspension string of toughened glass discs insulator type. In Malaysia, the typical 275 kV suspension insulator string has 16 toughened glass discs and 2849 mm overall string length, including fittings at the top and bottom of the string. Figure 7 shows details of 275 kV suspension insulator string construction.



(**a**) (**b**)

Figure 6. The 132 kV steel lattice tower (**a**) with 275 kV glass discs insulator and (**b**) electrical clearances under still air.



No	Legend
1	Bow shackle
2	Twisted ball eye link
3	Socket clevis
4	Twisted clevis eye
5	Yoke plate
6	Arching horn
7	Pivot suspension clamp

Figure 7. Malaysia's typical suspension string of toughened glass discs insulator type for 275 kV transmission line system.

The available phase-to-phase and phase-to-ground clearances in the existing 132 kV transmission line system in still air condition show that there are adequate electrical clearances between the phase-to-phase and phase-to-ground to uprate to a 275 kV transmission line system, as shown in Table 8. However, the phase-to-earth clearance does not satisfy the electrical clearance requirement in still air.

Table 8. Minimum electrical clearance of 132 kV steel lattice tower with 275 kV glass discs insulator.

Clearance Type	Minimum Clearance (m)	Result
Phase-to-earth	0.70	Not fulfilled
Phase-to-phase	3.57	Fulfilled
Phase-to-ground	15.83	Fulfilled

8.2. Analysis Process—By Adjusting Insulator Length and Its Creepage

To fulfil the requirement of electrical clearance, 132 kV transmission towers were modified by adjusting insulator lengths and creepage distance. As summarised in Table 9, the existing suspension string insulator length is 2240 mm, while the proposed suspension string insulator length is 1640 mm; however, its creepage distance is slightly more significant than the existing suspension string insulator. Besides these, the existing and proposed suspension string insulators had similar mechanical and electrical characteristics. Meanwhile, the proposed suspension insulator string has 12 toughened glass insulator discs and a 2289 mm overall string length, including fittings at the top and bottom of the string.

Table 9. Proposed suspension string insulator.

		Existing	Proposed
Type		Standard profile glass	Fog type profile glass
Disc material		Glass	Glass
Mechanical characteristics			
Minimum mechanical failing load	kN	80	80
Dimension			
Diameter	mm	255	280
Spacing	mm	140	140
Minimum creepage distance	mm	320	445
Electrical characteristics			
Power frequency withstand voltage			
Dry one minute	kV	70	80
Wet one minute	kV	40	50
Dry lightning impulse	kV	100	125
Puncture withstand	kV	130	130
Approximate net weight	kg	4.0	5.8
Number of discs		16	12
Minimum total creepage	mm	5120	5340
The total length of discs (without fittings)	mm	2240	1680
Total weight	kg	64.0	69.6

Figure 8 shows the available minimum phase-to-earth clearances of 1.24 m which are significantly not meeting the required phase-to-earth clearance of 1.80 m and 1.90 m in switching and lightning overvoltages for voltage uprating the 275 kV transmission line system. Table 10 shows the minimum electrical clearances for the proposed model under still air condition.

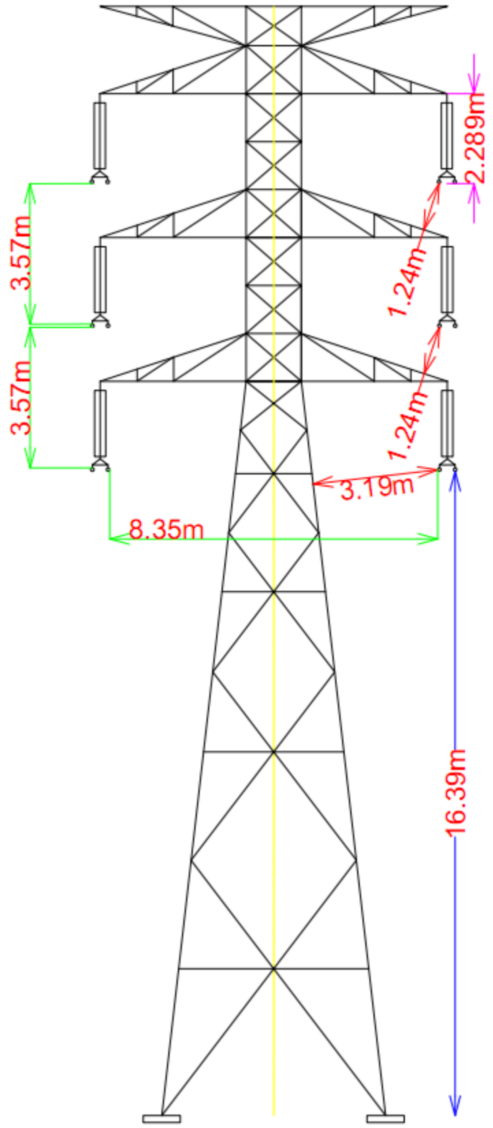


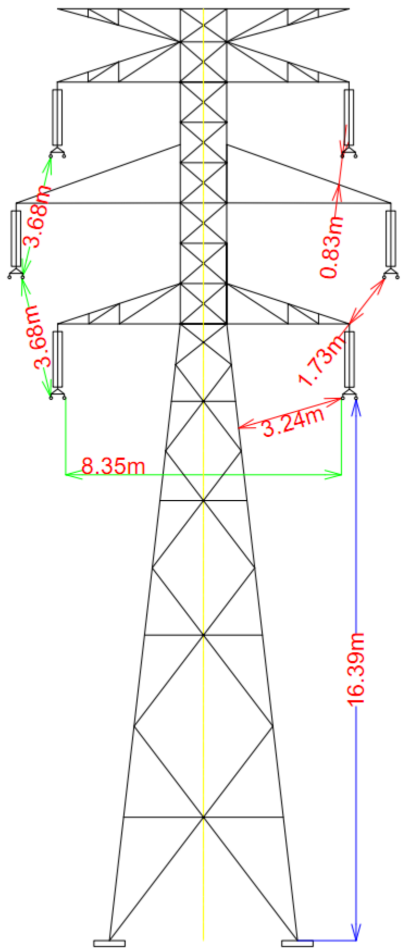
Figure 8. Voltage uprating proposed model by adjusting insulator length and its creepage distance.

Table 10. Minimum electrical clearance of the proposed voltage uprating.

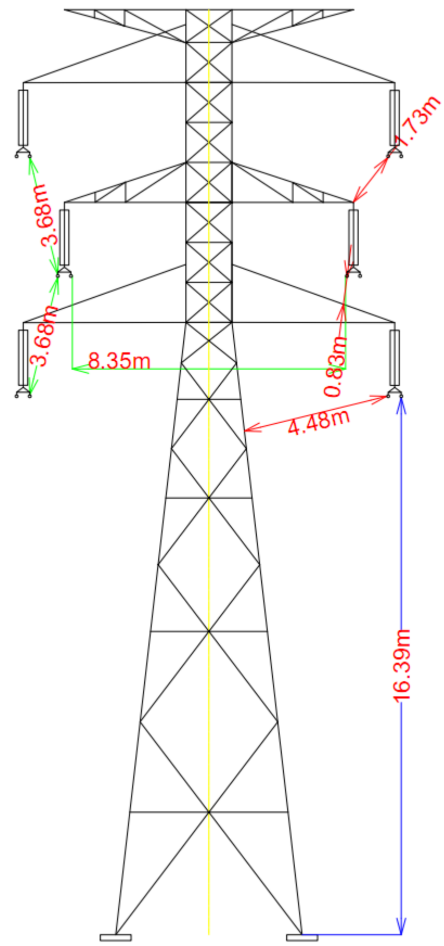
Clearance Type	Minimum Clearance (m)	Result
Phase-to-earth	1.24	Not fulfilled
Phase-to-phase	3.57	Fulfilled
Phase-to-ground	16.39	Fulfilled

8.3. Analysis Process—By Adjusting Crossarm Length and Its Position

Two towers, namely Model A and Model B, were proposed to fulfil electrical clearances requirements for this uprating. Both models were structurally modified by adjusting cross-arm length and position, as shown in Figure 9. The proposed cross-arm materials were made up of fiberglass composite. Model A and Model B showed that available minimum phase-to-earth clearances are 0.83 m and 0.83 m which are significantly not meeting the required phase-to-earth clearance of 1.80 m and 1.90 m in switching and lightning overvoltages for 275 kV transmission line system. Table 11 shows the minimum electrical clearances for the proposed model under still air condition.



(**a**) Model A—Midsection crossarm



(**b**) Model B—Top and bottom section crossarm

Figure 9. Voltage uprating proposed model by adjusting crossarm length and its position.

Table 11. Minimum electrical clearance by adjusting crossarm length and its position.

Clearance Type	**Minimum Clearance (m)**		**Result**
	Model A	Model B	
Phase-to-earth	0.83	0.83	Not fulfilled
Phase-to-phase	3.68	3.68	Fulfilled
Phase-to-ground	16.39	16.39	Fulfilled

8.4. Analysis Process—By Improving Conductor Air Clearance

Minimal modification of the tower structure was made by increasing structure height to cater for electrical clearances under still air conditions. The top of the tower (redline) was added, expanding the structure height by 2.22 m. Meanwhile, the top, midsection, and shield crossarms (green line) were repositioned within the existing 132 kV transmission tower structure. The proposed 275 kV transmission height is 30.44 m, as can be seen in Figure 10.

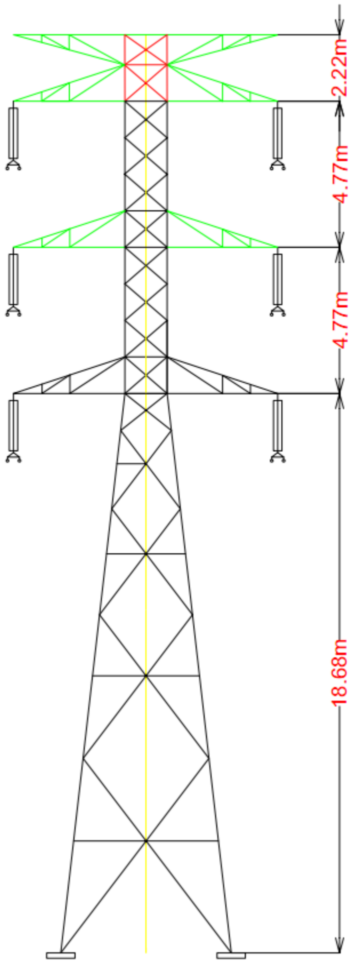


Figure 10. The proposed model of the existing 132 kV transmission line by adjusting crossarm length and its position.

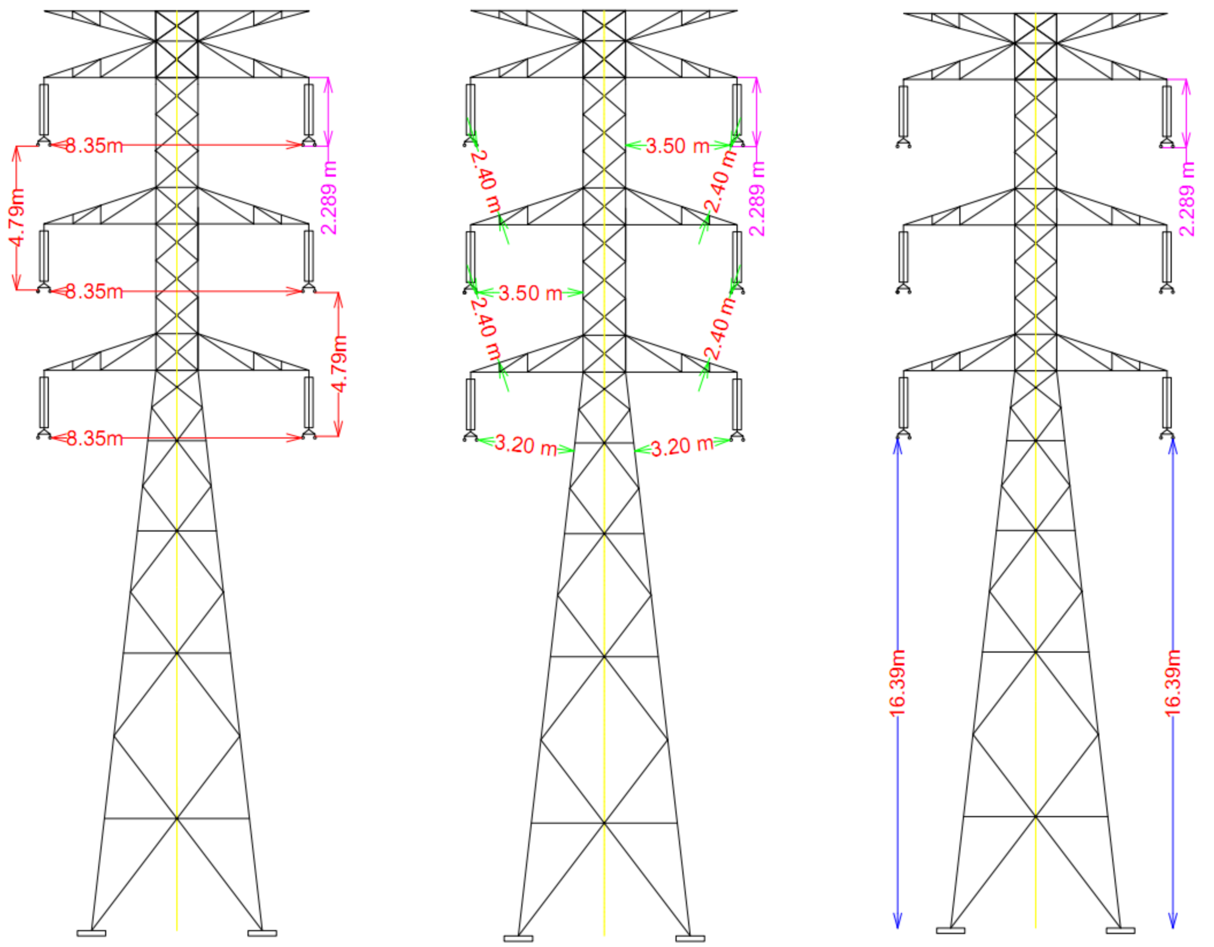
9. Analysis of Electrical Clearance on the Proposed Voltage Uprating Transmission Line

9.1. Under Still Air

Therefore, the minimum available electrical clearances between phase-to-earth, phase-to-phase, and phase-to-ground for the voltage 132 kV transmission line system under still air are now 2.40 m, 4.79 m, and 16.39 m, as shown in Figure 11. Meanwhile, Table 12 shows that the available minimum clearance requirement in the proposed 275kV transmission line system under still air condition, and it shows that there is adequate air for electrical clearances as per the requirements.

Table 12. Minimum electrical clearance under still air.

Clearance Type	Minimum Clearance (m)	Result
Phase-to-earth	2.40	Fulfilled
Phase-to-phase	4.79	Fulfilled
Phase-to-ground	16.39	Fulfilled



(**a**) (**b**) (**c**)

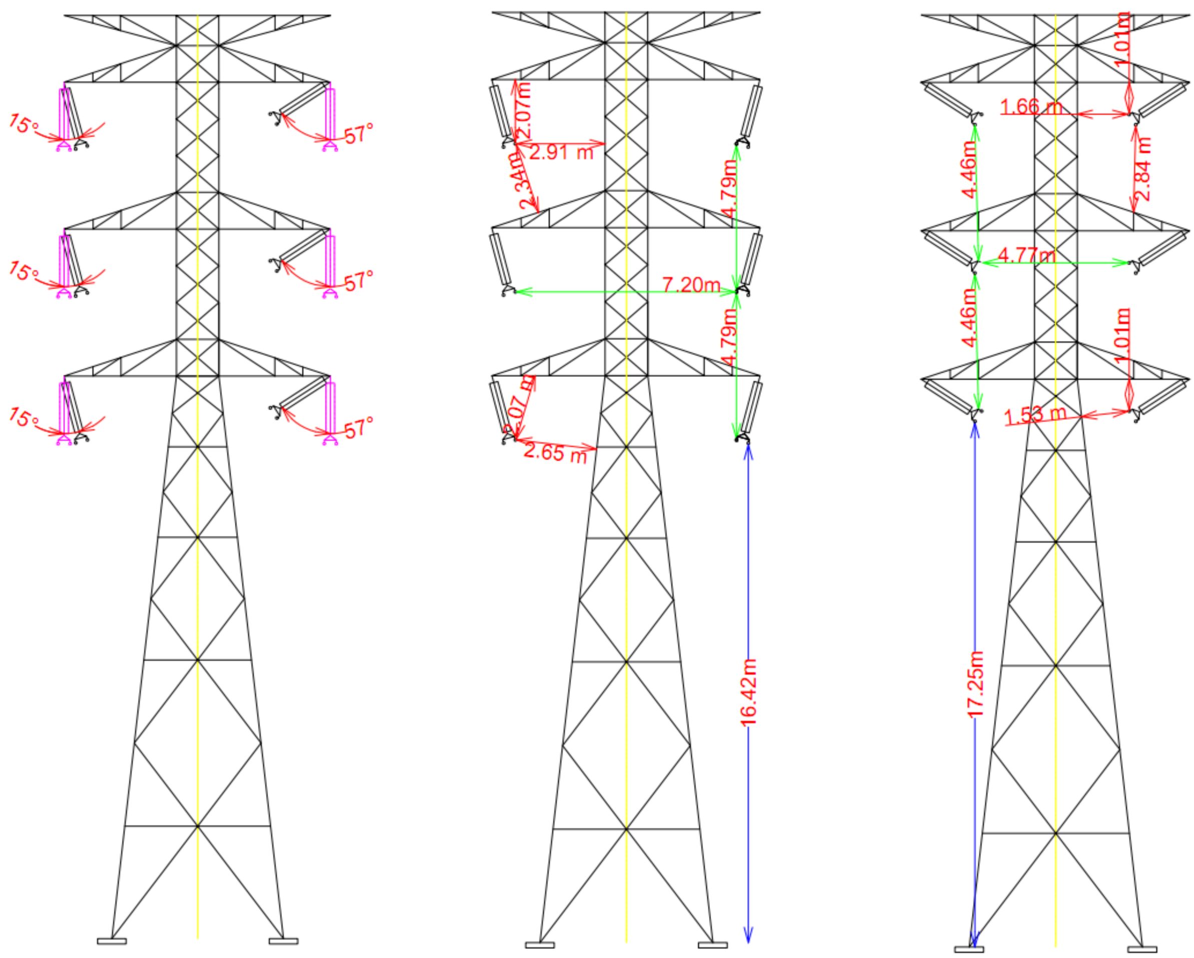
Figure 11. Available electrical clearances under still air condition for (**a**) phase-to-phase, (**b**) phase-to-earth, and (**c**) phase-to-ground.

9.2. Under Normal and Extreme Wind Conditions

Figure 12 shows the air of electrical clearances during the normal swing and extreme swing. The normal swing angle is 15°, and the extreme swing angle is 57°. During normal wind conditions, the minimum available phase-to-earth, phase-to-phase, and phase-to-ground clearances are 2.07 m, 4.79 m, and 16.42 m, respectively. Meanwhile, under extreme wind conditions, the minimum available phase-to-earth, phase-to-phase, and phase-to-ground clearances during normal wind load are 1.01 m, 4.46 m, and 17.25 m, respectively. It can be seen that the available clearances are sufficient to operate at a 275 kV transmission line system, as shown in Table 13.

Table 13. Minimum electrical clearance under wind conditions.

Clearance Type	**Minimum Clearance (m)**		**Result**
	15°	57°	
Phase-to-earth	2.07	1.01	Fulfilled
Phase-to-phase	4.79	4.46	Fulfilled
Phase-to-ground	16.42	17.25	Fulfilled



(**a**) (**b**) (**c**)

Figure 12. (**a**) Swing angle conditions and available electrical clearances under (**b**) normal wind, and (**c**) extreme wind conditions.

10. Electrical Parameters and Environmental Impact of the Proposed Voltage Uprating

There are various environmental impacts due to transmission lines in-services, such as risks to the health and safety of the public and workers. In general, transmission lines are electric and magnetic field producers in their vicinity. The high voltage of lines generate an electric field, while the current flowing through high voltage lines generates a magnetic field [18]. Thus, in this study, it is clearly shown that the voltage uprating could be a significant concern due to the changes in the electric and magnetic field.

Therefore, the proposed model of the existing 132 kV transmission lines takes into consideration the potential changes to the electric and magnetic field limitation by fulfilling statutory and safety regulations. According to [18], several parameters, such as the electric field, magnetic field, radio interference, and audio noise produced around the transmission lines, are influenced by the operations of the voltage, clearances, conductor spacing, height, cross-section, and bundle. Table 14 shows the effect parameters are due to transmission lines' adjustments. Thus, two main elements are further analysed to assess the effects of its electrical parameters, including phase-to-phase clearance and conductor height above ground.

Table 14. Effect of transmission line adjustments [18].

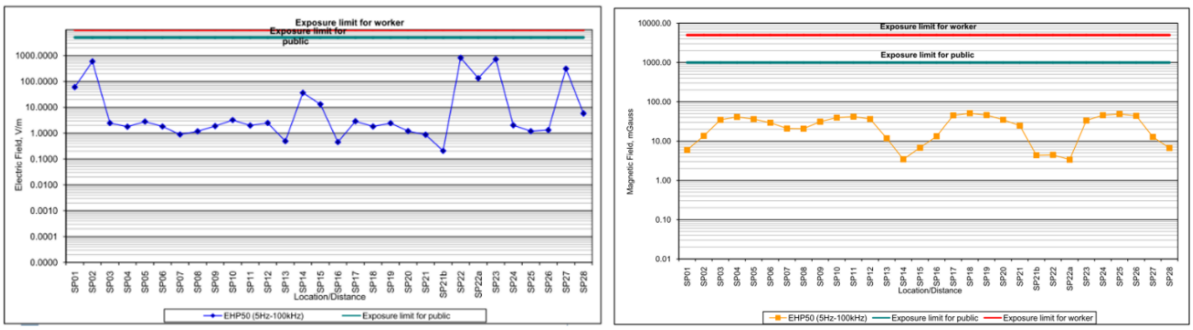
Parameter	Electric Field	Magnetic Field	Radio Interference	Audio Noise
Phase-to-phase clearance	Increase	Increase	Slight decrease	Decrease
Conductor height above ground	Decrease	Decrease	Slight decrease	Slight decrease
Number of subconductors	Increase	No significant effect	Decrease	Decrease
Subconductor spacing	Slight increase	No significant effect	Slight increase	Slight increase
Total conductor cross-section	Slight increase	No significant effect	Slight decrease	Slight decrease

In Malaysia, the Malaysian Nuclear Agency (MAA) and Malaysia Standard (MS) specify guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields and the majority of the national standards have adopted the recommendations of the guidelines issued by an International Commission on Non-Ionizing Radiation Protection (ICNIRP) [83–85]. Therefore, the permissible exposure limits in terms of electric and magnetic fields are stipulated in terms of limiting the exposure of the general public and works to electric and magnetic fields. Table 15 shows the exposure limits of electric and magnetic fields applicable in Malaysia.

Table 15. Lists of permissible exposure limits [84].

Parameters	Public Exposure	Occupational Exposure
Electric field (kV/mm)	5	10
Magnetic field (μT)	100	500

The MAA has measured the electric and magnetic fields at a typical 275 kV transmission line (Bandar Seri Putra, Selangor) and upon measuring both the phase-to-phase and phase-to-ground clearances, it was found that the typical 275 kV transmission produced electric and magnetic fields lower than the exposure limit both for the public and for workers [84]. Figure 13 shows that the measured values of the electric and magnetic fields for several towers are quite lower than the exposure limits of the public and workers.



(a) (b)

Figure 13. (**a**) Electric field, and (**b**) magnetic field value for typical 275 kV transmission line in Malaysia [84].

In this study, the electrical parameters (i.e., electric field, etc.) were not significantly affected by the phase conductor's height from the ground (phase-to-ground), even when the voltage uprating tower model had experienced structural modification. This is due to the fact that the tower adaptation only involved the shield, top, and mid-section crossarm being repositioned, as shown in Figure 10. In addition, the proposed voltage uprating transmission line shown that the minimum available clearance of phase-to-ground under still air condition is 16.39 m, which is double the required minimum clearance of 7.0 m needed for 275 kV transmission line operation. It is believed that the proposed voltage uprating transmission line fulfils statutory and safety regulations.

Since the level of voltage increase from 132 kV to 275 kV, it was found that there is a slight reduction of the electrical clearance (phase-to-phase) for the proposed voltage uprating transmission line. The minimum available clearance of phase-to-phase is 4.79 m, as summarised in Table 12. Meanwhile, for the typical 275 kV transmission line in Malaysia, the minimum available clearance of phase-to-phase under still air condition is 5.55 m. There is a slight percentage of the difference between phase-to-phase for proposed voltage uprating transmission line and the typical 275 kV transmission line in Malaysia is 14%. However, there is should be sufficient phase-to-phase clearance for a maximum load operation, which is almost double the required minimum clearance of 2.6 m (for switching overvoltages) needed for 275 kV transmission line operation. Therefore, it is anticipated that the electric and magnetic fields do not affect the proposed voltage uprating line, even when it has experienced a decrement of phase-to-phase clearance. It is believed that the proposed voltage uprating line is considered in safety and margin design and this could not lead to any risks for the safety and health of the public or of workers.

11. Conclusions

Voltage uprating is one of the best options to increase the power transfer capability of the existing transmission line system. An electrical clearance analysis of the existing transmission is essential, as it determines the actual electrical clearance requirements, i.e., phase-to-phase, phase-to-earth, and phase-to-ground.

At the preliminary stage, the electrical clearance of the existing 132 kV transmission line system with 275 kV suspension string insulator is insufficient for voltage uprating study due to technical issues. It was shown that the phase-to-earth electrical clearances contributed to some concerning issues.

Based on the electrical clearances' analysis and study, it was demonstrated that the techniques of adjusting insulator length and its creepage and improving conductor air clearance significantly help fulfil the required electrical clearances. As a result, it was shown that technical issues, i.e., phase-to-earth, can be overcome by increasing the phase-to-earth clearances, leading to the fulfilment of the requirement under still air and wind conditions. The voltage uprating of the 132 kV existing transmission line system requires only minimal structure modification but is able to gain substantial economic viability compared to having a whole new development of 275 kV transmission line system. Thus, it clearly helps to provide better and more sustainable solutions for asset management and power system operation in optimising the grid transfer capability for utilities.

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