Wind and Structures, *Vol. 28, No. 6 (2019) 381-388*
DOI: https://doi.org/10.12989/was.2019.28.6.381

Geospatial analysis of wind velocity to determine wind loading on transmission tower

Nur H. Hamzah*[1] and Fathoni Usman[2]

[1]*College of Graduate Studies, Universiti Tenaga Nasional, Kajang, Malaysia*
[2]*Institute of Energy Infrastructure, Universiti Tenaga Nasional, Kajang, Malaysia*

(Received January 26, 2019, Revised April 12, 2019, Accepted April 21, 2019)

Abstract. This paper described the application of Geospatial Analysis in determining mean wind speed, V_h for wind load calculation imposed to electrical transmission tower structural design. The basic wind speed data on available station obtained from Malaysian Meteorology Department is adjusted by considering terrain and ground roughness factor. The correlation between basic wind speed, terrain factor and ground roughness stated in EN-50341-1 is used to obtain the V_h for overhead transmission line elements 50 m above ground. Terrain factor, k_r and ground roughness, z_0 in this study are presented by land use types of study area. Wind load is then calculated by using equation stated in design code EN-50341-1 by using the adjusted mean wind speed. Scatter plots of V_h for different k_r and z_0 are presented in this paper to see the effect of these parameters to the value of V_h. Geospatial analysis is used to represent the model of V_h. This model can be used to determine possible area that will subject to wind load which severe to the stability of transmission tower and transmission line.

Keywords: geospatial analysis; mean wind speed; wind loading; transmission tower; structural design

1. Introduction

Transmission line is one of the crucial components in power networking system for a Nation. Transmission lines in Peninsular Malaysia cover 22,478 km length of transmission network. The lines are able to supply the highest demand of 17,788 MW on 2016 which increase from 16,822 MW on 2015. Breakdown of transmission line absolutely will disrupt power networking system. Energy Commission (2014) reports in Performance and Statistical Information on Electricity Supply Industry in Malaysia 2014, there are a few factors that can contribute to the power supply interruption including the natural disasters (i.e., wind, storm, flood, landslide, others) which increases from 5.77% on 2014 to 8% on 2015.

Malaysia is located at the equatorial region of the earth which faces different types of monsoon season throughout the year. The seasons can be categorized as northeast monsoon, southwest monsoon and inter-monsoon seasons. Malaysia Meteorology Department (2019) stated that the northeast monsoon usually occurs on early November until March which brings steady wind of 5.14 m/s to 15.43 m/s. It also known as wet season because during this season, Malaysia is receiving more rainfall. Southwest monsoon usually commences on late half of May or early June until September. The wind flow is generally light below 7.7 m/s and relatively known as dry season except for Sabah.

Besides the two monsoons, inter-monsoon is when the wind is typically light and variable and it happens starting on late March until early May and October until mid of November. However, thunderstorm activity is higher during the inter-monsoon periods. During this season, the equatorial line trough lies over Malaysia.

Issue on structural damage due to environmental factor such as thunderstorm, flood, landslide and others becoming increasing nowadays. Wan *et al*. (2015) stated a few factors of windstorm occurrences in their study such as age of houses, type of building, topography, elevation height, roof connection, vegetation, construction standards and local human behavior. Windstorm occurrence in several parts of Malaysia has severely affected humans, causing damage to property as well as fatality. Fig. 1 shows the windstorm occurrence and Fig. 2 shows the number of damages caused by windstorm occurrence during the study years of 2007 to 2012 stated in study conducted by Wan *et al.*

Nowadays, determination of wind load is different with the old days. The method in determining wind load is enhanced by understanding the wind characteristics, topographical features and how structures respond to the resulting loads. Design codes such as ASCE 74 “Guidelines for Electrical Transmission Line Structural Loading”, and the National Electricity Safety Code (NESC) Rule 250C have discuss on gust response factor and application of wind to tower structures. Kempner (2009) summarized the old methods practiced in determining wind load imposed to transmission tower structure was mainly based on performance of wind mill tower. The early National Electrical Safety Code, NESC documents started with the base concurrent loading case on 17.9 m/s on a 2.54 cm diameter conductor. The resulting forces were then adjusted by load (overload) factors. Adjustment for the characteristics of wind such as topographical features is not

*Corresponding author, Mr.
E-mail: nurmiza.hamzah@gmail.com

http://www.techno-press.com/journals/was&subpage=7 ISSN: 1226-6116 (Print), 1598-6225 (Online)

taken into account in this method.

Ilenin and Varga (2017) did a study on wind load calculation of overhead electrical lines exceeding AC 1kV by referring to a few standard such as STN 33 3300, STN EN 50 341-1, STN EN 50 423-1 and STN EN 50 341-2-23. The study compares the value of wind load by the calculation using these different codes. In the STN 33 3300, it is assumed that wind direction is horizontal. The STN EN 50 431 describes that meteorological data is significant in determining the design wind load acting on the overhead electric line member. The standard considers the terrain category and topography effect in the calculation which modifies the mean velocity and intensity of turbulence. Brewer (2017) in his study as well refer to EN 50 431 to calculate wind loading on transmission tower structure and EN 1990-1-4 to determine mean wind velocity. EN 1990-1-4 considers wind directional factor, orography factor, terrain factor and roughness length in determining the mean wind speed.

Geospatial analysis has been described in a study by Hamzah *et al.* (2018) as an approach which using statistical analysis on the data that have geographical aspect on it. The application of the analysis includes climate change modeling, weather monitoring, human population forecasting as well as to describe the pattern of wind velocity and wind direction at particular area.

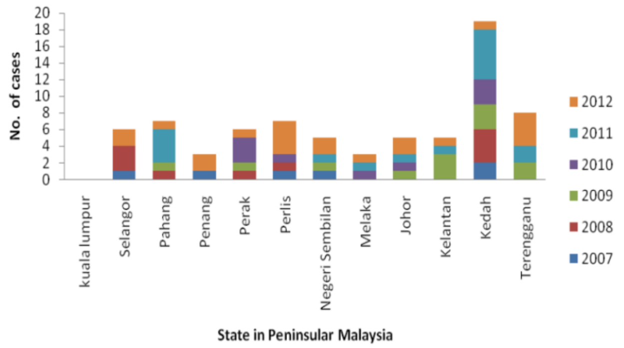


Fig. 1 Statistic of cases occurred in each state in Peninsular Malaysia

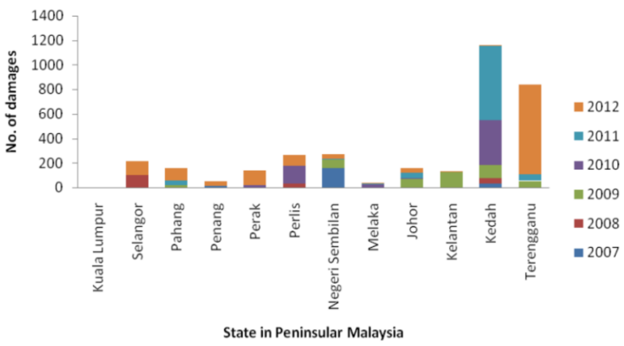


Fig. 2 Statistic of damages in each state in Peninsular Malaysia (2007-2012)

Previous study shows that geospatial analysis is useful in the study of wind characteristic. Study on wind energy potential in Malaysia by applying the spatial analysis to determine the distribution of wind speed throughout the country have been conducted (Masseran *et al.* 2012, Ibrahim *et al.* 2014). Ibrahim *et al.* (2014) mentioned that studies on wind characteristic of the site before constructing a wind system are needed to reduce costs. GIS-based spatial wind mapping is giving a geographical distribution of wind resource and very useful for decision making and planning in wind energy development.

The aim of this study is to determine the effect of terrain factor and ground roughness parameter toward design average wind speed of transmission tower in order to calculate wind loading imposed to tower structure.

2. Method

This section presents how data is collected and the methods used in obtaining the wind speed for wind loading calculation.

2.1 Data collection

The basic wind speed data also known as $V_{b,0}$that will be used in this study is referring to the measured wind speed recorded at different meteorological stations. Due to limitation of wind data, the analysis is conducted by using daily maximum wind speed data for year 2015 over Selangor and Kuala Lumpur area. Wind data with 50 years return periods should be used to achieve the acceptable reliability level for design wind load calculation. In this study, data of daily maximum wind speed for year 2015 on available wind stations over the study area is gathered from Malaysian Meteorological Department, MMD. Terrain factor, k_r and roughness length, z_0 in this study are categorized based on the land uses data in the form of map available from Federal Department of Town and Country Planning. All the mapping and classification in this study is conducted by using ArcGIS 10.1.

2.2 Geospatial analysis

2.2.1 Wind mapping

Alnuaimi *et al.* (2014) summarized a few methods in obtaining the basic wind speed which are Gumbel and Gringorten method. Gumbel developed an easily usable methodology for fitting recorded monthly or manual wind speed. Gringorten method is considered a simple modification of Gumble's extreme value procedure. Alnuami et al. used the Gumbel and Gringorten method in order to obtain the basic wind speed in Oman before develop it into basic wind speed map. Ibrahim *et al.* (2014) conducted a study on wind characteristics and GIS-based spatial wind mapping in Malaysia to investigate the wind resources in the country. Weibull Distribution method and IDW spatial wind mapping is used in the study to prove the location that have high potential of wind resources. 5 years wind data is used in the study. However, Muzathik *et al.*

(2009) stated that 1 year wind data would be sufficient to study the wind potential. In this study, wind maps were generated based on 1-year wind data from MMD in ArcGIS 10.1. Table 1 shows the sample of maximum wind speed data for available stations along the year 2015 obtained from Malaysia Meteorology Department.

There are about 12 wind stations available over Selangor and Kuala Lumpur area as shown in Fig. 3 and it is unrealistic to set up meteorological stations everywhere. The statistics of daily maximum wind speed could be spatially interpolated from those measured data for sites which not covered by the measured values as mentioned by Ye (2013). Interpolation methods divided into deterministic methods and geo-statistical methods. In this study, deterministic interpolation method which is Inverse Distance Weighting, IDW with 10 m by 10 m grid size is used. Luo *et al*. (2008) mentioned in their study about this IDW interpolation method. IDW assumes that each measured point has a local influence that diminishes with distance. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Ye (2013) as well explained that by using IDW method, the prediction is calculated by using a linearly weighted combination of the observe values. When the distance increases, the influence of the measured location decreases as the weight is the function of the inverse distance. Fig. 4 shows the wind speed interpolated throughout study area using the maximum wind speed along 2015 which will be considered as $V_{b,0}$ in the analysis.

Spatial wind mapping provides a visual determination of potentially higher wind resources. IDW method estimates an unknown value as the weighted average of its surrounding points, in which the weighted value is the inverse of a distance raised to a power. From the result, the areas that have low wind speed or high wind speed can be determined by the colors from purple to green. The map shows that most of the areas at south to west region of Selangor are having higher wind speed compared to other region.

Table 1 Maximum wind speed along 2015

Station	Latitude	Longitude	Speed (m/s)	Direction (^{0})
FRI Kepong	3.233333	101.6333	8.8	237.89
Jln Acob Estate	3.133333	101.3833	31.3	232.86
KLIA Sepang	2.730833	101.7031	23.2	156.77
Mardi Klang	2.983333	101.4833	34	180.97
P.P Sg Besar	3.666667	100.9833	15.4	187.33
P. Lat Pert Kalumpang	3.633333	101.5500	20.1	222.35
Parlimen	3.148611	101.6778	16.4	183.89
Petaling Jaya	3.101944	101.6450	17.1	196
Pusat Pert Serdang	3.000000	101.7000	13.1	210.71
Pusat Pert. Tjg. Karang	3.416667	101.1833	19	209
Subang	3.130556	101.5525	20.2	191.61
Tennamaran Estate	3.395556	101.4167	26.5	136.67

Fig. 3 Available wind stations over Kuala Lumpur and Selangor area

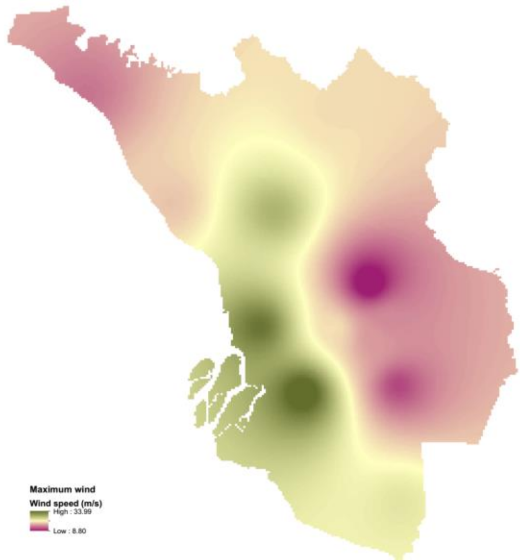


Fig. 4 Map of maximum wind speed along 2015

2.2.2 Topography and terrain roughness parameter

According to EN 50341-1 (2012), terrain condition and ground roughness are part the factors that contribute to the mean wind speed, V_h(h) for overhead transmission line elements 10 m above ground. Wind speed near the ground varies with terrain roughness, i.e., buildings, trees, etc., and topography. In Recommendation of Loads on Building, AIJ (2005) explained that the friction force from terrain roughness and the concentration or blockage effects from topography, influence the atmospheric boundary layer from the ground to the gradient height. Terrain roughness causes a gradual decrease in wind speed toward the ground. The domain that is influenced by terrain roughness is called the boundary layer, where the wind speed profile changes with terrain roughness category. The boundary layer depth increases with fetch length, which means that the wind speed profile extends to a higher elevation downstream. In addition, the boundary layer tends to develop faster when the terrain is rougher. In the other hand, roughness category changes due to urbanization and varies due to wind. Eq. (1) shows the correlation between terrain condition, ground roughness and the obtained site wind speed. Land use data considered in this study is categorized according to terrain category specified in Table 2 which specified by EN 50341-1 (2012) to define the value of k_r and z_0.

$$V_h \text{ (h)} = V_{b,0}\ C_{dir}\ C_0\ k_r\ \ln\frac{h}{z_0} \qquad (1)$$

Where,

V_h =Wind speed at arbitrary height above ground
$V_{b,0}$ = Basic wind speed
C_{dir} = Wind directional factor, recommended value is 1
C_o = Orography factor, recommended value is 1
k_r = Terrain factor
h = Reference height above ground
z_0 = Roughness length

In order to relate and synchronize the obtained land use data with the terrain characteristics, the land use types are generalized as in Table 3.

For example in class 1, the categorized land uses are stranded land & recreation, paddy field and water bodies. The land uses are classified as class 1 based on the terrain description stated in Table 2 which are lakes or flat and horizontal area with negligible vegetation and without obstacles. Fig. 5 shows the classified land uses into particular k_r and z_0 throughout the study area.

Table 2 Terrain factor and ground roughness parameter for different terrain categories

Terrain Category	Characteristic of the terrain	k_r	z_0
0	Sea or coastal area exposed to the open sea	0.155	0.003
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0.169	0.01
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 times obstacle heights	0.189	0.05
III	Area with regular cover of vegetation or buildings or with isolated obstacles with a separation of maximum 20 times obstacle heights (such as villages, suburban terrain, permanent forest)	0.214	0.3
IV	Area in which at least 15% of the surface is covered with buildings which average height exceeds 15 m	0.233	1

Table 3 Classification of land uses

Class	Type of land uses	k_r	z_0
1	Stranded land & recreation/ Paddy field/ Water bodies/Wetlands	0.169	0.01
2	Residential/ Transportation	0.189	0.05
3	Industry/ Agriculture/ Land forests	0.214	0.3
4	Business & services / Institution & public facilities/ Infrastructure & utility	0.233	1

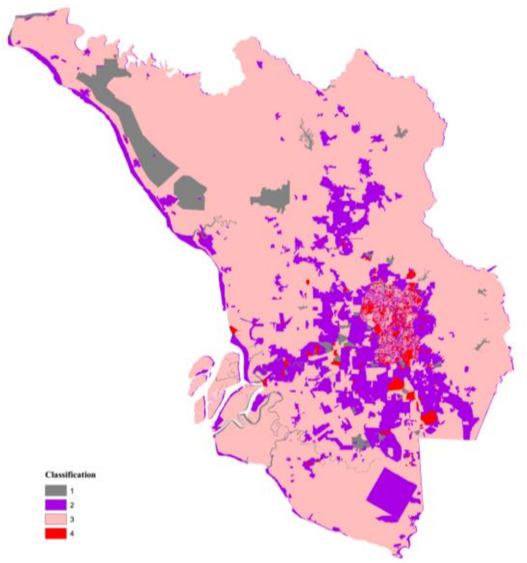


Fig. 5 Classified land use

All the input layers correspond to Eq. (1) which consist of wind speed, terrain factor and ground roughness parameter with 10 m by 10 m grid size are gathered in the form of raster data in order to obtain the correlation by using raster calculator tool in ArcGIS. C_{dir} and C_0 are assumed as 1 as per recommended by the code. While h can be input according to the desired height above ground. In this study the height 10 m above ground is considered. Raster calculator is one tool in geospatial analyst that is used to create and execute a map of algebra expression which presents the output in raster form. Eq. (1) is added in the tool dialog box to get the mean wind speed, V_h. Raster calculator tool is going to calculate the tabulated V_h throughout Kuala Lumpur and Selangor area.

3. Result and discussion

This section presents the result for this study followed by discussion of the result.

3.1 Geospatial analysis

3.1.1 Wind mapping

This study compared the value of V_h for three different wind data. Figs. 6(a)-6(c) show the wind map for March which represents northeast monsoon, September which represents southwest monsoon and the wind map of maximum wind speed in each station along a year respectively. Wind map is used to study the wind pattern at study area. Different size of arrow scattered in the map clearly indicates the wind speed and wind direction which correspond to $V_{b,0}$ in this study.

3.1.2 Topography and terrain roughness parameter

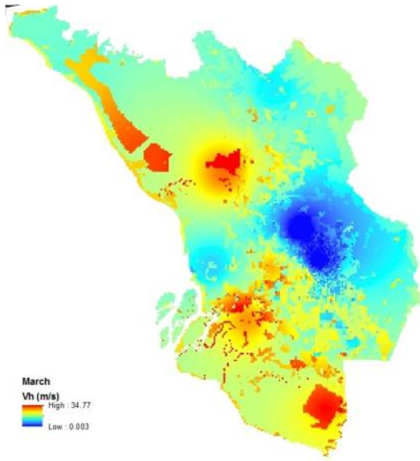
Combination of terrain factor and ground roughness in Eq. (1) gives a significant effect to the value of mean wind speed. Figs. 7 (a)-7(c) show the model of output raster in this study for 50 m above the ground using wind speed data in March, September and maximum wind speed in 2015. As a result, the value of V_h can be determined all over the study area, not only at the wind stations available.

(a)

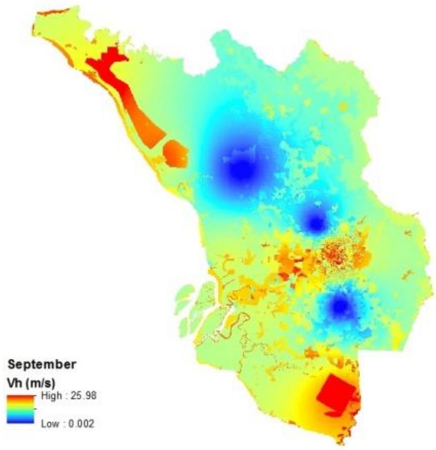
(b)

(c)

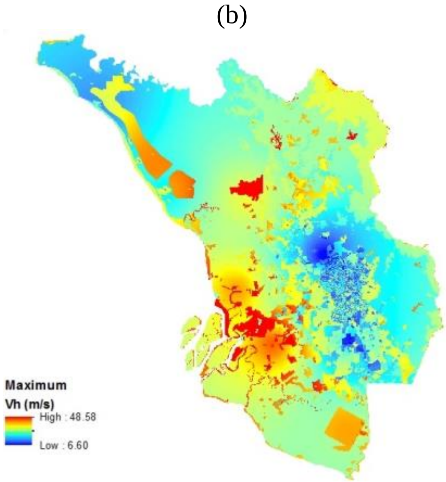
Fig. 6 (a) March, (b) September and (c) Maximum



(a)



(b)



(c)

Fig. 7 (a) March, (b) September and (c) Maximum

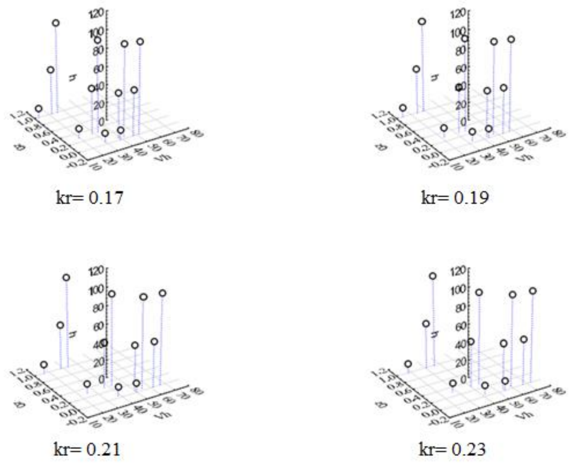


Fig. 8 Scatter plots of V_h for different k_r and z_0

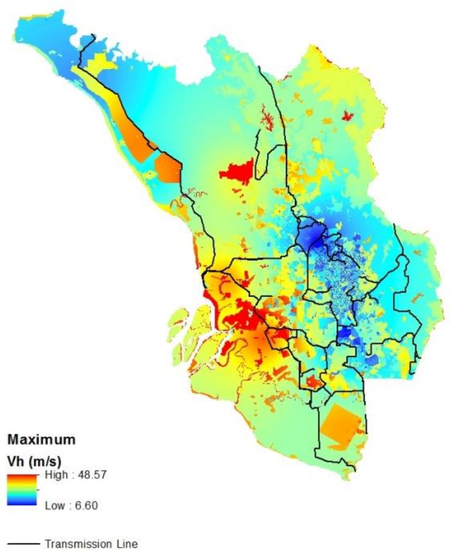


Fig. 9 Transmission line over the V_h map

From this study, it is found that the geospatial analysis can be used to represent the model of wind speed V_h based on EN 50341-1 (2012). This model can be used to determine possible area that will subject to wind load that severe to the stability of transmission tower and transmission line. Based on the model, the maximum value of V_h of 34.77 m/s is obtained during March and 48.58 m/s is obtained on September. The maximum V_h obtained using maximum wind speed data found to be 48.58 m/s which is greater than 33.5 m/s basic wind speed stated in MS 1553 for inland region.

Kiessling *et al.* (2003) stated in their book that terrain roughness contributes on the effect of wind speed as well as gust response factor. Higher value of ground roughness caused the wind flow to be slower and more turbulent. It can be shown by the scatter plot of V_h for different value of k_r and z_0 in Fig. 8.

Fig. 8 shows that at higher value of z_0 the value of V_h decreases at any height above ground. It also shows that at 100 m above ground the value of V_h can be double of the design wind speed applied to structure of transmission tower. The value of V_h is more than 70 m/s at 100 m for z_0= 0.01 and k_r 0.24.

For further observation, transmission line through the study area has been plotted on the V_h map to see which line is located at the area having high mean wind speed. Fig. 9 shows the transmission line, indicated by the black line which is lies over V_h map that having maximum wind speed data and 50 m height above the ground.

From Fig. 9, there are transmission line located at the area that having high mean wind speed. The future development of transmission tower can avoid those areas in order to avoid possible failure of the tower. Besides future development, the existing transmission line which located at the area having high mean wind speed as well should be monitored and well prepared for any possibilities.

3.2 Wind loading

When designing overhead lines in the ultimate limit state, the gust wind speed is critical. In EN EN 50341-1 (2012), it is optional to use the mean wind speed V_{mean} or the gust wind speed V_g as a basis for the extreme wind speed in accordance with the practice within each country. The code specified two approaches in determining wind action which are General Approach and Empirical Approach. In General Approach, the wind action is deduced, where the wind speed is adjusted by factor of ground roughness and terrain category as shown in this study. The dynamic wind pressure, q_h (in N/m2) in Eq. (2) is calculated using the obtained V_h.

$$q_h = \frac{1}{2}\rho * V^2{}_h(\mathrm{h}) \tag{2}$$

Where,

ρ = air density, 1.225 kg/m3

V_h = wind speed in m/s

However, peak wind pressure q_p(h) at the reference height above ground which includes the effect of turbulent intensity I_v(h) is needed for wind loading calculation. q_p(h) and I_v(h) are given in Eqs. (3) and (4) respectively. $c_0$and $z_0$are as determined in previous section.

$$q_p(\mathrm{h}) = [1 + 7\, I_v(\mathrm{h})]\; q_h \tag{3}$$

$$I_v(\mathrm{h}) = \frac{1}{c_0 \ln(\frac{h}{z_0})} \tag{4}$$

Besides General Approach, Mendera (2007) described that Empirical Approach is based on the calibration by a long and successful history of overhead lines construction. According to EN 50341-3, the basic wind pressure increases linearly with height z according to example in Eq.

(5). Fig. 10 shows the comparison of design wind pressures depending on height above ground for a) DIN VDE 0210/12.85, b) EN 50341-1, c) EN 50341-3-4, d) IEC 60826 compared by Kiessling *et al.* (2003). The figure differentiates between dynamic wind pressure of conductors and supports.

- Zone 1: q_z= 800+30 (z/10) N/m;
- Zone 2: q_z=1050+30 (z/10) N/m; (5)
- Zone 3: q_z=1300+30 (z/10) N/m

EN 50341-1 (2012) specified two methods in computing the wind force on lattice tower. One of the method stated that the forces shall be calculated for panel sections according to selected panel height intervals above the ground. The tower is divided into sections and the drag factor is linked to the frames of the tower sections, taking into account a sheltering effect of windward frames on leeward frames Eq. (6) is defined to calculate wind force on lattice tower.

$$Q_{WT} = q_p(h)\ G_t\ (1+0.2\sin^2 2\phi)\ (C_{t1}A_{t1}\cos^2\phi + C_{t2}\ A_{t2}\sin^2\phi) \quad (6)$$

Where,

q_p(h) = peak wind pressure

h = reference height above ground to be taken into account for the lattice tower section

G_t =structural factor for lattice tower, recommended value is 1

C_{t1}, C_{t2} = drag factor for lattice tower panel face 1 (respectively face 2) of the section being considered in a wind perpendicular to this panel, determined according to solidity ratio, χ, defined in Fig. 11

A_{t1}, A_{t2} = effective area of the elements of lattice tower panel face 1 (respectively face 2) of the section being considered

ϕ = angle between wind direction and the longitudinal axis of the lattice cross-arm

$$\chi = A_t \frac{2}{h(b1+b2)} \quad (7)$$

Where,

χ = solidity ratio of a tower panel

A_t = effective area of elements of a tower panel face projected normal to face. Bracing elements of the adjacent faces and of the diaphragm bracing members can be neglected.

Table 7 Sample calculation of wind force, Q_{WT} for ϕ 45̊

h(m)	q_h (kN/m^2)	q_h (kN/m^2)	C_t	Q_{WT} (kN)
9	0.69	2.12	χ=0.63, c_t=3.60	7.56
29.55	0.69	1.74	χ=0.017, c_t=3.84	1.99
41.25	0.69	1.66	χ=0.009, c_t=3.87	0.81
51.2	0.69	1.62	χ=0.004, c_t=3.88	0.43

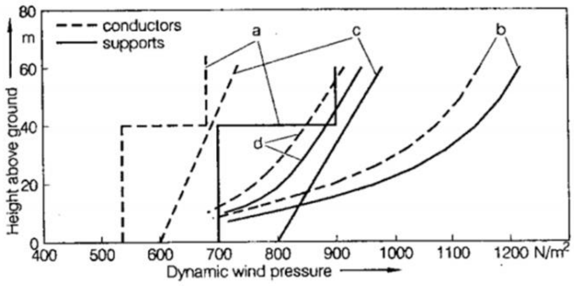


Fig. 10 Comparison of design wind pressures depending on height above ground

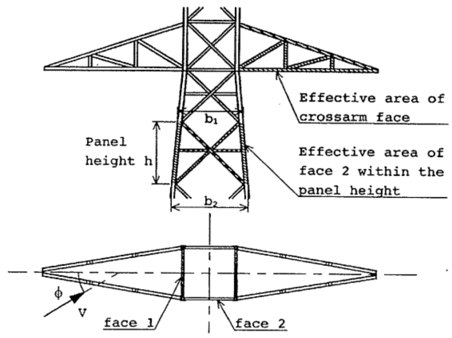


Fig. 11 Tower panel faces, cross arm and definition of solidity ratio

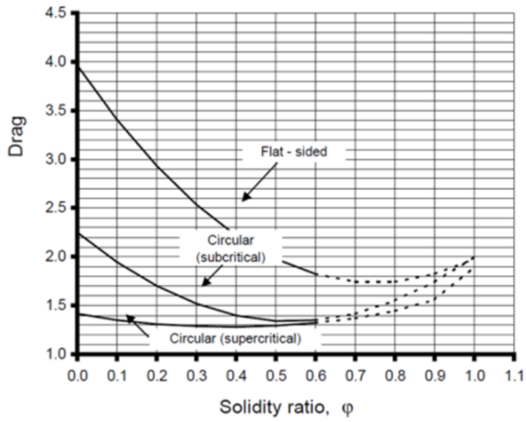


Fig. 12 Tower panel faces, cross arm and definition of solidity ratio

Table 7 shows the sample of wind force Q_{WT} on lattice transmission tower section according to EN 50341-1 for 48.58 m/s mean wind speed V_h along different height of the transmission tower. (Tian *et al.* 2014, Kamarudin *et al.* 2017 and Yang *et al.* 2016) considered 45̊ as the critical angle of wind attack that can cause collapse of transmission tower.

4. Conclusions

In this study, geospatial analysis has been conducted on the available wind data by considering the effect of terrain factor, k_r and ground roughness, z_0 of Kuala Lumpur and Selangor area. Land use data is classified based on terrain category specified in the design code to produce the map of V_h by considering all the factors contributing to mean wind speed. The obtained V_h is then can be used to determine the wind load imposed to every section of transmission tower structure which have different heights, according to the approach stated by EN 50341-1 (2012). The transmission line that located at the region which having high mean wind speed as well can be determined by plotting the transmission line over the V_h map.

Acknowledgments

The research described in this paper was financially supported by UNITEN R&D Sdn. Bhd through Project Grant No. U-TS-CR-17-01.

References

Alnuaimi, A.S., Mohsin, M.A. and Al-riyami, K.H. (2014), “A basic wind speed map for Oman”, *J. Eng. Res*., **11**(2), 64-78.

Brewer, A. (2017), “Dynamic wind load modelling of high overhead transmission line towers”, MSc. Dessertation; University of Iceland, Reykjavik.

Dinu, F. (2014), Europian Erasmus Mundus Master Course- Mast, Towers, Chimneys, SUSCOS.

Energy Commission (2014), “Performance and Statistical Information on Electricity Supply Industry in Malaysia”, Malaysia.

EN50341-1 (2012), Overhead Electrical Lines Exceeding AC 1 kV- Part 1: General Requirement- Common Specifications, Europian Standard, CENELEC; Brussels, Belgium.

Hamzah, N.H., Usman, F. and Omar, R.C. (2018), “Geospatial study for wind analysis and design codes for wind loading: A review”, *Int. J. Adv. Appl. Sci*., **5**(1), 94-100.

Ibrahim, M.Z., Yong, K.H., Ismail, M., Albani, A. and Muzathik, A.M. (2014), "Wind characteristics and GIS-based spatial wind mapping study in Malaysia”, *Int. J. Renew. Energ. Res*., **9**(2), 1-20.

Ilenin, S. and Varga, L. (2017), “Wind Load of Overhead Electrical Lines Exceeding AC 1 Kv”, International Scientific Symposium ELEKTROENERGETIKA, Slovak Republic, September.

Architechtural Institute Japan, AIJ (2005), Recommendations for Loads on Buildings: Chapter 6 - Wind Loads.

Kamarudin, S.A., Usman, F. and Omar, R.C. (2017), “Evaluation of overhead transmission tower subjected to predominantly wind loading”, *Int. J. Civil Eng. Geo-Environ*., 6.

KempnerJr, L. (2009), “Wind load methodologies for transmission line tower and conductor”, *Proceedings of the Electrical Transmission and Substation Structures Conference*, Texas, September.

Kiessling, F., Nefzger, P., Nolasco, J,F. and Kaintzyk, U. (2003), “Overhead power lines planning design construction”, Springer, Newyork.

Luo, W., Taylor, M.C. and Parker, S.R. (2008), “A comparison of spatial interpolation methods to estimate continuous wind speed surfaces using irregularly distributed data from England and Wales”, *Int. J. Climatology*, **28**, 947-959.

METMalaysia (2019), Malaysia Meteorology Department; Ministry of Energy, Science Technology, Environment and Climate Change, Malaysia. http://www.met.gov.my.

Masseran, N., Razali, A., Ibrahim, K., Zin, W.Z.W. and Zaharim, A. (2012), “On spatial analysis of wind energy potential in Malaysia”, *WSEAS T. Math*., **11**(6), 451-461.

Mendera, Z.K. (2007), “Bases of design of overhead electrical lines according to general tequirement of European standard EN 50341-1 : 2001”, *Adv. Steel Constr*., **3**(2), 553-564.

Muzathik, A.M., Nik, W.B.W., Ibrahim, M.Z. and Samo, K.B. (2009), “Wind resource investigation of Terengganu in the west Malaysia”, *Wind Eng*., **33**(4), 389-402. https://doi.org/10.1260/030952409789685708.

Tian, L., Yu, Q., Ma, R. and Wang, C. (2014), “The collapse analysis of a transmission tower under wind excitation”, *Open Civil Eng. J*., **8**, 136-142.

Wan Mohd Yusof, W.C., Noram Irwan, R., Mohd Khairul Azuan, M. and Taksiah, A.M. (2015), “Development of windstorm database system for wind damages in Malaysia”, *J. Civil Eng. Res*., **4**(3), 214-217. DOI: 10.5923/c.jce.201402.36.

Ye, W. (2013), “Spatial variation and interpolation of wind speed statistics and its implication in design wind load”, Ph.D. Dessertation; The University of Western, Ontario, London.

Yang, F.L. and Zhang, H.J. (2016), “Two case studies on structural analysis of transmission towers under downburst”, *Wind Struct.*, **22**(6), 685-701. http://dx.doi.org/10.12989/was.2016.22.6.685

CC