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B2 – Overhead Lines

Insight into the Trending of Solar Radiation and Ambient Temperature in Malaysia towards a Possible Implementation on Step-Wise Rating.

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1. SUMMARY

Traditional static line ratings for transmission lines usually take into account the worst case assumptions when determining line capacity rating. In Malaysia, these conservative ratings have been around for 40 years. The values used for ambient temperature, wind speed, solar radiation and other parameters have never been reviewed and thus the same ratings have been used for the past decades. In this regard, it is uncertain if the values assigned to the parameters are still relevant for the present and future application due to the fact that solar radiation values are not static and changes over time. Therefore, the level of certainty in which grid infrastructure is utilised in a highly efficient manner in transmitting power and electrical energy is debatable.

This paper particularly looks into the trending of actual solar radiation values over the past years as well as the annual trending of the parameters experienced in Malaysia and weighs out the possibilities in amending this value to suit the actual current weather at different periods of the year to achieve a more practical or suitable rating. Monthly median values of the solar radiation are evaluated and analysed for the past several years' occurrences. On top of that, the periods of year which has high solar radiation are separated from the periods which have low solar radiation to acquire a more flexible line rating that better suits the weather conditions at different months. Strict compliance with these conservative assumptions in designing for transmission systems will therefore tend to leave out a big portion of the year where the capacity of the transmission lines is underutilised. On the other hand, underestimated solar radiation parameter value would lead to higher actual conductor sag and therefore, lower margin of factor of safety. Two approaches are used to determine the impact of solar radiation and ambient temperature. The insight of these scenarios are discussed in this paper.

2. KEYWORDS

Transmission lines, Overhead lines, Ampacity rating, Static Line Rating, Solar Radiation, Ambient Temperature, Step-Wise approach, Review of Parameters

3. INTRODUCTION

The transmission line power transfer limit is defined by three main factors which are voltage, stability and thermal limits [1]. While voltage and stability limits are constrained by reliability concerns,

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conductor thermal limits are not only governed by reliability factor but the more critical issue is safety factor [1]. The maximum operating temperature is defined as point where clearance integrity is maintained (safety) and conductor annealing is avoided (reliability) [1]. Therefore, thermal line rating is determined by using worst case parameters and the maximum allowable sag and maximum acceptable temperature [1].

Tenaga Nasional Berhad (TNB), the Malaysian utility company practices Static Line Ratings which takes conservative parameters into considerations when determining a suitable ampacity rating [2]. The practice of static line ratings has been the first and only practice of line ratings in TNB. Static line ratings limits the amount of current that the conductor is allowed to transmit without breaching safety clearance or accelerate the ageing of conductors [3].

The main factors that determine the static ratings of a conductor are the solar heating, material of conductor, cooling effect of the wind and heat loss from conductor radiation due to temperature difference in ambient temperature and conductor temperature [3]. Due to the rigid characteristics of static line ratings, worst case assumptions were made to acquire conservative parameters to enable these ampacity ratings are valid at all times [3]. While the advantage that it brings is that there is ample buffer of safety margin to avoid any overheating of conductors which will lead to extreme sag that could cause a breach in high voltage clearance, conservative static line rating highly restricts the transmission grid operate at its most optimum capacity.

Another drawback of the current Static Line rating is that over time, the assumed conservative parameters that are used in the calculation to determine the line rating may no longer be valid. This is because weather parameters such as ambient temperature and solar radiation have a tendency to change over time.

Countries with advanced transmission grid technology have shifted to Real-Time Dynamic Line rating to maximize the capacity of their grid infrastructure and avoid overdesign just to prepare for worst case scenario[1]. The working basis of Real-Time Dynamic Line rating largely depends on weather conditions data that is continually monitored [4]. With these weather data, the line rating can be calculated and updated in real-time. This will allow the grid infrastructure to be optimized to a higher carrying capacity while still maintaining the temperature limit of the conductors within safe margin [4].

The implement Real-Time Dynamic Rating on transmission lines will require several meteorological sensors placed at several key strategic locations to collect reliable real-time data and software to crunch the data to acquire suitable real-time ampacity ratings. This requires a change in current practices.

Therefore, the objective of this paper is to look into updating the ambient temperature and solar radiation parameters on top of proposing a more flexible line rating design by using the maximum solar radiation reading as a conservative approach and also by using mean monthly peak solar radiation as an efficiency approach with the goal to optimize the current carrying capacity of the lines compared to the current practice.

4. BACKGROUND

4.1. Existing Parameters

Table 1 shows the existing static line ampacity rating used by the utility company in Malaysia, Tenaga Nasional Berhad (TNB) [2]. There are three main voltage levels for high voltage transmission system in Malaysia which is 132 kV, 275 kV and 500 kV. The type of conductors used are mainly Aluminium Conductor Steel Reinforced (ACSR) conductors which can have the balance of both capability in carrying the desired capacity and tensile strength to match the tower designs during the earlier days of developing the country's grid [5].

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Voltage (kV)	Type	Bundle	Ampere (A)	MVA/ Circuit
132	ACSR Batang (300mm^2)	1	616	141
275	ACSR Zebra (400mm^2)	2	1433	683
275	ACSR Zebra (400mm^2)	3	2150	1025
500	ACSR Curlew (525mm^2)	4	3233	2800

Table 1 Type and rating of the conductors and Voltage level practiced in Malaysia [2].

The ampacity rating in Table 1 is determined by the weather parameter assumptions as shown in Table 2. The conductor parameters for each ACSR conductors are according to the specifications published by the manufacturers. From the values and parameters acquired in Table 2 and the ampacity rating in Table 1, the solar radiation used is found to have been fixed at approximately 1122 $\mathrm{W/m^2}$.

Parameter Description	Unit	Value
Ambient Temperature	°C	32
Wind Velocity	m/s	0.4469
Elevation	m	50
Absorptivity of conductor surface	-	0.9
Emissivity of conductor surface	-	0.7
Latitude	North	3
Time	24 hrs	12:00
Conductor Temperature Limit	°C	75

Table 2 Parameter values and descriptions currently used for static rating ampacity calculation [2].

4.2. Ambient Temperature in Malaysia

Over the span of the past 100 years, the mean global temperature has increased by 0.3°C to 0.6 °C and the rate of warming has seen an acceleration at a rate of 0.15 °C per decade [6][7]. In Malaysia, the warming rates in most of the surveyed location have breached the 3 °C/100 years mark with Kuala Lumpur leading at a rates of between 3.5 °C/100 years and 4 °C/100 years, Melaka at 2.7 °C/100 years to 3.07 °C/100 years and Kuantan at a rate of 2.83 °C/100 years to 3.72 °C/ 100 years [6]. These data are comparable to the estimated projections of 3.7 °C/100 years to 4 °C/100 years for the areas around the Bay of Bengal [8].

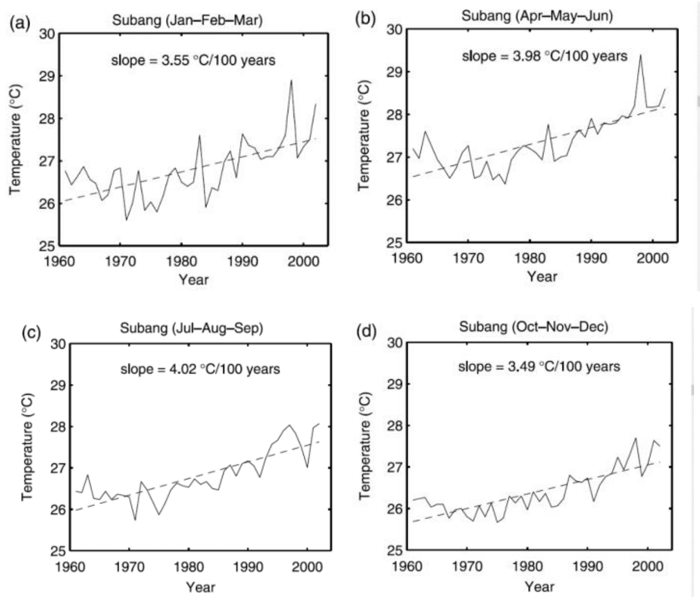

Figure 1 Temperature trend in Subang, Malaysia from 1960 to 2000 [6]
(a) Jan to Mar
(b) Apr to June
(c) July to Sept
(d) Oct to Dec

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The trend and inter-annual variability of the temperature in Malaysia is broken up over a 3 month period for analysis as shown in Figure 1. The periods are Jan-Feb-March, April-May-June, July-August-September and October-November-December. As observed from the trending, the slope is around 3.5 to 4 °C/100 years with the months of April to September at the higher rate while the months of October to March at a slightly lower rate.

4.3. Solar Radiation in Malaysia

Malaysia is a tropical country which experiences hot and humid weather throughout the year with monsoon season twice in a year [9]. The Latitude coordinates of Malaysia stretches from about 1° N to 6° N and the Longitude stretches from 100° E to 105° E covering both East and West Malaysia [9]. Due to the Earth tilt angle, the solar radiation levels are not uniform throughout the year and will deviate according to the position of the Sun. Solar radiation (W/m^2) is one of the major deciding factor in determining the ampacity of an overhead line conductor [10][11]. The location which has the highest solar radiation in Malaysia belong to Kota Kinabalu in Sabah and Chuping in Perlis as shown in Figure 2 [12]. Therefore, the solar radiation of these location would ideally serve as reference in determining the line carrying capacities. These are therefore appropriately conservative in nature.

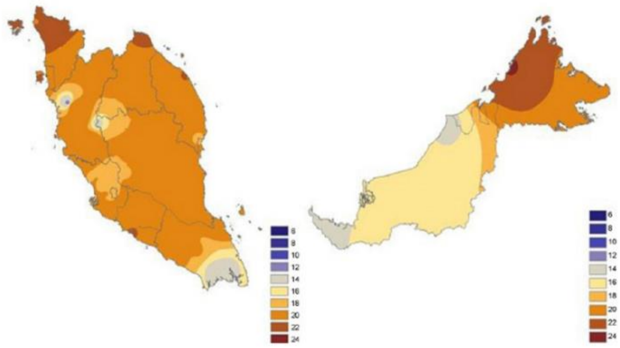

Figure 2 Malaysia average daily solar radiation distribution in terms of $\mathbf{MJ/m^2}$ [12]

4.3.1. Annual Trend of Solar Radiation in Kuala Lumpur

A case study of solar rooftop Photovoltaic (PV) was conducted at IKEA Cheras, Kuala Lumpur in year 2016 to 2017. This was the manifestation of the initial idea of an annual trend of solar radiation. In the data collected, rooftop PV generation contributes above 10% of the building's consumption in the months of March, September and October [13]. These months are considered as months with high exposure to solar radiation [13].

4.3.2. Annual Trend of Solar Radiation in Kota Kinabalu

In Figure 3, the solar radiation data is recorded daily and two values are displayed which shows the daily maximum solar radiation and daily average solar radiation. For the purpose of this paper, daily maximum solar radiation is more relevant and therefore used in the calculation.

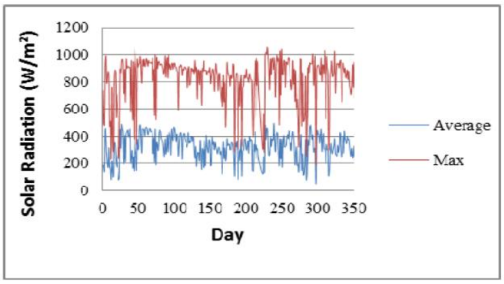

Figure 3 Daily Peak and daily average values of solar radiation in year 2013 in Kota Kinabalu [14].

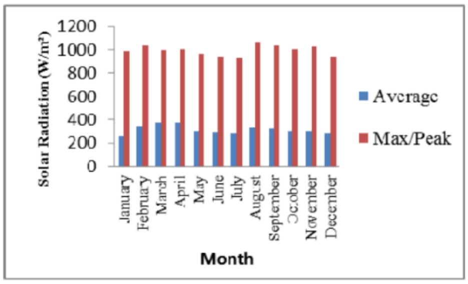

Figure 4 Monthly peak and monthly average solar radiation data in Kota Kinabalu in year 2013 [14].

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It is clear that the data displayed in Figure 3 is highest during the month of August to November. The highest solar radiation recorded in the year 2013 was 1056.10 $\mathrm{W/m^2}$ which falls on August 18 [14]. A day to day solar radiation data was deemed not appropriate in this analysis, instead a monthly solar radiation is used. Figure 4, a monthly solar radiation analysis, shows peak solar radiation and average solar radiation.

The month of April has the highest monthly average daily radiation at 378.76 $\mathrm{W/m^2}$ while the peak daily solar radiation falls in the month of August at 1056.10 $\mathrm{W/m^2}$ [14]. The annual solar radiation trend is now clearer with the average monthly solar radiation data. There are two peaks of solar radiation in a year which are in the months of February-April and August-November. The months from May to July experience a lower level of solar radiation.

4.3.3. Annual Trend of Solar Radiation in Perlis

Perlis in Northern Malaysia is known for its sunshine and holds the record for the highest recorded temperature in Malaysia at 40.1 °C [15]. Therefore most of the solar studies are performed in the state of Perlis due to its solar potential [16].

Figure 5 shows the daily solar radiation data and daily temperature recorded by the weather station in Ulu Pauh, Perlis from March 2011 to August 2011. It is noted that almost 95% of the days in the monitored duration receive around 40-70 % of the full solar radiation [17].

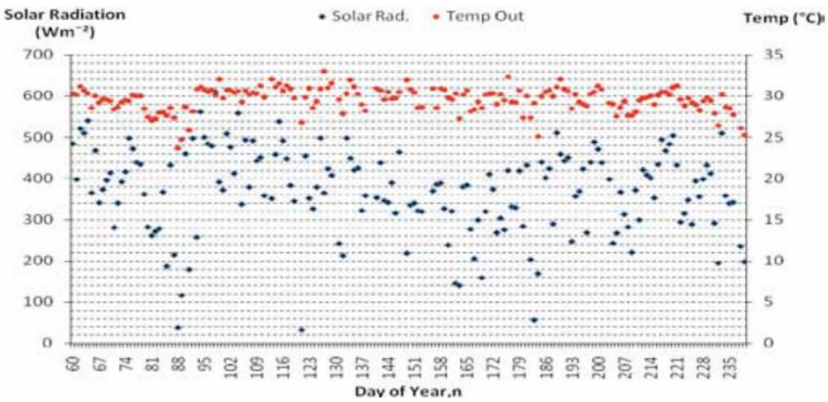

Figure 5 Solar Radiation data recorded in Perlis during the year 2011 [17]

Figure 6 shows the smoothed out version of the data presented in Figure 5 for better trend analysis. Raw data tend to have more outliers and hence it is difficult to identify its trend.

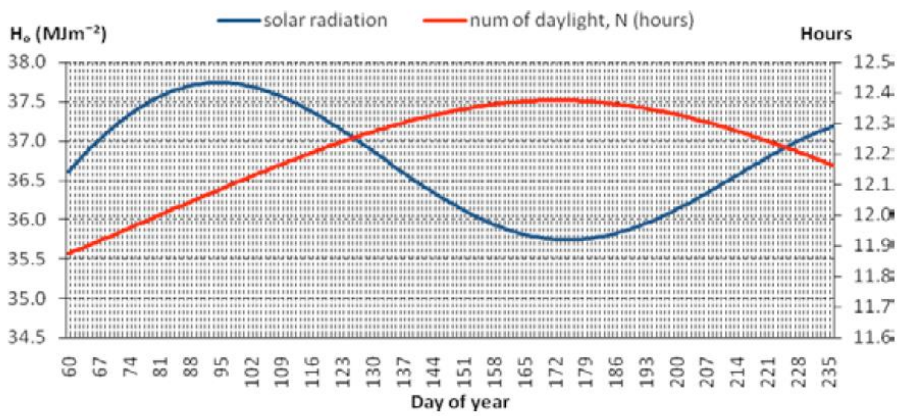

Figure 6 Smoothed out data of energy collected from Solar Radiation in Ulu Pauh, Perlis during March 2011 to August 2011 [17]

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Figure 6 shows a clear trend of solar radiation over the period of one typical year. After the 95th day of the year, the magnitude of solar radiation starts to drop gradually until it reaches the 172nd day of the year where it is the minimum before increasing again.

The trend suggested above is supported by data from another weather station in Kangar, Perlis as shown in Figure 7; which recorded solar radiation data from March 2011 until September 2011.

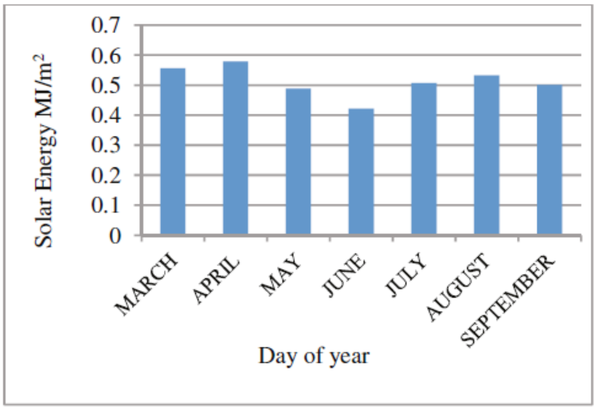

Figure 7 Solar energy recorded at Kangar, Perlis from March 2011 to September 2011 [18]

It is observed that the highest point of solar energy recorded was in April at $0.5782\mathrm{MJ/m^2}$ and the month with the lowest recorded solar energy was in June at $0.4215\mathrm{MJ/m^2}$ [18].

5. METHODOLOGY

The most complete set of recent data located in high solar radiation recordings acquired is from Penang and that is the data that is used in this study.

The IEEE 783 Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors is used to model the temperature of the conductors. The main equation which is the heat balance equation comprises four main components as shown in Equation (1).

$$q_c + q_r = q_s + I^2R(Tc) \qquad \text{Equation (1)}$$

Solar radiation contributes to one of the components in the heat balance equation which is the Solar Heat gain (q_s) component. This is shown in Equation (2).

$$q_s = \alpha \,.\, Q_{\mathrm{se}}.\sin(\theta)\,.\,\mathrm{A'} \qquad \text{Equation (2)}$$

From Equation (2) the solar heat gain component is influenced by the conductor solar absorptivity (α), solar radiated heat (Q_{se}), effective angle of incidence factor ($\sin(\theta)$), and the projected area of conductor (A')

While ambient temperature affects the heat loss by radiation (q_r) as shown in Equation (3)

$$q_r = 0.0178D\varepsilon\left(\left[\frac{T_c+273}{100}\right]^4 - \left[\frac{T_a+273}{100}\right]^4\right) \qquad \text{Equation (3)}$$

From Equation (3), heat loss by radiation is influenced by diameter of conductor (D), conductor emissivity (ε), conductor temperature (T_c), and ambient temperature (T_a).

From the IEEE 738 Standard, a model of the relationship between the conductor temperature, ampacity limit and solar radiation is established to analyse the effect of solar radiation on the ampacity limit.

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6. FINDINGS AND RESULTS

6.1. Raw Data - Daily Solar Radiation Data 2018 (Penang, North Malaysia)

The most complete set of solar radiation data collected comes from the IPENANGP2 weather station on Penang Island. Penang is located at Northern part of West Coast Malaysia. Due to its close proximity to Perlis, it is expected that the Solar Radiation readings from this weather station will have high levels of solar radiation that will be suitable to be used to determine parameters. The daily maximum solar radiation is displayed in Figure 8 and Figure 9.

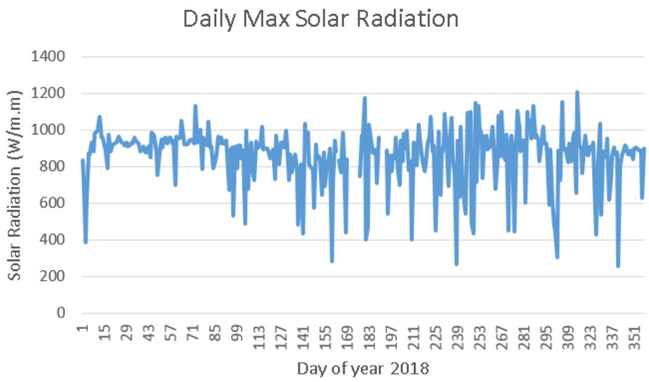

Figure 8 Daily Maximum Solar Radiation in Penang 2018[19]

It is noted that the average solar radiation in the year 2018 for Penang is at 1092.67 W/m^2 which is very high compared with at other recorded locations [19]. The peak magnitude of solar radiation for the whole year falls on the month of November at 1208 W/m^2 [19]. While the month with the lowest maximum solar radiation recorded is February with 991 W/m^2 [19].

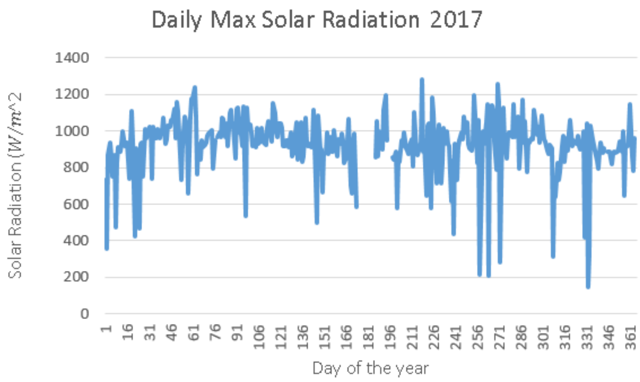

Figure 9 Daily Maximum Solar Radiation in Penang 2017 [19]

The average solar radiation in the year 2017 for Penang is at 1162.5 W/m^2 [19]. The peak magnitude of solar radiation for the whole year falls on the month of September at 1255 W/m^2[19]. While the month with the lowest maximum solar radiation recorded is June with 1069 W/m^2 [19]. With regards to the above and to ensure a good design criteria, the highest solar radiation value is taken and a graph is plotted for analysis in Figure 10.

6.1.1. Maximum Monthly Solar Radiation Data Analysis (year 2017 and 2018)

The first approach to review and update the ampacity line is to replace the existing solar radiation value with the maximum recorded solar radiation. The definition of maximum monthly

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solar radiation in this case is the highest recorded solar radiation in any day of the month. The compiled analysis is shown in Figure 10.

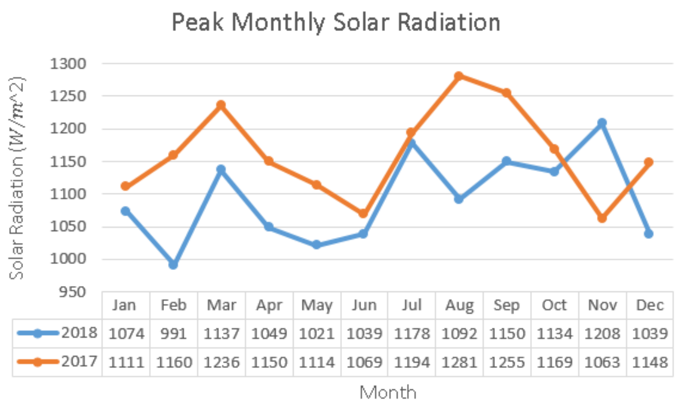

Figure 10 Monthly Peak Solar Radiation year 2017 and 2018 (IPENANGP2 weather station) [19].

There is a solar radiation trend that can be seen in Figure 10. The solar radiation peaks twice in a year, in this case the month of March is the first peak while the second peak happens during the months of July to October.

6.1.2. Median Monthly Solar radiation data analysis (2017 and 2018)

The second approach to review and update the ampacity line is to the existing solar radiation value with the median recorded solar radiation. The definition of median monthly solar radiation in this case is the middle value of each of the daily highest recorded solar radiation in each day of the month. The compiled analysis is shown in Figure 11.

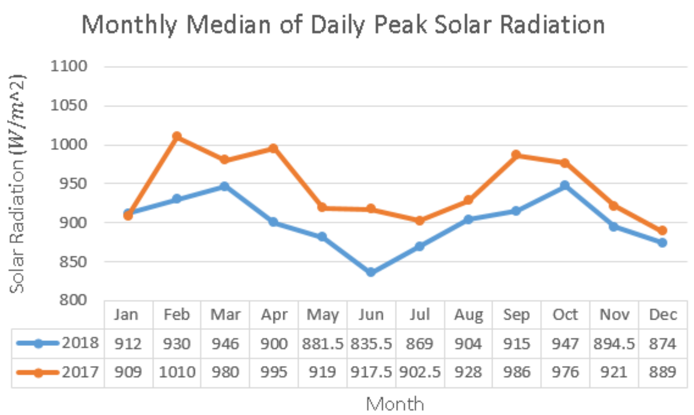

Figure 11 Monthly Median Solar Radiation Analysis 2017 and 2018 (IPENANGP2 weather station) [19].

From the median analysis, the annual trend of solar radiation is quite clear for both years as in the months of March and October are the peak months that receive abundant amount of solar radiation. While the months of June and December are the two lowest points in a year solar radiation levels are relatively low. The periods of Feb to April and September to October have recorded comparatively higher median solar irradiance than other months.

6.2. Monthly Analysis of Solar Radiation (year 2018)

In Table 3, it is shown that the months February to April and July to November recorded high maximum solar radiation. For the months of April to June, the solar radiation levels are relatively lower. It is also observed that the year 2017 has higher solar radiation levels based on

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the number of days that exceeds 1000 W/m^2 that is 90days, whereas 2018 has only a total of 33 days.

Year	Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2017	**Max (W/m^2)**	1111	1160	1236	1150	1114	1069	1194	1281	1255	1169	1063	1148
	Exceeds 1000* W/m^2	3	16	11	13	7	2	3	8	12	11	3	1
2018	**Max (W/m^2)**	1074	991	1137	1049	1021	1039	1178	1092	1150	1134	1208	1039
	Exceeds 1000* W/m^2	1	0	3	1	1	2	2	3	8	9	2	1

* Number of days in the month which solar radiation reading exceeds 1000 W/m^2

Table 3 Monthly Maximum Solar Radiation and tendency to exceed 1000 W/m^2 for 2017 and 2018.

The difference between the two years is in line with the overall trend decreasing solar radiation which correlates to the 11 year of solar magnetic activity cycle that spans from low solar activity to high solar activity back to low solar activity [20].

6.3. Case study - Monthly Ampacity limits on 2018 maximum solar radiation

The case study ampacity values using the monthly peak/max solar radiation values shown in Table 3 are calculated in order to analyse its variation and impact. These values are shown in table 4. The ampacity values are from replacing the existing solar radiation value with the monthly maximum solar radiation values. Ambient temperature is maintained at 32 °C to purely study the effects of solar radiation.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Max (W/m^2)	1074	991	1137	1049	1021	1039	1178	1092	1150	1134	1208	1039
ACSR Zebra (A)	727	744	713	732	738	734	704	723	710	714	698	734
ACSR Curlew (A)	820	841	804	826	833	829	793	815	800	805	785	829

Table 4 Monthly Ampacity limit for 1 bundle conductor, corresponding to Solar Radiation data 2018.

From the calculated ampacity above, it is found that in the months of March, July, September, October and November (months with high solar radiation levels), the existing ampacity rating will exceed the conductor temperature limit- – shown by the lower ampacity when compared to the existing ampacity values shown in Table 1; i.e. the capacity would have been reduced by limitation of maximum temperature conductor when the actual solar radiation is greater than the fixed parameter. While in the month of in the months of January, February, April, May, June, August, and December (low solar radiation levels), the conductors are actually capable to carry more current and therefore in actual condition, would have been underutilised. The largest deviation from ACSR Zebra is 6.6 % between February and November while the largest deviation for ACSR Curlew is 7.1 % with the same months.

6.4. Effects of Increased Ambient Temperature

The utility company in Malaysia, TNB uses the standard of 32°C for static line rating calculation but the most recent data as displayed in Table 5 shows that ambient temperature has increased beyond that.

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Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Max (°C)	33.0	33.8	33.8	34.7	35.8	34.2	35.5	36.2	35.8	33.9	32.7	32.9

Table 5 Monthly Maximum Ambient Temperature 2018 [19]

The ambient temperature of 32°C is no longer valid as the conservative rating due to the local temperature rise over the past 40 years in Malaysia.

6.5. Step-wise ampacity rating concept

Alternative to static rating, information on the trending of solar radiation could be implemented for a more flexible dynamic-like rating, or referred to here as step-wise rating. The concept is to apply the seasonal climatic solar radiation and the newly-identified and more suitable ambient temperature to the rating. The solar radiation data show a trend which correlates to the seasons and tilt angle of the Sun. Since the geographical location of Malaysia is located near the equator, during the equinoxes would theoretically be the time where highest solar radiation would be experienced while during the summer and winter solstices where the Sun is at the extreme North and South respectively would be when solar radiation levels are the lowest. The Equinoxes fall roughly on 20 March and 23 September every year. While the solstices usually fall on 21 June and 22 December every year.

The proposed period of each season is selected based on the solstices and equinoxes of the year. The equinoxes are selected as the anchors and the days near the equinoxes are labelled as days with high solar radiation while the solstices are the opposite. This is the main framework of how seasonal ampacity is divided. The zones are later fine-tuned with actual data from year 2017 and 2018 to further expand the equinox zone to provide buffer and increase line reliability.

The implementation of step-wise ampacity could be possible with two-perspective approach. One, a slightly conservative approach would be to use different maximum values of solar radiation and ambient temperatures to the identified periods; and another would be to use the median solar radiation values instead.

i) Seasonal Ampacity Limits (conservative approach)

The slightly conservative approach would be employing both the monthly maximum values for solar radiation and maximum ambient temperatures for the consecutive months shown below. Table 6 shows the seasonal step ampacity approach by grouping consecutive annual months together which are with higher and lower monthly maximum solar radiation values. The identified periods are then assigned with its seasonal ambient temperature based on the maximum ambient temperature apparent for that consecutive months.

Period	1 Mar – 7 Apr	8 Apr – 30 June	1 July – 26 Nov	27 Nov – 28 Feb
Max (W/m^2)	1137	1178	1208	1074
Max Temp (°C)	34.7	35.8	36.2	33.8
ACSR Zebra (A)	676	683	638	703
ACSR Curlew (A)	761	770	716	792

Table 6 Seasonal Conservative Ampacity limit corresponding to the peak solar radiation and ambient temperature in each period.

ii) Seasonal Ampacity Limits (efficiency approach)

The peak solar radiation reading in the day does not last long. Solar radiation usually lasts for 20 to 30 minutes at its peak before subsiding as shown in Figure 12. Therefore using a super conservative solar radiation parameter may not be an optimum approach to efficiently utilise the grid infrastructure. If a comparatively solar radiation value is used and the line rating is breached

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for the duration of the solar radiation peak, the excess loading would have been endured for 20 to 30 minutes only.

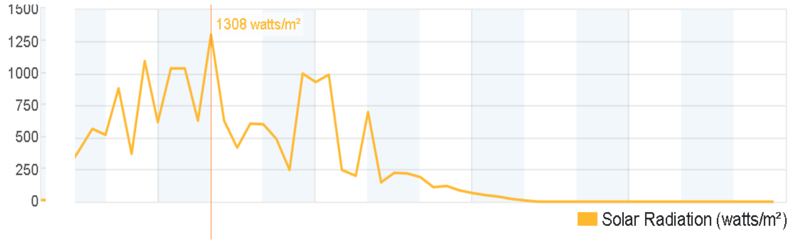

Figure 12 Typical Daily Solar Radiation profile [19].

To have a better view of the solar radiation a table form of the solar radiation profile shown in Figure 12 is displayed in Table 7.

Time of day	Solar Radiation (W/m^2)
12.31pm	1042
12.46pm	633
1.01pm	1308
1.16pm	653

Table 7 Solar Radiation recording from Figure 12 [19]

Therefore, an approach of using monthly median peak solar radiation is used instead of the maximum monthly peak solar radiation value. The efficiency approach ampacity rating is shown in Table 8.

Period	1 Mar – 7 Apr	8 Apr – 30 June	1 July – 26 Nov	27 Nov – 28 Feb
Median (W/m^2)	945	870	902	900
Max Temp (°C)	34.7	35.8	36.2	32.7
ACSR Zebra (A)	719.4	721.0	708.7	754.7
ACSR Curlew (A)	812.5	815.0	800.6	853.5

Table 8 Ampacity rating with Median Solar Radiation Values.

The reason why a median solar radiation value approach is comparably viable than a median ambient temperature approach is the fact that instantaneous incidence and transient nature of solar radiation which results often results in peak values not sustainable maintained for long periods of time. Whereas the maximum temperature usually lasts a lot longer as temperature change throughout the days is much slower compared to the spikes and dips of solar radiation.

7. ANALYSIS AND IMPACT

7.1. Comparison between the existing ampacity rating and proposed step-wise ampacity rating

The new conservative ampacity limits are compared with the existing static line rating of 717 Amperes for analysis in Table 9. An analysis of finding out the conductor temperature in the current weather condition if the existing ampacity calculation is still practiced is also shown.

Period	1 Mar – 7 Apr	8 Apr – 30 June	1 July – 26 Nov	27 Nov – 28 Feb
ACSR Zebra (A)	676.87	683.75	638.34	718.15
Percentage difference,%	-5.60	-4.64	-10.97	0.16
Conductor Temperature* (°C)	77.85	77.37	80.40	74.92

* Ampacity with re-assigned values for weather parameters

Table 9 Analysis for ACSR Zebra conductor.

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The same analysis is done for ACSR Curlew conductors as well. The existing ampacity limit for ACSR Curlew is 808 Amperes. This is shown in Table 10.

Period	1 Mar – 7 Apr	8 Apr – 30 June	1 July – 26 Nov	27 Nov – 28 Feb
ACSR Curlew (A)	761.64	770.54	716.38	809.84
Percentage difference, %	-5.75	-4.65	-11.35	0.21
Conductor Temperature*(°C)	77.83	77.30	80.41	74.88

* Ampacity with re-assigned values for weather parameters

Table 10 Analysis for ACSR Curlew conductor.

If the existing parameters in the rating is utilised with the current weather situation, the conductor will breach the 75°C conductor temperature limit and this may cause more sag that may lead to insufficient clearance and flashover on bare overhead conductors.

7.2. Comparison Between the Conservative Seasonal and Emergency Seasonal Line Rating

The difference in added ampacity between the conservative ratings and the emergency/efficiency rating is shown in Table 11 and Table 12.

Period	1 Mar – 7 Apr	8 Apr – 30 June	1 July – 26 Nov	27 Nov – 28 Feb
Conservative ACSR Zebra (A)	676.87	683.75	638.34	718.15
Emergency ACSR Zebra (A)	719.4	721.0	708.7	754.7
Percentage Difference, %	6.28%	5.45%	11.02%	5.09%

Table 11 Comparison between conservative static rating and emergency rating for ACSR Zebra.

Period	1 Mar – 7 Apr	8 Apr – 30 June	1 July – 26 Nov	27 Nov – 28 Feb
Conservative ACSR Curlew (A)	761.64	770.54	716.38	809.84
Emergency ACSR Curlew (A)	812.5	815.0	800.6	853.5
Percentage Difference, %	6.68%	5.77%	11.76%	5.39%

Table 12 Comparison between conservative static rating and emergency rating for ACSR Curlew.

Across the board, around a minimum of 5% gain of ampacity is achieved with the highest being is the around 12% in the September – November months. Therefore, a conclusion can be drawn that in the months of where a larger amount of ampacity gain is achieved are the months where high solar radiation do not happen consistently and often.

8. LIMITATIONS

Weather data availability was the main limitation in this study as the required solar radiation data needs to be in the power unit $(\mathrm{W/m}^2)$ while most acquired solar radiation available are in the unit of energy $(\mathrm{MJ/m}^2)$ or $(\mathrm{kWh/m}^2)$. With the unit of energy, the information about the crucial peak daily solar radiation is lost or could not explicitly be obtained. The solar radiation value used are taken from a weather station which records high solar radiation values. To achieve a more accurate representation of what the overhead lines are experiencing, solar radiation and ambient temperature sensors should be station at key location of the transmission towers to collect accurate data. This is because solar radiation and temperature varies with location and terrain.

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9. CONCLUSION

Existing static line rating parameters are outdated and need to be updated to comply with safety guidelines and monitoring the health of grid infrastructure. It is apparent that the change in the local climate calls for a review in the parameters used in the ampacity rating. Ambient temperature and solar radiation values that was used which was determined decades ago may be no longer valid to fit today's ambient conditions. Identifying annual trends in solar radiation could offer a possible step-wise ampacity rating in which benefit could be reaped from the added ampacity ratings during off seasons where solar radiation levels are relatively lower. While the most optimal form is dynamic line rating, a step wise line rating would assist utility companies to look into finding new ways to better utilise the existing grid infrastructure to meet modern demands.

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