International Journal of Energy and Power Engineering
2022; 11(2): 56-67
http://www.sciencepublishinggroup.com/j/ijepe
doi: 10.11648/j.ijepe.20221102.15
ISSN: 2326-957X (Print); ISSN: 2326-960X (Online)

Dynamic Line Rating Solution: Deployment Opportunities for the Power Transmission Grid of Vietnam

Xuan Truong Nguyen*, Tien Dat Nguyen

Department of Energy, University of Science and Technology of Hanoi, Vietnam Academy of Science and Technology, Hanoi, Vietnam

Email address:
nguyen-xuan.truong@usth.edu.vn (X. T. Nguyen), datnt.b8041@st.usth.edu.vn (T. D. Nguyen)
*Corresponding author

To cite this article:
Xuan Truong Nguyen, Tien Dat Nguyen. Dynamic Line Rating Solution: Deployment Opportunities for the Power Transmission Grid of Vietnam. *International Journal of Energy and Power Engineering*. Vol. 11, No. 2, 2022, pp. 56-67. doi: 10.11648/j.ijepe.20221102.15

Received: January 14, 2022; **Accepted**: April 23, 2022; **Published**: April 28, 2022

Abstract: Power system usually have standard static ratings (SLR) that determines load constraints. It refers to the maximum allowable conductor ampacity pre-determined by worst-case conditions (high ambient temperature, maximum solar radiation, and low wind speed) of their overhead transmission lines, that rises the line's temperature without infringing ground clearance and causing loss of conductor tensile strength. Line's dynamic capacity is created as an alternative to standard constant rating that is designed with reference to extreme weather and load conditions. Dynamic line rating allows assets the real power line's operating capacity using available information on weather conditions. DLR is hence often more flexible than SLR, that have a chance of extending capacity of existing power lines for some periods of time with favorable weather conditions for transportation higher electrical power capacity from production site to the load. This paper investigates the possibility of using dynamic line rating (DLR) to expand the existing power transmission capacity of overhead lines which can be implemented on 220 kV transmission lines in Vietnam, especially in some line areas with high-density of renewable energy integration. This work applies a DLR caculation models to determine the power lines' additional theoretical ampacity obtained by using this methodology for a Ninh Thuan region with distinct conditions regarding i) weather database, ii) topography and iii) wind and solar power resource. The results show that the dynamic rating is predominantly higher than the static rating, which potentially enhances the system's reliability. This research provides a comprehensive study of literature on dynamic line rating, current constraints on the power system based on the geography of Vietnam, and analysis in Python and Matlab environment of real-time weather databases applied to dynamic rating on a proposed case study.

Keywords: Dynamic Line Rating, Static Rating, Ampacity, Overhead Conductor, Thermal Capacity

1. Introduction

In many countries, like Vietnam, one of the main challenges is facing hot growth renewable energy sources (RES) integration and high-level of congestion to the power system. This is the need to upgrade or reinforce the transmission and distribution electric networks [1]. In general, the way to solve the additional power capacity while maintaining the principles of robustness, security, and reliability has always been to upgrade power lines. However, the construction of new lines is a lengthy process that requires a massive investment, intensive use of land, and presents heavy environmental impacts [2]. In short-term, it has become mandatory to introduce new solutions to increase the efficiency of the existing power transmission line system in a secure way and deliver the required capacity in a timely and economically viable way.

The limiting factors for the transmission capacity of overhead lines (OHL), i.e., the maximum allowed current or ampacity, are based on two main criteria: maximum conductor temperature, and minimum distance above ground or clearance [3]. Complying with these factors, the line ampacity is defined using a "static line rating" (SLR) employing conservative constant weather conditions over an extended period of time, days, months, or years. Typically, low wind speeds (0.6 m/s), full solar irradiance (1000 W/m^2), and high ambient temperature (40°C) are assumed for the SLR calculation [4]. However, the higher transmission capacity of an OHL is observed when wind speed is higher in the area where the line passes, due to line cooling effects. It is one of the reasons, why power systems do not use all their potential transmission capacity in operation. Dynamic line rating (DLR) is a novel solution used to determine the actual value of available power transmission capacity of overhead lines being underestimated by SLR [5]. Environmental conditions such as ambient temperature, humidity, wind speed and wind direction have significant impact on the heat balance of the power line, the weather parameters can dynamically vary the capacity of power line. The process of building new wind farms requires a lot of planning and analysis. Besides that, the connection of new wind farms to the grid is a challenge, causing by an insufficient power line's transmission capacity. When planning wind power integration, if dynamic line limits are considered instead of the conservative and static limits, estimated transfer capacity increases. DLR technology with monitoring system and forecasted line ampacity algorithm has a potential to connect new wind farms to the existing grid faster, by minimizing construction efforts on necessary transmission system [6].

A lot of pilot projects have been implemented in the US, Europe has shown that actual line ratings or DLR are higher than static rating up to 20-40% in the 95% of operation time of the power system [7-9]. The potential of using the DLR technique help to increase the reliability of power systems is therefore significant. This method led to the development of detailed numerical models: IEEE 738 [10] and CIGRÉ [11], that have been applied successfully to different geographical regions demonstrating DLR has a significant potential to increase the power capacity of transmission lines. In term of the DLR application, there are two approaches: (i) direct monitoring of the conductor's physical parameters (e.g., line temperature and sag monitoring), and (ii) indirect monitoring through the environmental parameters (e.g., wind speed and direction) that affect line ratings [7]. The first approach recognizably provides greater accuracy compared to the second approach. Significant research and development efforts are also being invested in the technological advancement of DLR to facilitate grid operators in making better planning and operational decisions in terms of capacity utilization of the existing OHL [12]. However, one of the key challenges is to quantify the potential benefits of DLRs to electric utilities through field studies on actual utility grids. In this context, it still needs to implement a lot of pilot project, research experiences in order to demonstrate the feasibility deployment of DLR and its best practices as one of key-solution of smart-grid technology.

DLR appears to be one of the potential technologies for the smart grid vision to fully exploit the ability of the transmission line with technical, cost benefits, and feasible pilot implementation project in a typical transmission, distribution lines in Vietnam electricity network [13, 14]. To specify these enormously beneficial aspects, the proposed work directly applies DLR with a theoretical calculation based on two heat balance models: IEEE and CIGRÉ in a case study using data analysis, programming, and assessment methods which are considered as supporting tools. The study will show the feasibility of applying DLR technology on an example transmission lines in Vietnam with a high level of wind speed and nearly overloaded assumption.

This paper consists of 5 sections. Section 2, we describes the background of power line thermal rating. Methodology and source data are summarized in section 3. Results of a case study are presented and analyzed in section 4. The last section provides major conclusions and indicates directions for our future work.

2. Power Rating Background

The electrical power system is built according to transmission capacity needs. The transmission lines are designed according to the standards and when using the static line ratings, the dimensioning is designed with reference to extreme weather and load conditions [2-5]. A transmission line is referred to as being thermally limited when heating considerations set the maximum power flow capacity on the line. These thermal limits (i.e., maximum current carrying capacity at a given voltage) are determined based on the maximum operating temperature of the conductor that prevents premature aging and that limits conductor sag to maintain minimum clearances under the line for safety. Overhead conductors expand at higher temperatures, lengthening the line and reducing the distance to the ground and other objects, which can result in arcing or faults if safe clearance distances are not maintained (Figure 1). Generally, the physical properties of the conductor (i.e, maximum temperature rating, electrical resistance, mechanical strength) and a set of environmental conditions (i.e., ambient air temperature, humidity, wind speed and solar insolation) are used to calculate thermal limits. Several designations are used to define the type of power line ratings or ampacity, for example: static line rating, seasonal line rating, ambient temperature adjusted line rating and dynamic line rating. Ambient temperature adjusted and dynamic transmission line ratings are more dynamic than static and seasonal ratings, and their rating values change on a more frequent basis.

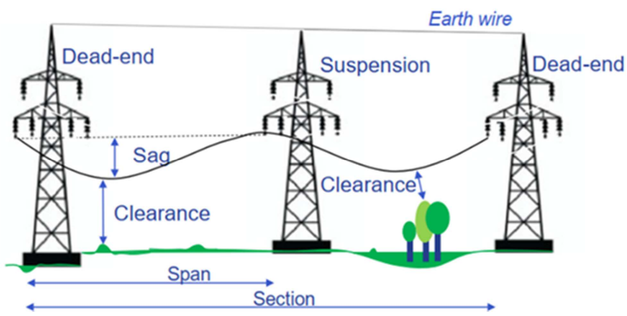

Figure 1. *Sag, clearance model, span for an overhead transmission line.*

2.1. Static Line Rating Approach

Line ampacity's concept is determined by the maximum unchanged amount of electrical current that a conductor can carry constantly before being deteriorated due to parameters related to the structure and design of the conductor, the ambient conditions of the environment, and the line's operating status to meet the security and safety criteria [15-17]. This rating is usually calculated using conservative assumptions for the transmission line operating environments such as average static weather conditions: average wind speeds and direction, average ambient temperatures, and solar conditions for summer and winter seasons. Thus, static ratings may remain unchanged for years, or may never change at all during the lifetime of a transmission line. Overall, SLRs produce an inflexible constraint that does not take advantage of changing or favorable environmental conditions in some periods of time that allow greater transportation usage. IEEE Standard 738 is used to calculate the rating for a given line based on a desired maximum operating temperature [18].

For some electricity networks (for example in the USA), the seasonal ratings are the most used ratings. Seasonal ratings are like static ratings but use a different set of ambient condition assumptions for summer and winter. Summer ratings are commonly used from May through October, and winter ratings are commonly used from November through April. Summer transmission line ratings use conservative ambient temperature assumptions and are often based on 95 or 100-degrees Fahrenheit. Winter ratings are often based on 32 degrees Fahrenheit [17].

2.2. Dynamic Line Rating Method for Maximizing Power Line Capacity

The application of DLR for an overhead line is crucial to dynamically exploit the available assets of the line's capacity by considering the variability of the environmental factors (wind speed, wind direction, ambient temperature) which play the role in dissipating the heat gained of the conductor due to solar irradiance, magnetic and Joule effect. Making a thermal calculation, line ampacity or line rating is calculated as the current intensity value which equals conductor temperature to its maximum allowable value. The DLR analysis strictly follows the steady-state heat balanced approach proposed by the IEEE and/or CIGRÉ models [5-19]. These models are similar regarding the calculation method; however they differ in the factors that they consider for the heat balance calculation [20]. The energy balance inside the conductor without any heat storage causes the amount of heat supplied completely convert into the outside environment by heat dissipation which is expressed under the simplified equilibrium equation of heat gained (by Joule effect (P_J), Solar heating (P_S)) and heat lost (by convection (P_c), radiation (P_r)) by EEE Standard 738 [10, 20]:

$$P_J + P_S = P_c + P_r \tag{1}$$

Every parameter presented in the heat balance equation has initial input weather-dependent variables: solar radiation S_I, wind angle θ, wind speed V_w, ambient temperature T_a, ampacity I and conductor surface temperature T_c so it can be displayed under a function form:

$$P_J(T_c, I) + P_S(S_I) = P_c(\theta, V_w, T_a, T_c) + P_r(T_a, T_c) \tag{2}$$

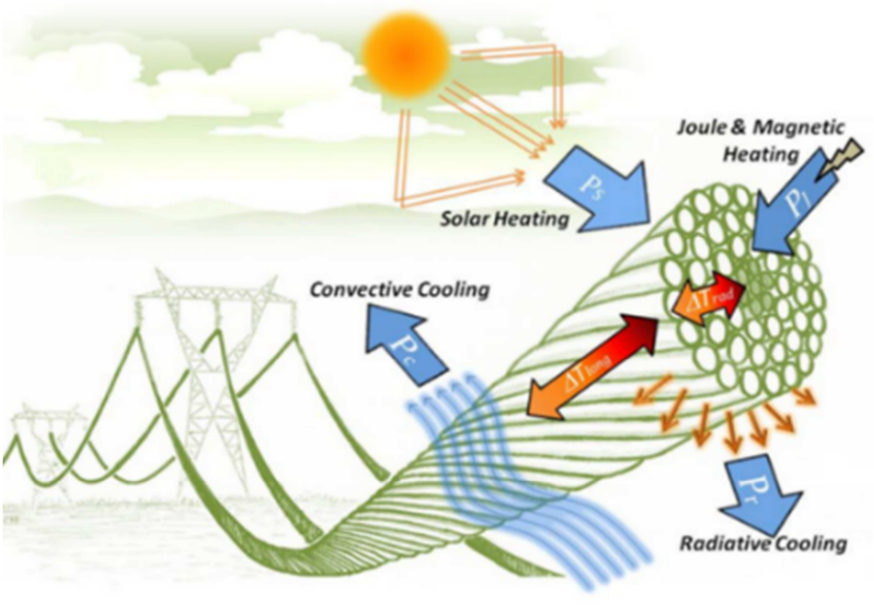

Figure 2. *Heat balance diagram of a conductor [2-11].*

In the application with the rating in real-time, these variables can be measured in the specified chosen time interval:

$$P_J\left(T_{c,t}, I_t\right) + P_S\left(S_{I,t}\right) = P_c\left(\theta_t, V_{w,t}, T_{a,t}, T_{c,t}\right) + P_r\left(T_{a,t}, T_{c,t}\right) \tag{3}$$

When ampacity for DLR is considered, the formula can be utilized with unchanged maximum allowable conductor temperature $T_{c,max}$ which gives the output of maximum ampacity in each time-step $I_{t,max}$ determining dynamic ampacity value [18]:

$$P_J(T_{c,max}, I_{t,max}) + P_S(S_{I,t}) = P_c(\theta_t, V_{w,t}, T_{a,t}, T_{c,max}) + P_r(T_{a,t}, T_{c,max}) \quad (4)$$

The CIGRÉ loading guidelines expand the formula (1) by corona heating (P_i), magnetic heating (P_M) and evaporative cooling (P_w) as shown by the equation (3) [11, 19]:

$$P_J + P_S + P_M + P_i = P_c + P_r + P_w \quad (5)$$

Based on the equation (1) the formula for calculation of the current rating (I) of the conductor (equation (6)) is developed:

$$I = \sqrt{\frac{q_r + q_c - q_S}{R(T_{avg})}} \quad (6)$$

Where: (q_r), is the rate of cooling due to radiation into surrounding medium, [W/m]; (q_c), is the rate of cooling due to convective heat transfer, [W/m]; ($R(T_{avg})$, is the specific conductor material resistivity at the average temperature (T_{avg}), [Ω/m]; (q_s), is the rate of heating due to solar irradiation, [W/m].

The convective cooling (q_c) for low wind speeds is calculated using the equation (7) and for high wind speeds using the equation (8). IEEE guidelines recommend calculating both variables (q_{c1}) and (q_{c2}) for each wind speed and using higher of two values:

$$q_{c1} = K_{angle}.k_{f,IEEE}.(T_c - T_a).\left(1.01 + 0.372.\left(\frac{D.\rho_f.V_w}{\mu_{f,IEEE}}\right)^{0.52}\right) \quad (7)$$

$$q_{c1} = K_{angle}.k_{f,IEEE}.(T_c - T_a).\left(0.0119.\left(\frac{D.\rho_f.V_w}{\mu_{f,IEEE}}\right)^{0.6}\right) \quad (8)$$

Where: overall conductor diameter D, [m]; the dynamic viscosity of air μ_f, and air density ρ_f, [kG/m^3]; k_f, is the thermal conductivity of the air at average temperature $(T_c + T_a)$=2, [W/m.K]; K_{angle}, is the wind angle coefficient, which is calculated:

$$K_{angle} = 1.194 - \cos(\theta) + 0.194\cos(2\theta) + 0.368\sin(2\theta) \quad (9)$$

where θ, [deg] is the angle between the overhead line conductor and the wind direction.

Dynamic line rating can have several levels of accuracy depending on how it is applied to the real power system. An example in Figure 3 illustrates how the deployment of DLR on an overhead line would result in a 25% capacity increase on the line 50% of the time, and a 15% gain 90% of the time [4]. Dynamic rating by application of weather model allows increasing the line capacity by up to 20%, depending on the weather conditions [21].

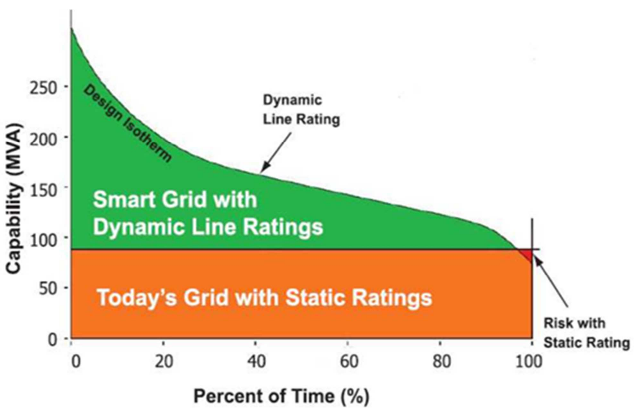

Figure 3. *Schematic comparison of static and dynamic capacity limit [4].*

The calculation methods are classified as indirect and direct methods [7-24]. The indirect method (Figure 4) uses the measuring data from equipment placed surrounding line system giving all concerning parameters (wind speed, wind direction, solar radiation, and ambient temperature), which is then put into heat exchange equations (1), (5) to calculate the maximum amount of allowable intensity that the overhead line can carry in that specified time interval. This approach requires the consideration of wind direction; therefore, the uncertainties caused by wind variability are projected to be substantial. As wind speed and direction vary along a transmission line, conductor temperature may change from one span to another. Thus, allowable line thermal capacity could vary from span to span. The line capacity is estimated at each span. Line rating is then determined by the average capacity overall line spans. The Direct method (Figure 5) uses the monitoring devices to gather data about the line characteristics via one of the following variables: conductor sag, line tension, conductor clearance to ground, or conductor temperature. The direct measurement parameters are used to calculate the effective wind speed that cools the conductor. The effective wind speed is the wind that for the measured current intensity, ambient temperature, and solar radiation results in the measured conductor temperature. This calculation is carried out by using both IEEE and CIGRÉ models mentioned above. The wind direction is assumed to be perpendicular to the conductor. Finally, ampacity is obtained from the calculated wind speed, which is perpendicular to the conductor, and the measured ambient temperature and solar radiation. The Indirect method is inherently less accurate than the direct measurement of sag or tension since an assumed relationship between conductor temperature and measured data from indirect methods is required. However, due to the limiting resources concerning the conductor temperature, sag or tension is unavailable; the indirect method with weather magnitudes will be used instead in this study.

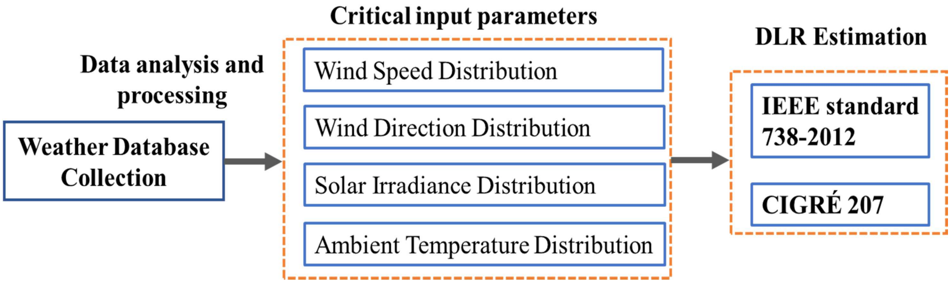

Figure 4. *Indirect method for dynamic rating calculation diagram.*

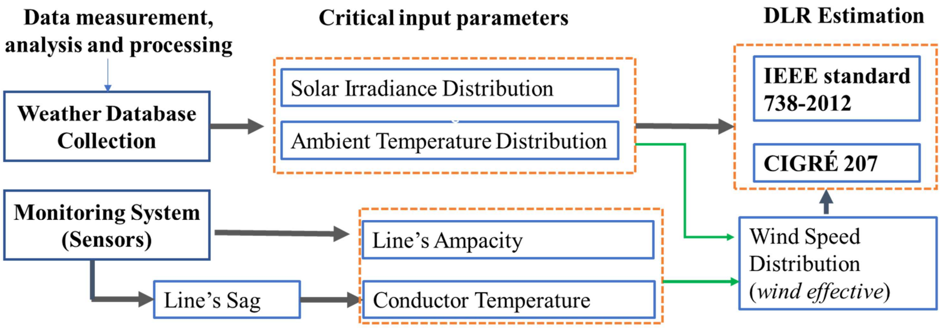

Figure 5. *Direct method for dynamic rating calculation diagram.*

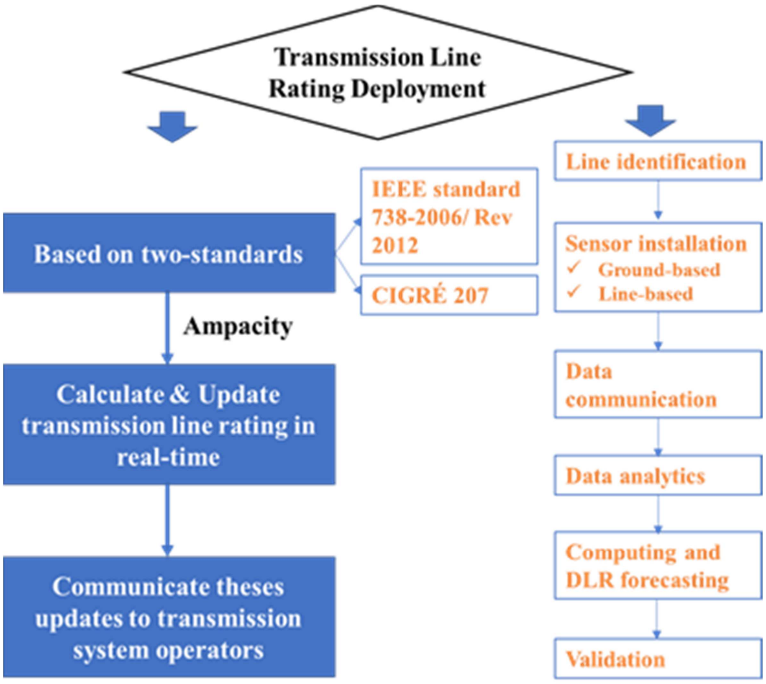

Figure 6. *Flowchart of the methodology application for transmission line rating implementation [14-24].*

Based on these standards, modern technologies work in a coordinated manner to calculate and update transmission line ratings in real-time, and to communicate these updates to transmission system operators (Figure 6). These technologies include remote sensing, measurement, communication, data analytics, high-performance computing, and automation. Implementing a DLR system requires the following steps: line identification; sensor installation; data communication; data analytics; computing and temperature forecasting; and, finally, validation [14-24].

3. Data Collection and Case Study

3.1. Vietnam Power System: Current State

Vietnam's electricity grid system is divided into separate regions: North, Central, and South, which had initially their own standards and technologies. Over time, with the unification of the country and the economic development, especially in the Southern region, it was necessary to unify the entire grid into a unified standard, to connect separate regional electrical systems, to transmit a large amount of capacity from the North to the South. The first 500 kV line with 1500 km was put into operation in 1994 after more than 2 years of construction. It integrates the 3 regional systems (previously operated independently), thereby enhancing the coordination, increasing the stability and the general reliability of the whole system. Since then, after more than 25 years of operation and expansion, the system has 26,497 km of 500 kV and 220 kV and nearly 21,559 km of 110 kV lines, according to the recent electricity of Vietnam (EVN) annual report in 2021 [25]. With the rapid development of the demand, the transmission system is heavily solicited for balancing the capacity of the system. The demand is not homogeneously distributed over the country. The North (with the region of Hanoi) and the South (with Ho Chi Minh City) absorb about 45% of the power each while the Central part acts mainly as a transmission corridor and production site. Transmission lines between the North and the Central part of Vietnam are always in high load status, especially in flood season [1, 25].

In recent years, the strong increase of renewable power generation, mainly solar and wind farms, integrating into the grid has also brought many challenges. Technically, wind or large solar power plants are often installed in areas far away from the load, so the transmission line is heavy and expensive. This power source is unstable and fluctuates in very large capacity in the short term and needs backup resources such as hydropower or battery storage systems. The grid system, which presently receives 16,500 MW installed capacity from solar power plants and 7,785 MW from rooftop solar by the end of 2020. This far surpassed the original 2020 target of 850 MW and is even approaching the tentative target of 18,600 MW of installed solar power capacity by 2030 that appears in the draft version of Vietnam's Power Development Plan VIII [26]. The power production from solar and wind energies rose from 4.7 TWh in 2019 to 9.5 TWh in 2020. It could face an increase of the installed capacity in coming years from renewable power plants with the integration of offshore wind farms, concentrated mainly in the Southern and Central regions putting a pressure on the upgrade of the transmission grid system (110, 220 kV, even 500 kV) to meet such a large capacity. Besides, the connection of new wind farms to the grid is an issue on its own. Sometimes wind farm owners have to wait for grid connection after construction of the wind farm has been finished. The boom in renewable energy projects is leading to difficulties in state management [27]. Building new transmission lines to release all the power from renewable power plants, EVN have also planned to build and put into operation energy storage systems, implement a smart grid technology to control and optimize the power operation. An initiative by the World Bank to smart grid solutions-based enhancement of power transmission in Vietnam included a separate dynamic line rating technology application to cope with the concerns regarding rapid load growth-based line ampacity insufficiency [28]. The dynamic rating technology has become increasingly important and is incorporated in the smart grid vision for the Vietnam power system [29, 30]. In fact, operating 220 kV and 500 kV power transmission lines, there are difficulties: the conductors have increased sag/clearance due to overload operation, high temperature or natural disasters, or sometimes lags due to sudden increase in load... leading to many incidents causing great economic losses. In shorterm, instead of building new transmission lines, new wind farms can be connected to the existing transmission system by applying DLR technique. An example of DLR implementation is presented in Figure 7 for 220 kV transmission lines in Vietnam [29, 30]. In the following part we present a case study of the existing line scenario and possibility to extend it’s ampacity with a potential for connecting the wind farm.

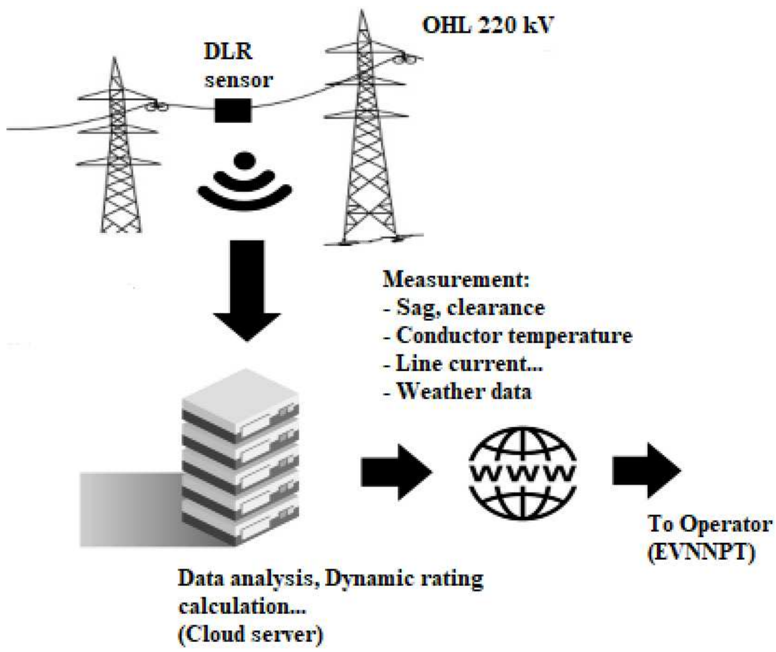

Figure 7. *Overall configuration diagram of dynamic line rating monitoring system for transmission power lines [29, 30].*

3.2. Overhead Transmission Line 117 km Nha Trang - Thap Cham 220 kV (Ninh Thuan Province)

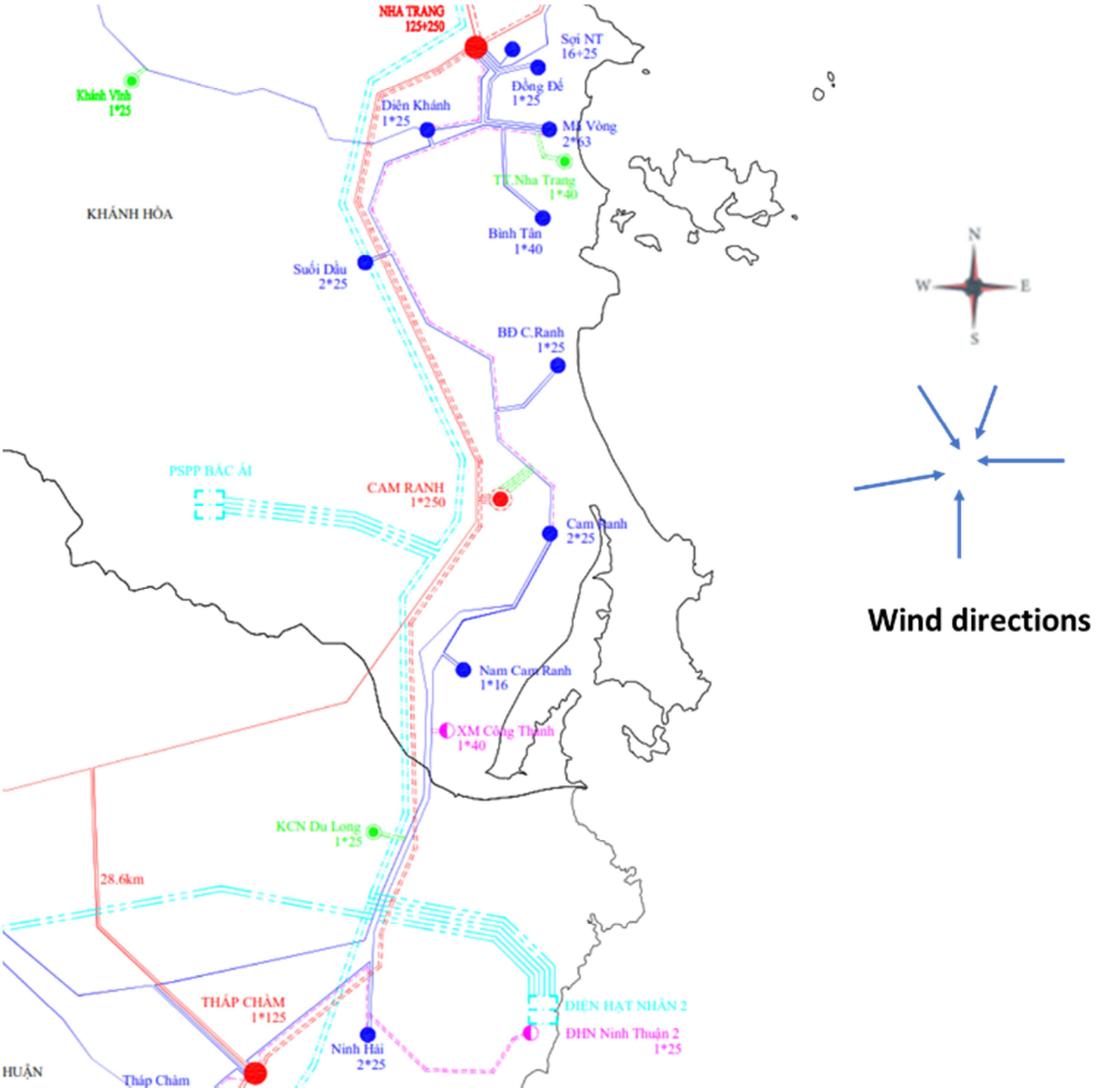

Figure 8. *Overhead transmission line 220 kV Nha Trang – Thap Cham (red line) according to the wind direction along line corridor [31, 32].*

To evaluate a potential benefit of the dynamic rating for wind power integration we use a overhead line located in the South Central Coast region in Vietnam. The transmission line 220 kV is located in Ninh Thuan province, as an area having the largest renewable energy (onshore wind power, offshore wind power, solar power) potential in Vietnam [33]. Until 2021, the number of completed solar power projects in Ninh Thuan was highest in Vietnam with the total installed capacity of 3,475 MW [34]. The DLR analysis was applied to the transmission line 220 kV, namely 274/Nha Trang - 276/ Thap Cham (Figure 8) which is required to meet the criteria by providing electricity for nearly high and overloaded regions or being bounded in the transmitting ability in segments releasing power from generation sources. The single circuit line contains high viability and possibility to install DLR system with medium-length of ~ 117 km, number of supports of 345 poles and assummed under overload situation [31, 32]. The static rating that the line operates is at 850 A (Table 1).

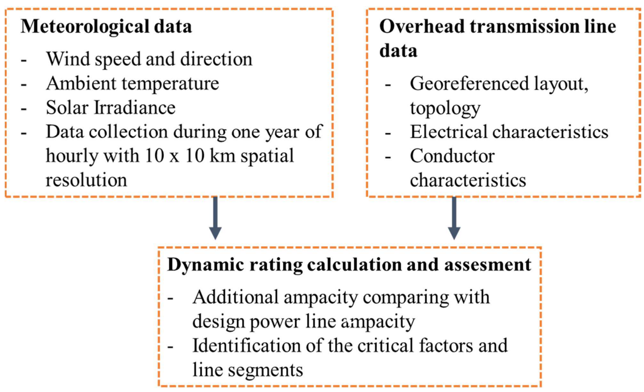

Figure 9. *Flowchart of the methodology application for transmission line rating implementation.*

Table 1. *Technical data of overhead transmission line 220 kV 274/Nha Trang – 276/ Thap Cham, 117 km.*

Specifications	Value
Line length	117.794 km
Number of poles	345
Line Section	394/51.1 mm^2
Conductor Material	1xACSR 400/ 51
Static Rating	850 A

The flowchart of the methodology proposed is presented in Figure 9. The first step is to collect the meteorological data around power line regions and the overhead transmission line data with information of the design power line capacity (reference value). Then, based on collected data the dynamic line rating is estimated, and the outcomes of this approach will be compared with the reference value. The method is applied to the case study to identify: (i) the additional power line capacity relative to the design specifications and (ii) lines' critical segments, i.e., each segment along the transmission line that affects the line's power transmission capacity.

Firstly, the record data for weather conditions is selected to be in 2021 with interval time recorded in each minute. The collected data from the online source [35] is taken in a typical location as the general land covering weather conditions of the study overhead transmission line with 30x30 km spatial resolution. This is an open data platform providing access to datasets and data analytics that are relevant to the energy sector. The data is then processed in Python to filter the critical parameters with the time range needed for the research. Each of the weather profiles on covering power line location is also used to make the distribution plots demonstrating its impact on the additional ampacity value of the study power transmission line. For the transmission line under analysis, the georeferenced layout and topology of the line (identification of all buses/substations power stations) and its electrical and conductor characteristics (resistance, reactance, material, and static rating) is collected from on-site survey. The lines operating at 220 kV was put into operation in 2018 and can carry loads from the wind and solar power farms [31, 32]. The congestion is assummed on the regional grid due to a large amount of connection of the renewable power sources.

As mentioned in the previous section, DLR method is classified as indirect and direct methods. Indirect methods measure weather-related data, while direct methods measure either conductor sag, conductor ground clearance, line tension, or conductor temperature. In the studied region, due to the limited database of the transmission line, many parameters related to the line's operation are not available. Furthermore, there have not been any pilot systems installed that allow assessing the practical benefits and effectiveness of DLR technology. For the further analysis of this research, we will consider DLR by application of weather model, which is the simplest DLR method. For the estimation of the correct rating of the conductor we have used IEEE and CIGRÉ guidelines.

The dynamic rating depend on the grid properties and specific ambient conditions at the line location. Therefore, the statistical analysis of the historical weather data is performed. The input databases are put into the heat exchange equation to observe, assess, and analyze the variations of the parameters and how frequently they benefit the line in each month of the year with each of typical wind speed and air temperature patterns determined by the distribution plot of atmospheric data. We make an assumption with the constant set of other equivalent remaining ones with high solar radiation (1000 W/m²), effective wind angle (90°), medium ambient temperature (25°C) [4]. Moreover, the conductor type for the studied example is specified with maximum allowable temperature (assumption at 100°C), absorbability (0.9) to calculate P_S and emissivity (0.7) to calculate P_r for the typical value of the conductor that has been used for five years in the industrial environment [36, 37].

4. Results and Discussion

4.1. Wind Speed Distribution and Assessment of The DLR Impact

The distribution of this parameter for each month is plotted and illustrated as in Figure 10 clearly showing four main categories of wind speed: low (0.5 m/s), medium (1.5 - 3 m/s), and medium-high range (~ 3.5 m/s - 5.0 m/s), high range (~ 5.5 m/s - 8.0 m/s). The medium-range has a significant proportion in most months of the year (except July and August) with a peak distribution of 30 - 45%; while the medium-high range is allocated more frequently in in most months of the year but with a lower peak proportion (about 5 - 15%). The low wind speed (0.5 m/s) and high-wind (5.5 - 8.0 m/s) speed appears to be insignificant with only about 5% - 10%.

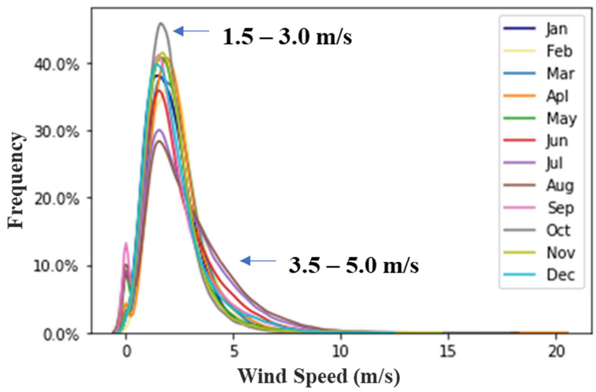

Figure 10. *Distribution of wind speed in the region of the transmission line.*

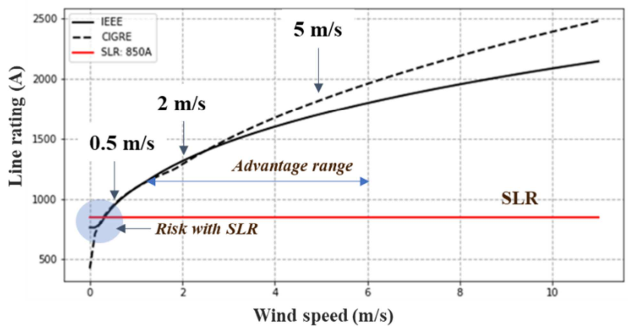

Figure 11. *The expected value of ampacity as a function of wind speed, assuming parameters T_c=100° C, q_s=1000 W/m^2, θ=90°, and T_a=25°C.*

The wind is the most influential parameter that affects the conductor temperature and the ampacity (Figure 11). Generally, wind speed has a significantly prevailing cooling impact on the variation of ampacity with the climb to nearly 1750 A or 105% raising in the typically measured range from 1.5 to 6.0 m/s, it starts to accelerate 40% compared with SLR from the medium wind-speed (2 m/s). In particular, low winds speed holds a small proportion in the whole wind range and causes the ampacity to lower than the static level in the worst operating condition. More importantly, the wind range (2.0 - 3.5 m/s) is witnessed as the main wind speed distribution in the region, potentially giving a great advantage for cooling effect for the transmission line (about 40 - 70% advantage compared with SLR).

In terms of model comparison (IEEE & CIGRE), a virtually identical expression is demonstrated in the figures of two measures in low and middle-range wind speed. But significant deviation becomes more and more remarkable when the wind speed goes beyond the medium level of 2 m/s and reaches sharply high values at nearly 500 A in the final restricted wind speed point. In this range, CIGRE has a greater amplitude than IEEE.

4.2. Wind Angle Distribution and Assessment of The DLR Impact

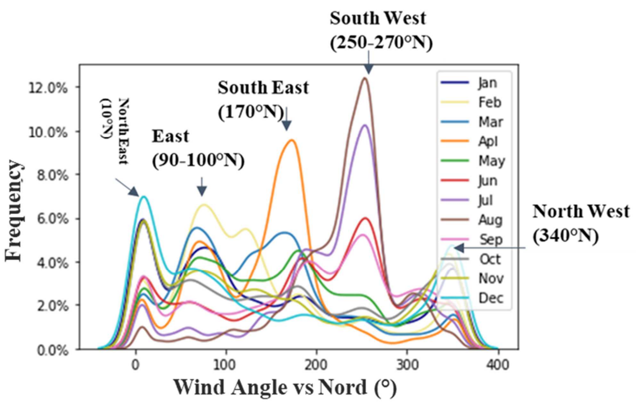

Figure 12. Distribution of the wind angle versus transmission line.

As can be witnessed (Figure 12), the chosen OHL region appears in five main wind orientations:

1. East (~ 90° - 100° N): mainly distributes from January – May;
2. Southeast (~ 170° N): mainly distributes from March, April;
3. Northeast (~ 10° - 20° N): mainly distributes from November, December, January;
4. Northwest (~ 340 - 350° N): mainly distributes from November, December;
5. Southwest (~ 250 - 270° N): mainly distributes from June, July and August.

As can be observed in Figure 13, in the range only greater than 40 degrees, DLR allows increasing the line capacity by more than 40%, depending on the wind speed distribution in the area. The cooling effect of wind speed is entirely observed when the incident angle reaches 90 degrees.

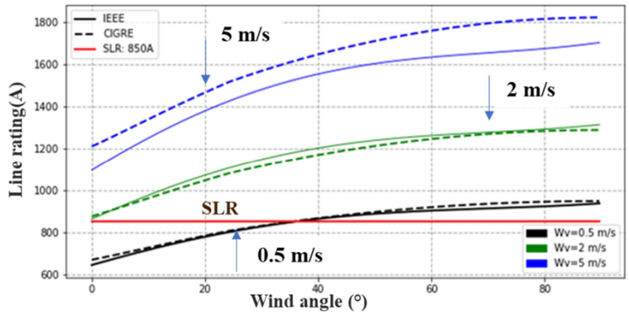

Figure 13. The expected value of ampacity as a function of wind direction with three wind speed levels, assuming parameters: T_c=100°C, q_s=1000 W/m², and T_a=25°C.

4.3. Solar Irradiance Distribution and Assessment of The DLR Impact

In Figure 14 present the solar radiation distribution at over 400 W/m², the amount of heat gain for the thermal transmission of the OHL is high on the initial months of the year with the main distribution around 500 W/m². Most of the months of the year, the line area is affected by quite high radiation intensity at the range of 800 - 1000 W/m².

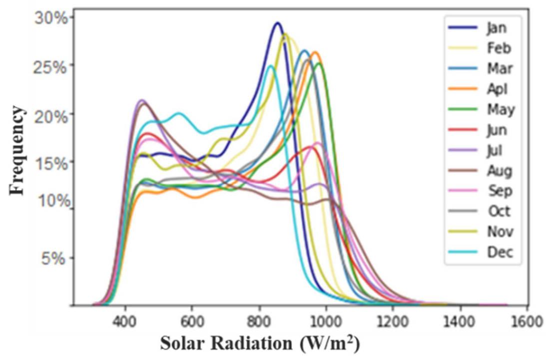

Figure 14. Distribution of solar irradiance in the region of transmission line.

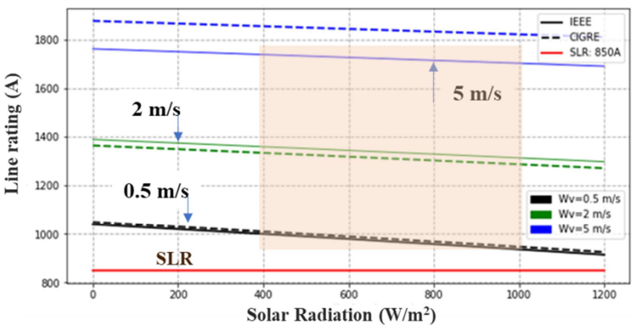

Figure 15. The expected value of ampacity as a function of solar radiation with three wind speed levels, assuming parameters: T_c=100°C, θ=90°, and T_a=25°C.

In Figure 15, although the radiation intensity distributed mainly in the area where the line passes is relatively high (400 - 1000 W/m²), even when the wind speed is low (0.5 m/s), the operating line does not take any risks with the SLR. In this case, the benefit of DLR is significant (17% - 100%) over SLR corresponding to wind speed of 0.5 m/s - 5.0 m/s.

4.4. Ambient Temperature Distribution and Assessment of The DLR Impact

The area where the transmission line passes through is affected by the ambient temperature in the range of 20 - 37°C. In most months of the year, the ambient temperature in the range of 24 - 27°C occurs with high frequency (15 - 28%). The probability of temperature range 30 - 35° is quite low (< 5%) (Figure 16).

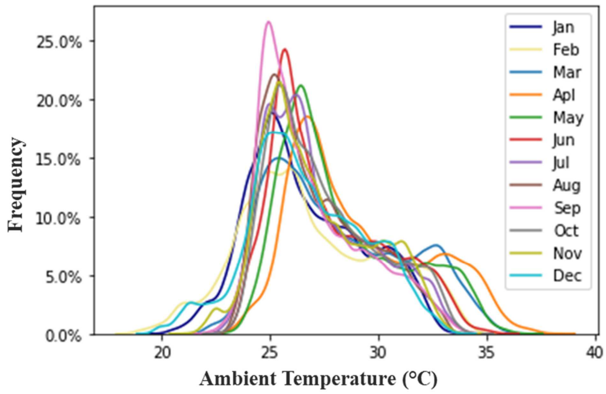

Figure 16. *Ambient temperature profiles in the region of the transmission line.*

Figure 17 demonstrates that ambient temperature has a significant impact on ampacity with a quasi-linear expression. Generally, the ampacity decreases considerably under hot ambient conditions. Therefore, the substantial distribution of the high-temperature range (24 - 35°C) in most of the months in the examined region can give a great reduction in ampacity. Especially, in low wind speed areas when the cooling effect is not adequate to refrigerate the line, the DLR goes below the SLR even the temperature is only in the high range at about 35°C, resulting in an unbeneficial manner in the ability of current-carrying. Fortunately, the most prevailing impact of mid-range wind speed with a large distribution in the case-study's region is significant to provide an adequate amount of cooling effect for the line, particularly for the tested area in Nha Trang - Thap Cham where the temperature range varies relatively from 24°C to 30°C annually. With these values, ampacity can still benefit from 40 to 50 % compared with SLR for medium wind speed conditions (> 2 m/s) and far more significant to reach about 90% in high wind speed one (> 5m/s).

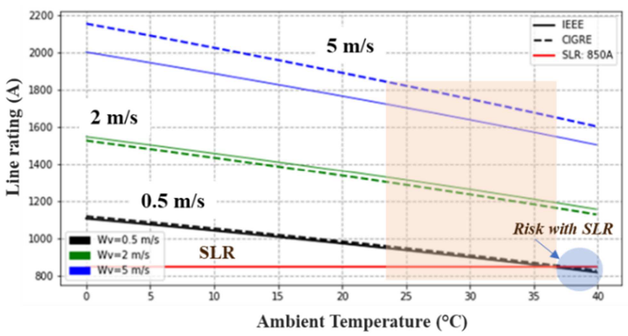

Figure 17. *The expected value of ampacity as a function of ambient temperature with three wind speed levels, assuming parameters: T_c=100°C, θ=90°, and q_s=1000 W/m^2.*

4.5. DLR Distribution for Typical Month with IEEE Model

The calculated DLR is then put into distribution plot and cumulative frequency expression to demonstrate how frequently each value of ampacity occurs in the dataset and to what proportional level the certain amount of ampacity accounts for. This is represented under the combination form of histograms and kernel density estimate. In which, the histogram shows the distribution of data based on the bins with each DLR value and then equivalently draws successive bars for the number of observations that fall in each bin range. In parallel, kernel density is represented under the form of a typical smooth Gaussian distribution to approximate the general shape of data distribution [15]. This distribution figure is specified and supported by boxplot for the dataset of ampacity in the total month, disadvantage and advantage amount under and over the static line. Besides, cumulative frequency is also added to demonstrate the percentage of the certain range when the calculated data is inversely reordered.

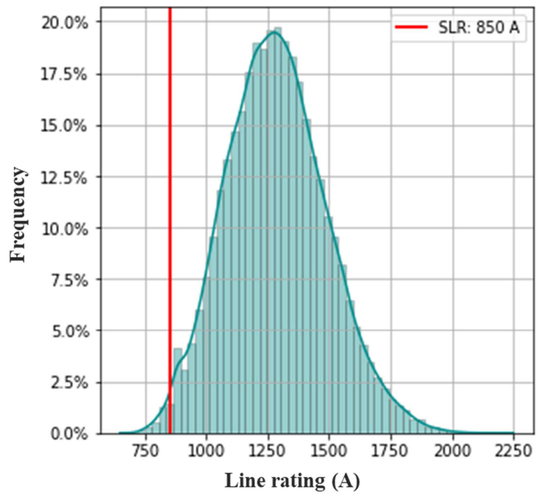

Figure 18. *Distribution plot of IEEE calculated ampacity in August.*

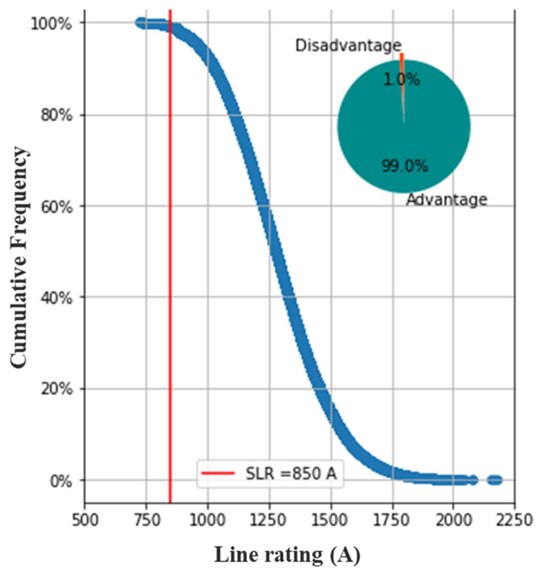

Figure 19. *Cumulative frequency of IEEE calculated ampacity in August.*

In August, the wind direction is Southwest (~ 250-270° N) with frequency of 15% (highest). The advantage of using the DLR is obvious: 99% of the line uptime with dynamic load rating is higher than static load; in which, the highest frequency at 20% of the time, the line allows to operate with a dynamic load higher than 40% of the SLR.

The CIGRÉ estimated rating is higher than the IEEE estimated one, as shown in Figures 11, 13, 15 and 17 above. These differences between standards are due to the distinct ways to calculate the solar heat gain. CIGRÉ estimates the direct, diffuse and reflected radiation while IEEE only includes the direct radiation [15]. CIGRÉ gives greater values of ampacity than that of IEEE, especially when convective cooling is remarkable with the increase of wind speed and effective angle of airflow, which can be indicated previously and in Figure 20 representing the distribution of subtraction IEEE and CIGRÉ under the violin plot. For the most part, these approaches have the quasi similar value while the 0 - zone difference is witnessed to distribute with the greatest value. The disproportion of these measures rises with the declining trend of distribution line, especially with relatively low ampacity (about 50-250 A); therefore, the difference between IEEE and CIGRÉ could be considered to be negligible. However, to determine a specific selection for data application with real value, the comparison with measurement is essential. Inherently, ampacity is the unmeasurable quantity so to serve for model evaluation, temperature comparison is replaced to be taken into account. IEEE value is often lower than that of CIGRÉ, which proves IEEE is more closed to the accurate number of thermal measurement sensor in reality.

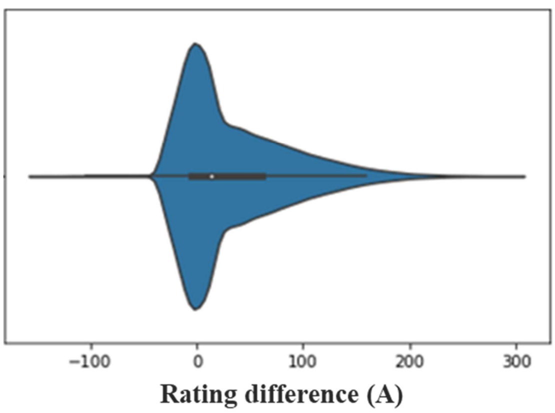

Figure 20. *Violin plot IEEE and CIGRÉ ampacity difference for case sudy line.*

5. Conclusion

In this paper, the impact of the dynamic line rating analysis in overhead power lines for the case study grid is assessed. The implemented DLR calculation uses the mathematical models IEEE and CIGRÉ approaches using data from an available online weather source. Compared to the design limits, the results show that the DLR analysis is suitable for regions with high wind speed, as expected, with an average rating higher than the static rating of 40% for a wind speed from 2 m/s, which constitutes a new result. The work provides a reference for the future development of the smart-grid concern in Vietnam, application of DLR technology to be considered as one of the key solutions with a real-time DLR monitoring system can contribute to fully exploiting, both economically and technically, the usable load capacity of the existing overhead transmission lines. Dynamic rating allows adding more capacity to the existing line in operation, when the environmental conditions are favorable (high wind speed, low ambient temperature). By using DLR, it is possible to use capacity of the line more effectively. There is a potential to connect new wind farms to the grid faster, by minimizing construction efforts on necessary transmission system in shorterm planning.

Acknowledgements

This word was supported by University of Science and Technology of Hanoi through research grant Ref. USTH.EN.01/21.

References

[1] Vu, T. T. N., Teyssèdre, G., Roy, S. L., Anh, T. T., Trần, T. S., Nguyen, X. T., Nguyễn, Q. V., *"The challenges and opportunities for the power transmission grid of Vietnam"*, European Journal of Electrical Engineering, vol. 21, No. 6, pp. 489-497, 2019.

[2] Soheila Karimi, Petr Musilek, Andrew M. Knight, *"Dynamic thermal rating of transmission lines: A review"*, Renewable and Sustainable Energy Reviews, Volume 91, Pages 600-612, 2018.

[3] Estanqueiro et al., *"DLR use for optimization of network design with very large wind (and VRE) penetration"*, 17th International Workshop on LS Integration of Wind Power into Power Systems, p. 8, 2018.

[4] Tapani O. Seppa., *"Guide for selection of weather parameters for bare overhead conductor ratings"*, CIGRE Brochure 299, 2006.

[5] Andrea Michiorri, Huu-Minh Nguyen, Stefano Alessandrini, John Bjørnar Bremnes, Silke Dierer, Enrico Ferrero, Bjørn-Egil Nygaard, Pierre Pinson, Nikolaos Thomaidis, Sanna Uski., *"Forecasting for dynamic line rating"*, Renewable and Sustainable Energy Reviews, vol 52, pp. 1713–1730, 2015.

[6] M. A. Bucher, M. Vrakopoulou, and G. Andersson, *"Probabilistic N-1 security assessment incorporating dynamic line ratings,"* IEEE Power Energy Society General Meeting, pp. 1–5, July 2013.

[7] Fernandez, E., Albizu, I., Bedialauneta, M. T., Mazon, A. J., & Leite, P. T., *"Review of dynamic line rating systems for wind power integration"*, Renewable and Sustainable Energy Reviews, vol 53, pp. 80–92. 2016.

[8] Marmillo, J, Mehraban, B, Murphy, S, and Pinney, N., *"A Non-Contact Sensing Approach for the Measurement of Overhead Conductor Parameters and Dynamic Line Ratings"*, CIGRE US National Committee, Grid of the Future Symposium, Cleveland, OH, 2017.

[9] Bruce J. Walker., *"Dynamic Line Rating, Report to Congress. United States Department of Energy"*, Washington, DC 20585, June 2019.

[10] IEEE Power and Energy Society, *"EEE Standard 738 - Standard for calculating the current temperature relationship of bare overhead line conductors"*, Technical Standard, 2012.

[11] J. Iglesias, G. Watt, D. Douglass, V. Morgan, R. Stephen, M. Bertinat, D. Muftic, R. Puffer, D. Guery, S. Ueda, K. Bakic, and S. Hoffmann, *"Guide for thermal rating calculation of overhead lines,"* CIGRE working group B2.43, p. 93, 2014.

[12] G. Coletta et al., *"On-Line Control of DERs to Enhance the Dynamic Thermal Rating of Transmission Lines",* in IEEE Transactions on Sustainable Energy, vol. 11, no. 4, pp. 2836-2844, Oct. 2020.

[13] In Vietnamese, https://nangluongvietnam.vn/cong-nghe-tien-tien-va-giai-phap-so-hoa-trong-van-hanh-luoi-dien-truyen-tai-viet-nam-27299.html

[14] GIZ, *"Technology Assessment of Smart Grids for Renewable Energy and Energy Efficiency"*, Technical report, pp. 22. 2019.

[15] Arroyo, A., Castro, P., Martinez, R., Manana, M., Madrazo, A., Lecuna, R., & Gonzalez, A, *"Comparison between IEEE and CIGRE Thermal Behaviour Standards and Measured Temperature on a 132-kV Overhead Power Line",* Energies, 8 (12), pp. 13660–13671, 2015.

[16] Dupin, R., Kariniotakis, G., & Michiorri, A, *"Overhead lines Dynamic Line rating based on probabilistic day-ahead forecasting and risk assessment,"* International Journal of Electrical Power & Energy Systems, 110, 565–578. 2019.

[17] Viafora, N., Delikaraoglou, S., Pinson, P., & Holbøll, J., *"Chance-constrained optimal power flow with non-parametric probability distributions of dynamic line ratings"*, International Journal of Electrical Power & Energy Systems, vol 114, 105389. 2020.

[18] J. Marmillo, J., Pinney, N., Mehraban, B., Murphy, S., Dumitriu, N., "*Simulating the Economic Impact of a Dynamic Line Rating Project in a Regional Transmission Operator (RTO) Environment",* CIGRE US National Committee 2018 Grid of the Future Symposium. 2018.

[19] L. Staszewski and W. Rebizant, *"The differences between IEEE and CIGRE heat balance concepts for line ampacity considerations,"* in 2010 Modern electric power systems, pp. 1–4, Sep 2010.

[20] Rácz, L.; Németh, B.; Göcsei, G.; Zarchev, D.; Mladenov, V. *"Performance Analysis of a Dynamic Line Rating System Based on Project Experiences",* Energies 2022, 15, 1003.

[21] K. Morozovska and P. Hilber, *"Study of the monitoring systems for dynamic line rating,"* Energy Procedia, vol. 105, no. Supplement C, pp. 2557 – 2562, 2017. 8th International Conference on Applied Energy, ICAE2016, 8-11 October 2016, Beijing, China.

[22] B. P. Bhattarai et al., *"Transmission line ampacity improvements of altalink wind plant overhead tie-lines using weather-based dynamic line rating"*, 2017 IEEE Power & Energy Society General Meeting, Chicago, IL, 2017, pp. 1-5.

[23] Couto et al., *"Impact of the dynamic line rating analysis in regions with high levels of wind and solar PV generation",* 2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), pp. 1206-1210, 2020.

[24] Kateryna Morozovska, Wadih Naim, Nicola Viafora, Ebrahim Shayesteh, Patrik Hilber., *"A framework for application of dynamic line rating to aluminum conductor steel reinforced cables based on mechanical strength and durability"*, International Journal of Electrical Power & Energy Systems, vol 116, 2020.

[25] Vietnam Electricity. (2021). Annual Report 2021, 29 pages. https://en.evn.com.vn/d6/news/Annual-Report-2021-6-13-2537.aspx

[26] Thang Nam Do, Paul J. Burke, Hoang Nam Nguyen, Indra Overland, Beni Suryadi, Akbar Swandaru, Zulfikar Yurnaidi, *"Vietnam's solar and wind power success: Policy implications for the other ASEAN countries,"* Energy for Sustainable Development, Volume 65, Pages 1-11, 2021.

[27] https://en.vietnamplus.vn/overloaded-renewable-energy-affects-power-system-operation/201165.vnp (accessed on 07 May 2021).

[28] World Bank: Smart Grid to Enhance Power Transmission in Vietnam. Available online: http://documents.worldbank.org/curated/en/779591468187450158/pdf/103719-WP-P131558-PUBLICVN-Smart-Grid-Book-2-21-16.pdf (published on 2016).

[29] In Vietnamese, https://www.pecc1.com.vn/d4/news/Cong-nghe-tien-tien-va-giai-phap-so-hoa-trong-van-hanh-luoi-dien-truyen-tai-Viet-Nam-8-1754.aspx

[30] https://nppmb.vn/tin-tuc/tin-tuc-npmb/vai-net-co-ban-ve-giam-sat-nhiet-dong-duong-day-2133.html#.YeEU2PgSmUl (accessed on 31 March 2021).

[31] The world bank – Data catalog (2016), *"Vietnam – Electricity transmission network",* https://datacatalog.worldbank.org/dataset/vietnam-electricity-transmission-network-2016

[32] In Vietnamese, https://www.evn.com.vn/d6/news/Thi-cong-duong-day-220kV-Nha-Trang-Thap-Cham-Con-vuong-mac-trong-boi-thuong-giai-phong-mat-bang-6-13-25637.aspx

[33] Vu Minh Phap, Doan Van Binh, Nguyen Hoai Nam, A. V. Edelev, M. A. Marchenko, *"Analysis of Economic-Technical Potential of Renewable Power Sources for the Establishment of National Renewable Energy Center in Ninh Thuan Province, Vietnam",* E3S Web Conf. 209 06022 (2020).

[34] https://en.vietnamplus.vn/ninh-thuan-strives-to-become-renewable-energy-hub/221844.vnp (accessed on February 13, 2022).

[35] ENERGYDATA. INFO: https://energydata.info/about_us, by the World Bank Group.

[36] Hussien, Z. F., Azlan Abdul Rahim, A. A., & Abdullah, N., *"Transmission and Distribution"*, TNB Research, Malaysia. Power Electronics Handbook, 3rd ed., 1357-1375.

[37] K. Morozovska and P. Hilber, *"Risk analysis of wind farm connection to existing grids using dynamic line rating,"* 2018 IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), pp. 1-5, 2018.