JJEE

Volume 12 | Number 2 | June 2026 | Pages 273-292

Jordan Journal of Electrical Engineering

ISSN (print): 2409-9600, ISSN (online): 2409-9619

Homepage: jjee.ttu.edu.jo

Enhancing Transmission Capacity through Dynamic Thermal Rating: Evidence from a transmission line in North-Central Nigeria

Ibrahim Abdullateef[1], Bilkisu Jimada-ojuolape[2*], Lambe Mutalub Adesina[3], Abdulwaheed Musa[4], Olalekan Ogunbiyi[5], Monsurat Omolara Balogun[6]

[1, 2, 3, 4, 5, 6] Department of Electrical and Computer Engineering, Faculty of Engineering and Technology, Kwara State University, Malete, Kwara State, Nigeria

E-mail: bilkisu.jimada@kwasu.edu.ng

Received: Oct 21, 2025 *Revised: Mar 17, 2026* *Accepted: Apt 25, 2026* *Available online: Jun 15, 2026*

***Abstract*—** Dynamic Thermal Rating (DTR) has gained increasing attention as a strategy to unlock additional transmission capacity by integrating real-time environmental conditions, in contrast to the conservative assumptions underlying Static Thermal Rating (STR). This paper presents one of the first empirical evaluations of DTR for the Nigerian grid, focusing on the Oshogbo–Ganmo transmission line in North-Central Nigeria. A Python-based simulation framework, aligned with the CIGRE standard, was developed using 2020–2021 historical load records, conductor parameters, and environmental variables, including wind speed, solar radiation, and ambient temperature. Results show that in over 99% of the study period, DTR values surpassed the actual load current, with line ratings often double or triple the STR. These outcomes reveal significant underutilized thermal headroom and demonstrate DTR's potential to improve asset utilization, defer costly network reinforcements, and strengthen system reliability. By linking DTR deployment to the Nigerian context, this study contributes evidence on its feasibility in sub-Saharan grids and underscores its relevance to sustainable energy integration, aligning with UN Sustainable Development Goal 7 on affordable, reliable, and sustainable energy. Policy recommendations include real-time environmental monitoring infrastructure and the development of standardized DTR guidelines to facilitate large-scale adoption.

***Keywords*—** Dynamic thermal rating; Nigerian power grid; Power system reliability; Static thermal rating; Sustainable energy; Transmission line capacity.

1. INTRODUCTION

The electrical power system is one of the most sophisticated infrastructures in the world, and its primary purpose is to provide an economical and reliable channel for electrical energy to move from the power generation sites to consumers across vast distances [1, 2]. The power system comprises three hierarchical levels, viz. Generation, transmission, and distribution. With the ever-increasing demand for electricity, there is a pressing need to enhance the efficiency and reliability of power systems.

In Nigeria, electricity is generated between 11.5 – 16 kV and stepped up by a step-up transformer to 330 kV at the power stations. Transmission begins with the transportation of voltage, 330 kV, along transmission lines (otherwise referred to as conductors) and is stepped down by a transformer to 132 kV at the transmission substation. This voltage is further

* Corresponding author

DOI: https://doi.org/10.5455/jjee.204-1761025349

transported along transmission lines to injection substations and stepped down to 33 kV [3]. This marks the end of transmission and the beginning of the distribution phase.

All electrical instruments are built to carry currents, which in turn produce heat. The limitation on the amount of heat that can be tolerated is typically expressed as the current rating, which must be strictly adhered to in order to prevent insulation meltdown, transformer explosion, and line burning [1]. This current rating is commonly referred to as thermal rating, line rating, or ampacity. For consistency, this study adopts the term thermal rating. In the context of power transmission, thermal rating is the maximum amount of electrical current a transmission line can carry without exceeding its thermal limits. This is critical because excessive current can cause overheating, leading to conductor sag, insulation damage, or even failure of the line [4, 5].

Thermal rating can be static or dynamic. Static Thermal Rating (STR) is the conventional approach used for determining the thermal capacity of transmission lines [6, 7]. Static thermal rating (STR) is conservative by design, as it is based on worst-case environmental conditions. This conservatism ensures the safety and reliability of transmission lines but often leads to significant underutilization of their capacity [8].

Dynamic Thermal Rating (DTR) is a method of determining the real-time current-carrying capacity of a transmission line by continuously monitoring environmental conditions (e.g., temperature, wind speed, solar radiation) and conductor temperature. By continuously monitoring environmental data, DTR systems can recalibrate thermal ratings in real-time, allowing operators to make informed decisions about load management. This shift not only enhances operational efficiency but also reduces the risk of overheating and associated failures [9]. DTR methods are classified into two groups: direct and indirect methods. Direct methods of DTR determination involve the use of direct monitoring devices such as weather monitoring stations, temperature monitoring systems, and power donuts, placed along the transmission lines to measure power line characteristics such as conductor temperature, line tension, ground clearance, and conductor sag [10].

In indirect methods, line rating is estimated from weather data that is measured or forecasted along the transmission line. The basic principle of weather-based line rating calculations is the evaluation of the conductor heat balance equation [10]. The International Council on Large Electric Systems (in French: Conseil International des Grands Reseaux Electriques, CIGRE) [11], Institute of Electrical and Electronics Engineers (IEEE) [12], and International Electrochemical Commission (IEC) [13] have standards in which the algorithms to estimate the thermal rating of conductors and the temperature of the conductor are described based on the heat balance concept.

By utilizing real-time data, DTR can increase the effective capacity of existing transmission lines, reducing the need for new infrastructure. For instance, studies by Ritzmann and Wright [14] and Karimi et al. [10] demonstrated that DTR systems could increase transmission capacity by (10-30)% compared to static ratings. By improving energy flow and minimizing outage risks, DTR enhances the overall resilience of power transmission networks, enabling them to better withstand extreme weather events and fluctuations in energy demand. This resilience is crucial for managing extreme weather and supporting sustainable energy in the face of climate change.

Optimizing line usage can delay or eliminate the need for expensive upgrades or new lines. By using the DTR system, only operational adjustments to the rating of existing transmission lines are required without the need for new infrastructure [1]. For example, Michiorri et al. [15] demonstrated that adopting DTR systems could postpone the construction of new transmission lines by up to five years, leading to significant cost savings for utility providers. The adoption of STR systems has also helped in mitigating the environmental damage caused by the power system sector. In Spain, the DTR system in 2015 saved more than 1100 tons of CO_2 [8]. More efficient use of existing infrastructure reduces the environmental impact of building new transmission lines, leading to more sustainable energy management practices. Research indicates that DTR can raise installed photovoltaic capacity by 15–27% and increase net revenues by up to 27% [9].

While DTR improves system reliability by enabling higher transmission capacity, it increases the risk of thermal overloads and system instability, which could potentially lead to cascading line tripping and load loss [16]. However, these risks can be mitigated through the integration of complementary systems such as System Integrity Protection Schemes (SIPS) and Phasor Measurement Units (PMUs), as highlighted by Jimada-Ojuolape & Teh [17] and Jimada-Ojuolape [18], respectively. These systems enable rapid response to abnormal conditions, reduce the likelihood of load curtailment, and enhance overall system reliability. Other operational risks in DTR deployment include potential inaccuracies in weather forecasts and sensor data, which can lead to uncertainty in ampacity estimates and increased risk of conductor aging or failure if not properly managed [19, 20].

Communication network reliability is critical for DTR effectiveness. However, failures in wireless communication can reduce DTR availability, and thus impact grid reliability [21]. Risk mitigation strategies involve optimizing sensor placement, uncertainty assessment, and robust communication design to safely deploy DTR systems without compromising transmission line integrity or grid stability [22, 23].

Nigeria's 330kV transmission network is forced to operate at full or beyond its capacity due to heavy power demand [24, 25]. Constructing new transmission lines for thermal capacity enhancement requires a huge investment and also leads to environmental pollution problems [26]. The Oshogbo-Ganmo line is a critical component of the Nigerian electricity grid, serving as a major transmission corridor for delivering electricity to key demand centres. Considering the drawbacks of the static thermal rating system, this research seeks to determine the DTR for the Oshogbo-Ganmo Transmission line in order to demonstrate the prospect for a dynamic thermal rating system for optimum line capacity utilization. DTR is particularly relevant in regions with fluctuating weather conditions, such as Nigeria. The more efficient use of existing transmission capacity means that less reliance on additional fossil fuel generation is needed to meet peak demand, thereby promoting a cleaner energy future.

The implementation of the DTR technology to expand network capacity has been explored in several studies. However, no studies have been conducted to assess the prospects of DTR implementation on the Nigerian power network. Therefore, this study investigates the feasibility of implementing the DTR system for the Oshogbo–Ganmo transmission line in the Nigerian power network. Thus, the following novel contributions are presented in this article:

1. To analyse the influence of local weather and load data on DTR for a real power system scenario, specifically the Oshogbo-Ganmo transmission line of the Nigerian power network.
2. To evaluate how DTR enhances transmission reliability and optimizes existing infrastructure capacity, supporting cost-effective and sustainable energy strategies.

The rest of the paper is organized as follows. The factors affecting thermal rating, heat balance equations, and review of past studies are discussed in the literature review section 2. The methodology applied in this study is extensively outlined in Section 3. Section 4 presents the results and discussion. Section 5 outlines the future research, recommendations, and conclusions drawn from the study.

2. LITERATURE REVIEW

2.1. Factors Affecting Thermal Rating of Transmission Lines

Several factors influence the thermal rating of transmission lines and can be classified into weather and environmental conditions, electrical and mechanical load variations, and conductor properties. Wind speed, ambient temperature, and sunshine intensity are the main environmental factors affecting the thermal capacity of transmission lines [26]. As ambient temperature rises, the resistance in the conductive materials of the lines increases, which can lead to higher energy losses and reduced transmission efficiency. Conversely, lower temperatures can enhance conductivity, allowing for more efficient power transfer [10, 26]. Wind can help dissipate heat generated by electrical resistance, cooling the lines and allowing them to carry more current [10]. On the other hand, high winds can cause physical stress on the lines, potentially leading to sagging or even structural damage [27]. Direct sunlight increases the conductor temperature, leading to thermal expansion and higher electrical resistance. This impact is particularly pronounced in regions with high solar radiation, where transmission lines are exposed to intense sunlight for extended periods, potentially reducing their thermal capacity and efficiency [28].

Power flow and Current magnitude are electrical load variations that affect the thermal rating of transmission lines. Increased power flow leads to higher current magnitudes, which generate heat due to resistive losses. This heating effect raises the conductor temperature and can reduce the thermal capacity of the line. The current magnitude is critical as excessive current can result in overheating, causing material degradation, increased electrical resistance, and reduced efficiency [10]. Line sag and line tension are vital mechanical load factors that influence the thermal rating of transmission lines. Line sag results from thermal expansion due to increased conductor temperature. Excessive sag can lead to reduced ground clearance, posing safety risks such as electrical faults or ground contact [29]. Higher tension reduces sag but increases mechanical stress on the conductor. Balancing tension is critical to maintaining structural integrity while optimizing thermal performance.

The thermal rating of transmission lines is significantly influenced by conductor properties, including thermal capacity, emissivity, material type, diameter, and age. Thermal capacity refers to the conductor's ability to absorb and dissipate heat generated by electrical resistance and environmental factors such as solar radiation. High-temperature conductors like Aluminium conductor steel supported (ACSS) and Aluminium composite core conductors (ACCC) can operate at temperatures up to 250°C, compared to traditional Aluminium conductor steel reinforced (ACSR) conductors, which are limited to around 100°C [30, 31]. ASCR conductors have lightweight, high-strength, corrosion-resistant, and excellent conductivity and are widely used as transmission lines [23]. Emissivity measures how effectively a conductor radiates heat. It is influenced by surface properties such as coatings and oxidation. High emissivity enhances radiative cooling, improving thermal performance under high current loads.

Small-diameter conductors exhibit higher resistances and lower cooling rates, making them more susceptible to overheating under heavy loads [30]. Conductors with larger diameters have lower electrical resistance and better heat dissipation, enabling higher thermal ratings. Larger conductors also cool more effectively due to increased surface area exposed to wind and radiation. Aging affects the conductor's emissivity due to surface oxidation and wear, reducing its ability to radiate heat effectively. Mechanical properties such as tensile strength also degrade over time, increasing sag risks under high temperatures [31].

The integration of real-time data on environmental conditions, electrical loads, and mechanical factors in DTR systems enables safer operation by continuously monitoring and adapting to varying conditions, thereby maximizing transmission capacity while ensuring compliance with safety standards [10].

2.2. The Heat Balance Equation

The heat balance concept behind the IEEE and CIGRE standards is based on the fact that the heat absorbed and the heat released through a conductor are always in equal proportion to each other, which is supported in physical science by the first law of thermodynamics, as shown in Eq. (1) [1]. Fig. 1 depicts the heat balance components.

$$Heat\ absorbed = Heat\ released \quad (1)$$

The IEEE heat balance equation is defined by IEEE [18]:

$$Q_c + Q_r = Q_j + Q_s \quad (2)$$

Joule Heating, Q_j, acting upon an energized transmission conductor, is the resistive (Joule) heating caused by the electrical current passing through a resistive conductor.

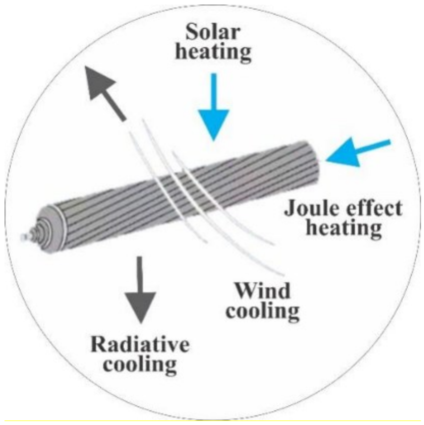

Fig. 1. Overhead conductor heat balance components.

Solar heating (solar heat input per unit length), Q_s is the only thermal force that is entirely independent of the conductor temperature or weather parameters. It is a function of the conductor's location and orientation on Earth, the Sun's position in the sky, cloud cover, and the "darkness" of the conductor's surface called absorptivity (between 0 and 1).

It is typically 10% to 30% of the joule heating, Q_j [4]. Convection, Q_c, represents the transfer of heat that occurs as an object (conductor) comes into physical contact with a surrounding fluid (air) at a different temperature.

This is the largest heat loss term, even with still air [4]. Convective cooling occurs in two forms, depending on nearby wind speed. It is divided into two forms: natural convection and forced convection. At high wind speeds, forced convection predominates while natural convection becomes negligible; conversely, at low wind speeds, natural convection dominates and forced convection has minimal effect [26]. Radiative Cooling, Q_r, is present in all operating scenarios [32]. The radiation heat loss per unit length is normally between 25% and 35% of the convection loss, even at high conductor temperatures [4].

2.3. Existing Research in the field

To fully understand the effectiveness of DTR systems in overcoming static rating constraints, it is essential to examine real-world applications and case studies that illustrate their successful implementation. Several studies have demonstrated the successful application of dynamic thermal rating technology in power transmission systems.

Kim and Morcos [33] applied DTR to an existing 154 kV double-circuit transmission line in Korea, with the conductor temperature specified at 40°C. The results showed that the maximum allowable load could be further increased to about 135% for the actual load. They also noted that even at a wind speed of zero, the load could still be increased to 89% under the DTR system, which highlights the efficiency of DTR systems. Michiorri et al. [15] explored the application of DTR across different power system components for an overhead line in Belgium, revealing that the benefits of DTR extend beyond transmission lines to include other elements of the power grid. Their work emphasizes the importance of a holistic approach to DTR implementation, where the entire system is considered to maximize efficiency gains. Uski [34] suggested a method for the estimation of the economic feasibility of the application of DTR in congested power transmission connections, and it was demonstrated on a power transmission from Sweden to Finland. The study revealed that the DTR system can relieve bottlenecks and is applicable for congested transmission connections between electricity market price areas. Safdarian et al. [6] quantitatively assessed DTR's benefits in a Finnish distribution network using a quantitative approach. They aimed to demonstrate its effectiveness in reducing load and generation curtailments, particularly in overhead line systems. The approach entailed gathering weather and load data, applying thermal models to calculate circuit ratings, and conducting reliability analyses through simulations. Their results indicate significant improvements in reliability and cost savings associated with DTR, suggesting it as a viable solution for modern distribution networks facing capacity challenges. In the study of Vinklers et al. [35], a European power system tidal simulation methodology was applied to evaluate the prospects of employing DTR in alleviating congestion in Switzerland's power lines, and the result shows that the use of DTR could result in at least a 12% boost of ampacity for the Swiss cross-border interconnection in 2030. In the study of Bhattarai et al. [36], DTR was implemented on four-line segments located in the southern part of Alberta, Canada. They reported an over 75% increment in the DTR over the STR. In the study of Liu et al. [37], a DTR method based on the transient thermal balance was proposed on a 500 kV quad bundle transmission line in Zhejiang Province, China. They analysed thermal ratings under different conditions, and the results showed that the DTR was at least 3 times the STR values. Rodrigo and Rishanthi [38] explored the feasibility of DTR in Sri Lanka using the PLSCADD software. Five existing transmission lines across the country were selected to represent the diverse weather and topographical conditions. Their results indicated that the minimum ratio of DTR to STR was 1.65, which indicated a significant efficiency of DTR over STR.

Yangchun et al. [39] employed a live simulation model (LSM) for real-time DTR using data from a 110-kV transmission line in China, which enhances accuracy by eliminating the need for meteorological parameters. They combined nonlinear parameter estimation with a tabu search algorithm to correct systematic deviations in real-time monitoring data, yielding a DTR calculation with less than 1% average error and a root mean square error under 10%. The study illustrated the potential of LSM for improving transmission capacity without major infrastructure changes. Lebedov et al. [40] studied the impact of DTR on the Romanian transmission grid. The result proved that the DTR is a more economical and faster solution for improving the current carrying capacity of the lines. Cagigal et al. [5] also utilized the real-time meteorological data and conductor temperature measurements to assess the feasibility of the DTR system for a 220 kV overhead line located in the province of La Rioja, Spain. The results showed that the DTR system increased the thermal rating by over 180%. Table 1 provides a summary of the literature review.

Table 1. Summary of the reviewed literature.

Case study	**Method**	**References**
Korea	Analytical	[33]
Belgium	Analytical	[15]
Sweden	Analytical	[34]
Finland	Analytical	[6]
Switzerland	Analytical	[35]
Canada	Analytical	[36]
China	Analytical	[37]
Sri Lanka	PLSCADD software	[38]
China	Live Simulation Model and Tabu Search	[39]
Romania	Analytical	[40]
Spain	Analytical	[5]
Present study (Nigeria)	Analytical	

Analytical refers to the use of IEEE or CIGRE calculation approaches.

Numerous researchers have studied the power instability and losses in Nigeria. The solutions proposed include the incorporation of flexible alternating current transmission system (FACTS) devices along the transmission lines [41, 42] and upgrading the system by constructing additional generating stations and transmission lines [24]. From Table 1, it is evident that the effects of incorporating a DTR system along Oshogbo-Ganmo transmission lines and other transmission lines in Nigeria have not been studied, indicating a research gap in that area. This gap justifies the importance of this research, which aims to demonstrate the substantial potential of DTR systems in enhancing the efficiency, reliability, and capacity of power transmission lines in Nigeria.

3. METHODOLOGY

3.1. Study Area

The J7H2 Oshogbo transmission line is a high-voltage power line operating at 330 kV, designed to enhance the reliability and efficiency of power delivery across an 8.7×10^4 m stretch. Engineered with a robust conductor area of 22 × 350 mm² and a steel diameter of 9 mm, the line ensures optimal mechanical strength and electrical performance. With a thermal rating of 9 MVA and a current-carrying capacity of 760 A, the J7H2 line is capable of sustaining high power flows, making it a critical component in the energy distribution network [43]. Jebba, Kainji, Egbon, and Benin are all generating stations and are interconnected feeders. Oshogbo-Ganmo is a grid interconnection transmission line, which implies that power can flow from Ganmo to Oshogbo and vice versa, depending on the dynamics of the feeder at a point in time. The Oshogbo-Ganmo transmission lines run on bus 29 to bus 39. Fig. 2 shows the Oshogbo-Ganmo power network. Fig. 3 illustrates the 52-bus version of the power network with the Oshogbo-Ganmo line highlighted for emphasis.

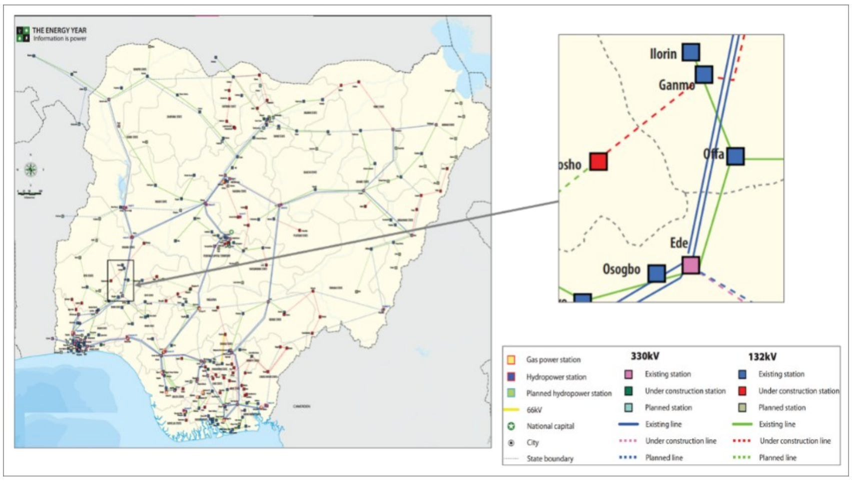

Fig. 2. Map of Nigeria Power Network showing the Study Site [44].

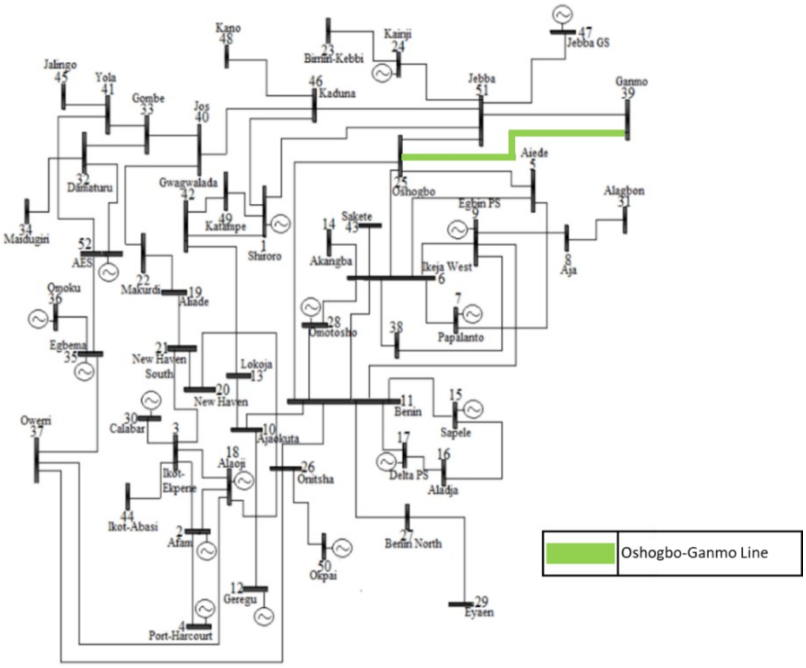

Fig. 3. 52-bus version of the power network with the Oshogbo-Ganmo line.

3.2. Data Collection

The transmission line conductor properties and load data were obtained from the Ganmo Sub-station, and the environmental data were obtained from the European Commission EU Science Hub website. The details of the data collected are presented in Table 2.

Table 2. Study data.

Data Category	Data Components [Units]	Data resolution or Value	Source
Environmental (Ganmo Sub-station)	Ambient temperature [℃]	Hourly (January 2020- November 2021)	European Union Science Hub [45]
	Wind speed [m/s]		
	Solar irradiance [W/m]		
Load	Load Current [A]	Hourly (January 2020- November 2021)	Ganmo Sub-station
Conductor Properties	Conductor type	ACSR	Ganmo Sub-station
	Conductor outside Diameter [mm]	25.62	
	Core Diameter [mm]	24.11	
	Outer strand diameter [mm]	8.68	
	Maximum allowable conductor temperature [°C]	80	
	Length [m]	8.7×10^4	
	Conductor AC resistance at 25°C, $R_{ac}(T_1)$ [Ω/m]	8.94×10^{-5}	
	Conductor AC resistance at 75°C, $R_{ac}(T_2)$ [Ω/m]	1.07×10^{-4}	
	Emissivity, ε	0.8	
	Absorptivity of the conductor surface, α	0.8	
	Wind angle of attack, δ	90	
	Inclination to the horizontal, β	0	
	Height above sea level [m]	30	

At the time this study was conducted, load current data were only available for the period between January 2020 and November 2021. As a result, the corresponding environmental data were limited to this timeframe, which restricted the scope of the analysis to this period.

3.3. Computer Program Implementation

The CIGRE standard [11] was employed in this study for the thermal rating calculations. The basis of the calculations is the heat balance equation (Eq. (3)).

$$I_c^2 \cdot R(T_c) + Q_s = Q_c + Q_r + m \cdot C_p \frac{dT_c}{dt} \quad (3)$$

where:

I = conductor current [A]

$R(T_c)$ = alternating current (AC) resistance of conductor at temperature T_c.

Q_s = Solar radiation heat gain [W/m],

Q_c = Convection heat loss [W/m],

Q_r = Radiation heat loss [W/m],
m = mass of conductor per unit length [$kg \cdot m^{-1}$],
C_p = specific heat capacity of the conductor material [$J \cdot kg^{-1} \cdot K^{-1}$]

The total specific heat of the conductor is equal to the sum of the specific heat of the components of the conductor [37].

3.3.1. *STR Implementation*

For STR, $\frac{dT_c}{dt} = 0$, hence Eq. (3) simplifies to:

$$I_c^2 \cdot R(T_c) = Q_c + Q_r - Q_s \tag{4}$$

$$I_c = \sqrt{\frac{Q_c + Q_r - Q_s}{R(T_c)}} \tag{5}$$

To compute the STR, which is a single value for the entire dataset, the worst-case scenario is assumed by considering:

- Highest ambient temperature,
- Lowest wind speed, and
- Highest solar radiation.

3.3.2. *DTR Implementation*

For DTR implementation, $\frac{dT_c}{dt} \neq 0$ and $m \cdot C_p$ is considered. For the aluminium conductor steel reinforced (ACSR) conductors, the mass and specific heat of aluminium and steel per unit length are shown in Table 3.

Table 3. Mass (m) and specific heat (C_p) of aluminum and steel per unit length [37].

Material	m [$kg \cdot m^{-1}$]	C_p [$J \cdot kg^{-1} \cdot K^{-1}$]
Aluminium	1.116	955
Steel	0.5119	476

The DTR computation steps, as outlined in CIGRE [11] and Liu et al. [37], are adopted in this study.

From Eq. (3),

$$dT_c = \frac{I_c^2 \cdot R(T_c) - Q_c - Q_r + Q_s}{m \cdot C_p} \cdot dt \tag{6}$$

The simplest way to model the variations of all the parameters is to assume the ambient meteorological conditions are constant during a period of time [16].

Discretizing the temperature increment over small time steps, Δt, we get:

$$\Delta T_c = \frac{I_c^2 \cdot R(T_c) - Q_c - Q_r + Q_s}{m \cdot C_p} \cdot \Delta t \tag{7}$$

Hence, the conductor temperature is updated by iteration using:

$$T_{n+1} = \Delta T + T_n (n = 0,1,2 \ldots) \tag{8}$$

where:

T_{n+1} = new conductor temperature
T_n = old conductor temperature

The program uses time-stepped simulation to track conductor temperature T_c over 1 hour (3600s) using 10-second intervals. The shorter the interval of time, the more realistic the solution [11].

The Radiative Heat Loss (Q_r), Solar Heat Gain, (Q_s), and the Convective Heat Loss (Q_c) are computed as outlined in CIGRE [11]. The flowchart for the program implemented is illustrated in Fig. 4, and the steps are summarised below:

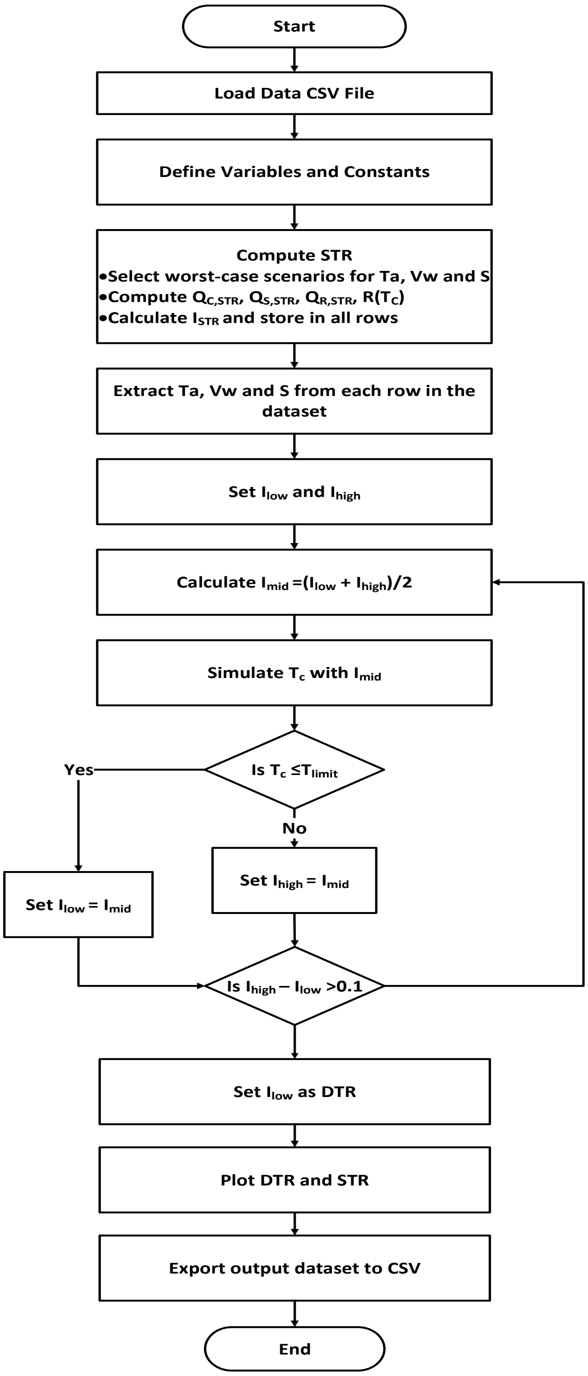

Fig. 4. Program flowchart.

1. Load the comma-separated value (CSV) file containing the historical load current, conductor properties, and environmental data (ambient temperature (Ta), wind speed (Vw), and solar radiation (S)).
2. The STR (I_{STR}) is computed by selecting worst-case values for the environmental data and calculating the Q_r, Q_s, and Q_c.

3. The DTR for each data row is computed using the bisection method by finding the maximum current that does not cause the conductor temperature to exceed its limit as described below:
   i. The Assumption is that at lower current, I_{low}, the final temperature will be below the limit i.e., $T_c \leq T_{limit}$, while for higher current, I_{high}, it will exceed the limit.
   ii. Define tolerance = 0.1.
   iii. Set $I_{low} = 0$, $I_{high} = 1000$.
   iv. At each iteration:
      - Pick $I_{mid} = \frac{I_{low}+I_{high}}{2}$
      - Simulate the temperature for 1 hour with this current
      - If $T_c \leq T_{limit}$, this current is safe → update I_{low}
      - Else, it's unsafe → update I_{high}
   v. Repeat until the current converges within a small error threshold, i.e., the difference between I_{high} and I_{low} is small (0.1 A).
4. Graphs comparing DTR with STR are generated, and the calculated DTR and STR values are stored in a CSV file for comparative analysis.

The computational analysis and simulations were performed using the Python version 3.11 programming environment on a standard personal laptop equipped with an Intel Core i5 processor and 8 GB RAM. The algorithm was implemented using libraries such as NumPy, Pandas, and Matplotlib for numerical computation, data processing, and visualization. These calculations require only basic mathematical operations and converge rapidly, resulting in low computational overhead. The successful execution of the model on modest computing hardware demonstrates that the proposed approach has minimal computational requirements and can be feasibly implemented in real-time operational environments.

4. RESULTS AND DISCUSSION

Fig. 5 – Fig. 8 show the current rating plots for January and May in 2020 and 2021. The plots indicate the values of the actual hourly load current, the DTR, and the STR for the Oshogbo–Ganmo high-voltage transmission line for the study period, with each data point representing hourly intervals.

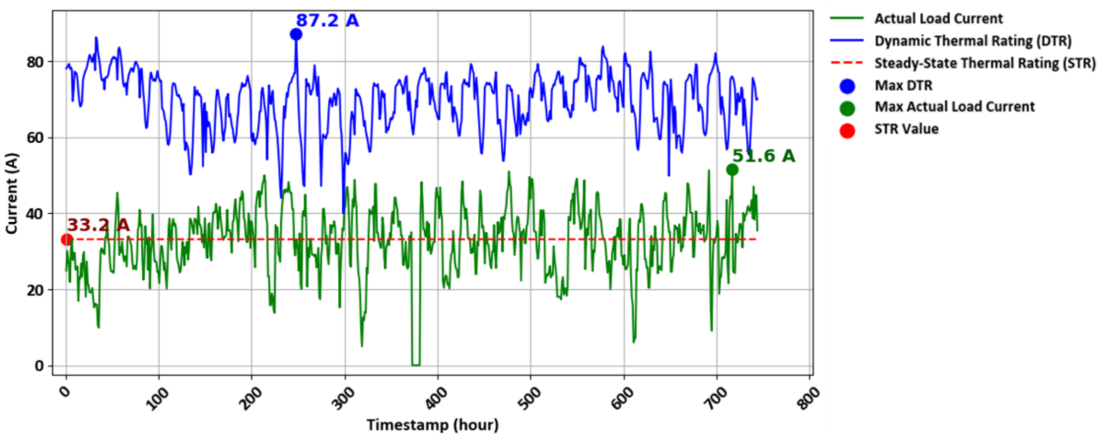

Fig. 5. January 2020 current rating plot.

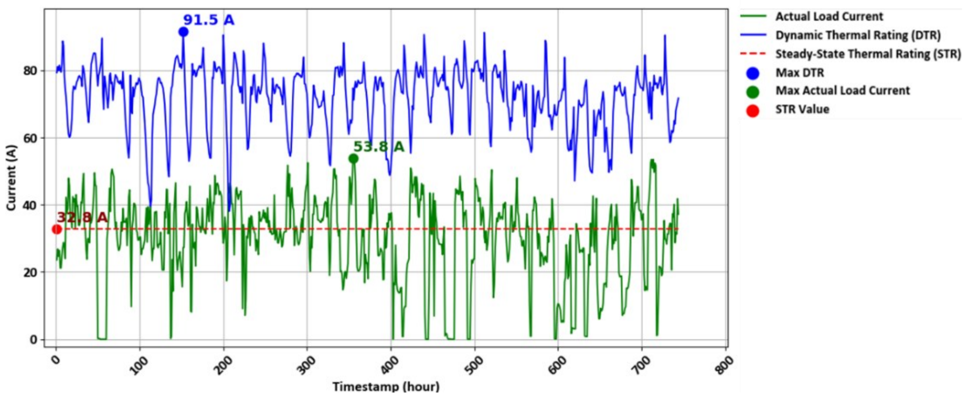

Fig. 6. May 2020 current rating plot.

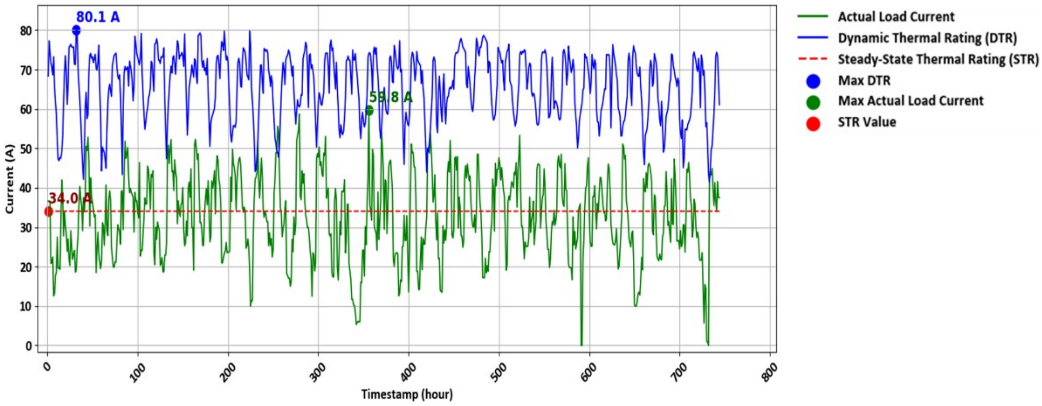

Fig. 7. January 2021 current rating plot.

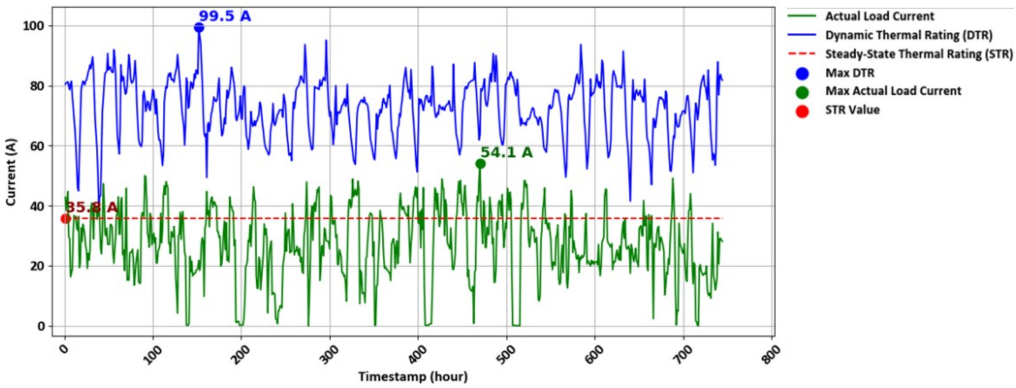

Fig. 8. May 2021 current rating plot.

January and May represent the dry and wet seasons, respectively, in Nigeria. As shown in Fig. 5–Fig. 8, the DTR consistently exceeded both the actual load current and the STR for these months in 2020 and 2021, while the STR remained constant. This observation highlights the effectiveness of DTR in utilizing transmission capacity throughout the year in a tropical region such as Nigeria. The constant value of STR further confirms its conservative nature, as it assumes worst-case weather conditions and does not reflect real-time environmental variations. For more insights into the variation of the three current ratings, further analyses such as trend plots, correlation analysis, and seasonal comparisons were conducted.

1. Trend plot of actual load current, STR, DTR

Fig. 9 illustrates the trend plot for the DTR, STR, and actual load current for the study period. The vast gap between DTR and the actual load represents unused capacity that could be exploited to improve operational flexibility and reliability. Hence, transmission lines operating on DTR systems can accommodate more power to meet the energy demand [23].

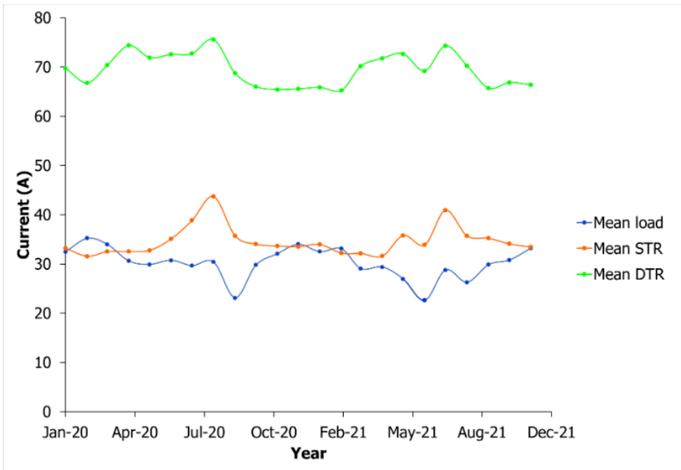

Fig. 9. Trend plot for current ratings.

2. Unused DTR capacity

This represents the difference between the DTR, and the actual load as shown in Fig. 10.

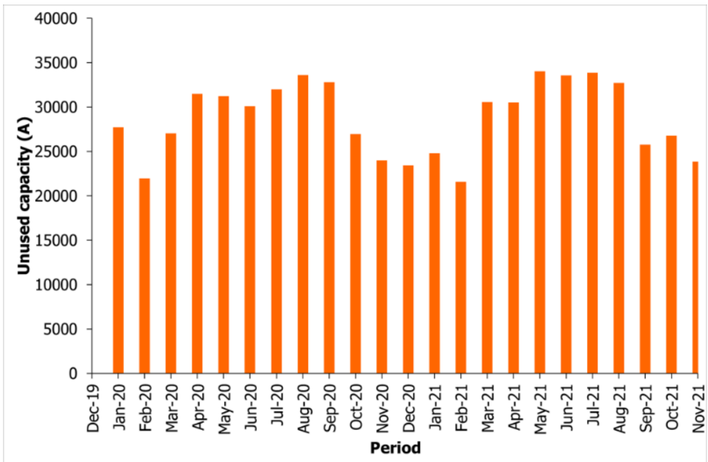

Fig. 10. Unused capacity of DTR.

Fig. 10 shows the monthly unused DTR capacity along the transmission line. This demonstrates the significant benefits of DTR in enhancing transmission capacity [10] and reducing the need for costly new infrastructure investments [1]. Fig. 11 presents the hourly plot for the entire study period. DTR consistently exceeds both the actual load current and the STR, with STR remaining constant across the study period. For a more intricate investigation, the comparison of the hourly values for actual load current, DTR, and STR for the study period is presented in Table 4.

Table 4. Comparison of actual load with STR and DTR.

Parameters	Comparison	Total overload duration [hr]	Overload Duration [%]
Actual Load vs DTR	Actual Load > DTR	110	0.65
	DTR >Actual Load	16690	99.34
Actual Load vs STR	Actual Load > STR	8530	50.82
	STR >Actual Load	8270	49.18
DTR vs STR	DTR > STR	16800	100.00
	STR > DTR	0	0.00

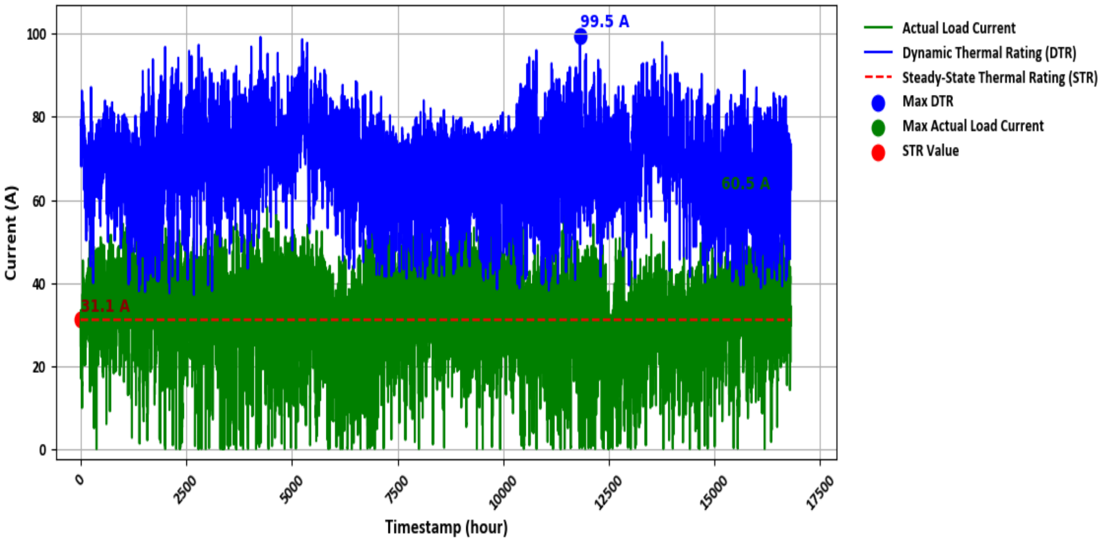

Fig. 11. Current ratings for the entire study period.

From Table 4, over the study period, it was observed that the actual load current exceeded the DTR in only 110 hours of overload duration, which is equivalent to 0.65% of the total time. The DTR exceeded the actual load current in 16,690 hours of overload duration, which indicates that for 99.34% of the time, the DTR was sufficiently higher than the actual load current, suggesting that the transmission line had significant unused thermal capacity when evaluated under dynamic conditions. In contrast, the actual load current exceeded the STR for a total of 8,530 hours of overload, corresponding to 50.82% of the total time, implying that if STR were used as the basis for safe operation, the system would be flagged as overloaded nearly half the time. Table 4 showed that the STR exceeded the actual load current for 8,270 hours (49.18% of the total time), indicating underutilization of the conductor's thermal capacity when STR is used as the reference. A comparison of DTR and STR shows that DTR exceeded STR throughout the study period (16,800 hours), indicating a 100% exceedance and emphasizing the superior efficiency of DTR over STR. The DTR values often doubled or even tripled the STR. This is expected, as DTR incorporates real-time ambient temperature, wind speed, and solar radiation. This underscores the benefits of transitioning toward dynamic line rating systems that utilize real-time meteorological data to adjust allowable loading dynamically. The higher DTR values compared to STR observed in this study align with the findings of previous research [29, 31, 33], further emphasizing the potential of DTR to enhance thermal capacity utilization in transmission systems. As DTR largely depends on the environmental conditions, unfavourable environmental conditions such as low wind speed, high solar radiation, and high temperature are expected to lower the DTR, as observed in [46], contrary to that observed in this study. However, in this study, it was observed that the favourable weather conditions during the period of the study contributed to the high values of DTR. Furthermore, the STR values currently in use is highly conservative and shows the line capacity is largely underutilised.

3. Pearson Correlation Analysis

In order to understand the influence of ambient temperature, wind speed, and solar radiation on DTR, the study period was divided into the predominant seasons in Nigeria, i.e., dry (November – March) and wet (April – October). Pearson correlation analysis was conducted to understand the relationship. Fig. 12 and Fig. 13 present the correlation plots between the environmental factors and DTR for the dry and wet seasons, respectively, with the correlation coefficients indicated on the plots.

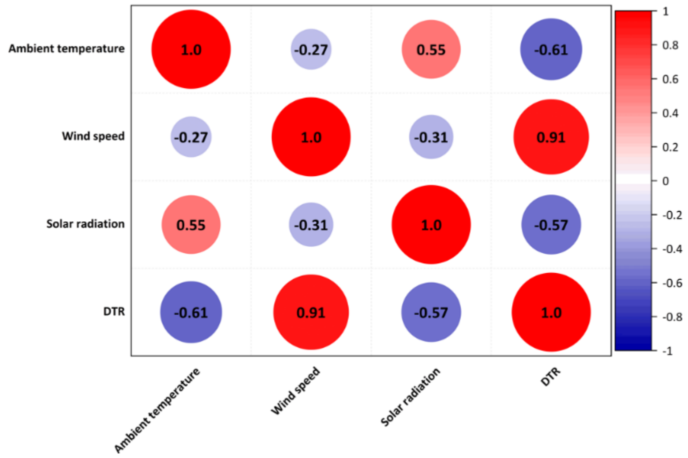

Fig. 12. Correlation plot of environmental factors and DTR for the dry season.

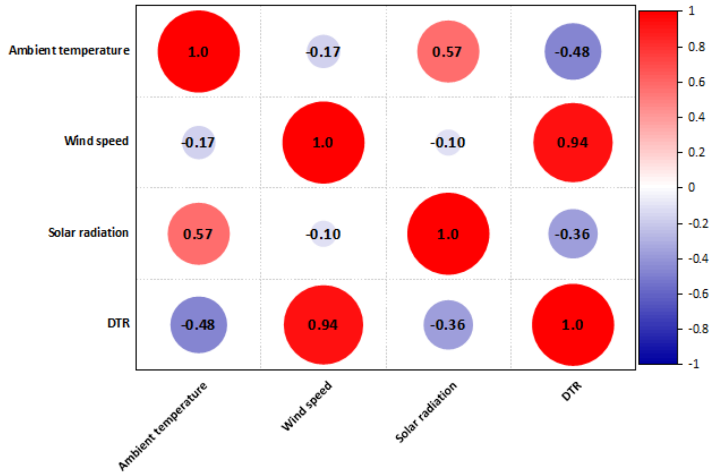

Fig. 13. Correlation plot of environmental factors and DTR for the wet season.

From Fig. 12 and Fig. 13, a strong positive correlation (R) between wind speed and DTR was observed for both dry and wet seasons ($R_{dry} = 0.91, R_{wet} = 0.94$), indicating that increased wind enhances the cooling of the conductor, resulting in higher thermal capacity. In contrast, ambient temperature shows a negative correlation with DTR for both seasons, consistent with the principle that higher temperatures reduce the conductor's ability to dissipate heat, leading to a lower thermal rating of the conductor. The figures showed that DTR has a negative correlation with solar radiation and ambient temperature, which affirms the principle that high solar radiation and ambient temperature reduce the thermal capacity of conductors. The weaker correlation between solar radiation and DTR ($R_{dry} = -0.57, R_{wet} = -0.3$) in comparison with ambient temperature and DTR ($R_{dry} = -0.61, R_{wet} = -0.48$) indicates that temperature has a higher negative effect on DTR than solar radiation. A negative correlation between the temperature and wind speed ($R_{dry} = -0.27, R_{wet} = -0.17$) reveals an inverse relationship between the two environmental variables. High wind speed helps to cool the transmission lines, while low wind speed results in a generally hot line [16]. These relationships highlight the significant impact of environmental conditions on conductor thermal rating, which STR fails to capture due to its fixed nature.

These results confirm that the Oshogbo-Ganmo transmission line has been under-utilized for the vast majority of the observed period when assessed using DTR. While STR ensures safe operation under all possible scenarios, it does not reflect the potential gains in capacity that can be achieved through real-time monitoring. This highlights an opportunity to increase power transfer during favourable conditions without compromising safety. Implementing DTR in real-time operations could enable a considerable increase in current-carrying capacity without compromising safety, thereby allowing for better accommodation of peak loads, enhanced integration of renewable energy sources, and possible deferral of infrastructure upgrades.

4. Implications of Load Growth on DTR

Electricity demand in many developing power systems continues to grow due to population growth, urbanization, and industrial expansion. Under such conditions, DTR becomes increasingly valuable because it allows transmission operators to safely utilize the additional thermal capacity of existing lines under favourable weather conditions. In the near future, moderate load growth is expected to increase the frequency at which transmission lines operate close to their static thermal limits. In such scenarios, DTR can provide operational flexibility by allowing higher permissible current flow when ambient temperature, wind speed, and solar radiation conditions permit enhanced conductor cooling. In the long run, sustained demand growth may significantly increase the loading of critical transmission corridors. While DTR alone may not eliminate the need for network reinforcement, it can substantially delay expensive infrastructure upgrades by unlocking latent capacity in existing assets. This can be particularly beneficial in regions where transmission expansion projects face financial, regulatory, or environmental constraints. A conceptual trend of future load growth is shown in Fig. 14 (assumed 3% annually) compared with the static rating limit and the potential DTR limit as obtained in the results of this study.

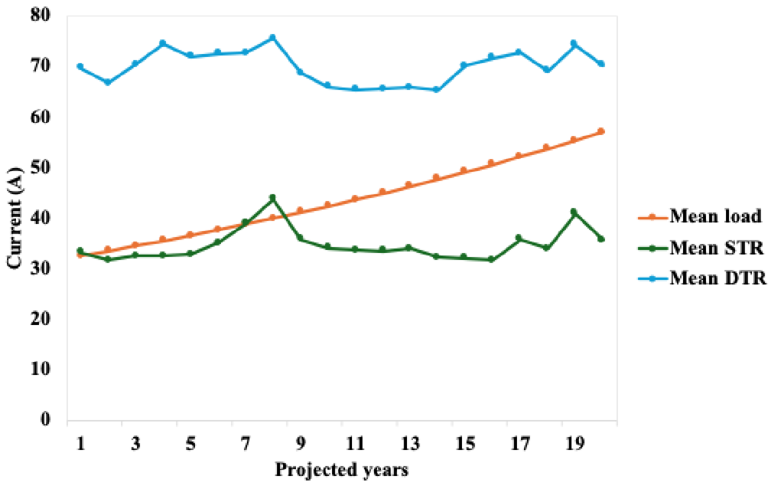

Fig. 14. Trend plot for projected load growth.

The figure demonstrates that with load growth, the operating current will eventually exceed the average static rating to a great extent. However, the average DTR capacity provides significant additional margin, meaning the line can safely carry higher currents under favourable weather conditions. This supports the argument that DTR can delay transmission reinforcement despite increasing demand.

5. CONCLUSIONS

This study assessed the feasibility of implementing a DTR system for the Oshogbo–Ganmo transmission line by developing a Python-based model. The results showed that DTR values consistently exceeded both actual load current and STR, highlighting significant underutilized capacity. These findings demonstrate that DTR can substantially improve operational efficiency, enhance reliability, and strengthen the resilience of Nigeria's transmission network. In this study, the analysis was constrained by the unavailability of long-term load current data, reliance on historical records, and the absence of field validation with real-time DTR measurements. These limitations point to future research opportunities, including the establishment of comprehensive monitoring systems, validation of simulation results through field studies, and the development of localized DTR models that reflect Nigeria's climatic and geographical context. Further work should also examine the long-term economic benefits of DTR adoption and support the creation of standardized practices and policies that will maximize its contribution to reliable, sustainable, and cost- effective power system operation.

REFERENCES

[1] J. Teh, "Analysis of Dynamic Thermal Rating System of Transmission Lines," England, 2016.

[2] M. Balogun, M. Ahmed, A. Ajani, "Reliability assessment of 33kv feeder, (a case study of transmission company of Nigeria, Ganmo work centre)," World Journal of Innovative Research, vol. 6, no. 1, pp. 77-83, 2019.

[3] K. Nnoli, "Implementation of a Dynamic Network Model of the Nigerian Transmission Grid for Investigations on Power System Stability," *Engineering Archive*, pp. 1-20, 2019, doi: 10.31224/osf.io/r82zn.

[4] D. Douglass, W. Chisholm, G. Davidson, I. Grant, K. Lindsey, M. Lancaster, D. Lawry, T. McCarthy, C. Nascimento, M. Pasha, J. Reding, T. Seppa, J. Toth, P. Waltz, "Real-time overhead transmission-line monitoring for dynamic rating," *IEEE Transactions on Power Delivery*, vol. 31, no. 3, pp. 921–927, Jun. 2016, doi: 10.1109/tpwrd.2014.2383915.

[5] M. Cagigal, J. Rosendo-Macias, A. Bachiller, L. Mateo-Sánchez, R. Hermana, "Dynamic line rating in overhead transmission lines. Monitoring methods and field application," *Dyna (Bilbao)*, vol. 1, 2022, doi: 10.6036/10729.

[6] A. Safdarian, M. Degefa, M. Fotuhi-Firuzabad, M. Lehtonen, "Benefits of real-time monitoring to distribution systems: dynamic thermal rating," *IEEE Transactions on Smart Grid*, vol. 6, no. 4, pp. 2023-2031, 2015, doi: 10.1109/TSG.2015.2393366.

[7] N. Safari, S. Mazhari, C. Chung, S. Ko, "Secure probabilistic prediction of dynamic thermal line rating," *Journal Of Modern Power Systems And Clean Energy*, vol. 10, no. 2, pp. 378-387, 2022, doi: 10.35833/MPCE.2020.000641.

[8] A. Arroyo, P. Castro, R. Martínez, M. Mañana, A. Madrazo, R. Lecuna, A. Gonzalez, "Comparison between IEEE and CIGRE thermal behaviour standards and measured temperature on a 132-kv overhead power line," *Energies*, vol. 8, pp. 13660-13671, 2015, doi: 10.3390/en81212391.

[9] Y. Li, Y. Wang, C. Kang, J. Song, G. He, Q. Chen, "Improving distributed PV integration with dynamic thermal rating of power distribution equipment," *iScience*, vol. 25, no. 8, p. 104808, 2022, doi: 10.1016/j.isci.2022.104808.

[10] S. Karimi, P. Musilek, A. Knight, "Dynamic thermal rating of transmission lines: a review," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 600–612, 2018, doi: 10.1016/j.rser.2018.04.001.

[11] CIGRE Working Group B2.13, *Guide for Thermal Rating Calculations of Overhead Lines*. CIGRE, 2014.

[12] IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors, IEEE Standard 738, 2012, doi: 10.1109/IEEESTD.2013.6511656.

[13] *Overhead Electrical Conductors - Calculation Methods for Stranded Bare Conductors*, IEC Standard TR 61597, 2021.

[14] D. Ritzmann, P. Wright, W. Holderbaum, B. Potter, "A method for accurate transmission line impedance parameter estimation," *IEEE Transactions on Instrumentation and Measurement*, vol. 65, no. 10, pp. 2204–2213, 2016, doi: 10.1109/tim.2016.2556920.

[15] A. Michiorri *et al.*, "Forecasting for dynamic line rating," *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 1713–1730, 2015, doi: 10.1016/j.rser.2015.07.134.

[16] B. Jimada-Ojuolape and J. Teh, "Composite reliability impacts of synchrophasor-based DTR and SIPS cyber–physical systems," *IEEE Systems Journal*, vol. 16, no. 4, pp. 6231–6242, 2021, doi: 10.1109/JSYST.2021.3122022.

[17] B. Jimada-Ojuolape, J. Teh, "Impacts of communication network availability on synchrophasor-based DTR and SIPS reliability," *IEEE Systems Journal*, 2021, doi: 10.1109/JSYST.2021.3132657.

[18] B. Jimada-Ojuolape, "Reliability enhancement of synchrophasor-based DTR system considering N-1 contingency for PMU placement," International Future Energy Electronics Conference, 2021, doi: 10.1109/IFEEC53238.2021.9662031.

[19] A. Rashkovska, M. Jančič, M. Depolli, J. Kosmac, G. Kosec, "Uncertainty assessment of dynamic thermal line rating for operational use at transmission system operators," *IEEE Transactions on Power Systems*, vol. 37, no. 6, pp. 4642-4650, 2022, doi: 10.1109/TPWRS.2022.3144740.

[20] J. The, C. Lai, "Risk-based management of transmission lines enhanced with the dynamic thermal rating system," *IEEE Access*, vol. 7, pp. 76562-76572, 2019, doi: 10.1109/ACCESS.2019.2921575.

[21] J. The, C. Lai, "Reliability impacts of the dynamic thermal rating system on smart grids considering wireless communications," *IEEE Access*, vol. 7, pp. 41625-41635, 2019, doi: 10.1109/ACCESS.2019.2907980.

[22] J. The, I. Cotton, "Risk informed design modification of dynamic thermal rating system," *IET Generation, Transmission & Distribution*, vol. 9, no. 15, pp. 2697-2704, 2015, doi: 10.1049/iet-gtd.2015.0351.

[23] B. Jimada-Ojuolape, J. Teh, B. Alharbi, "Synchrophasor-based DTR and SIPS cyberphysical network reliability effects considering communication network topology and total network ageing," *IEEE Access*, vol. 11, pp. 128184-128197, 2023, doi: 10.1109/ACCESS.2023.3335377.

[24] F. Agbontaen, S. Ike, "Loadability analysis of the existing 330 Kv transmission network of the nigerian electricity grid," *Nigerian Research Journal of Engineering and Environmental Sciences*, vol. 2, no. 2, pp. 416-423, 2017.

[25] R. Ebune, O. Ezechukwu, J. Aneke, "Enhancement of power flow control in nigeria 330kv transmission network using D-facts devices," *Iconic Research and Engineering Journals*, vol. 2, no. 4, pp. 94-100, 2018.

[26] Z. Peng, J. Shi, Y. Li, J. Huang, J. Zhao, "Study on dynamic line rating of overhead transmission line based on large-scale new energy power grid connection," *Journal of Physics: Conference Series*, vol. 2488, no. 1, p. 012004, 2023, doi: 10.1088/1742-6596/2488/1/012004.

[27] E. Fernandez, I. Albizu, M. Bedialauneta, A. Mazon, P. Leite, "Review of dynamic line rating systems for wind power integration," *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 80-92, 2016, doi: 10.1016/j.rser.2015.07.149.

[28] M. Dabbaghjamanesh, A. Kavousi-Fard, S. Mehraeen, "Effective scheduling of reconfigurable microgrids with dynamic thermal line rating," IEEE Transactions on Industry Electrons, vol. 66, no. 2, pp. 1552–1564, 2019, doi: 10.1109/tie.2018.2827978.

[29] Federal Energy Regulatory Commission, *Managing Transmission Line Ratings*. Washington, DC, USA, 2019, https://www.ferc.gov/sites/default/files/2020-05/tran-line-ratings.pdf.

[30] A. Abboud, J. Gentle, J. Coffey, K. Parikh, “Sensitivity effects of high-temperature overhead conductors to line rating variables,” CIGRE Centennial, 2021.
[31] Y. Yaqoob, A. Marzuki, C. Lai, J. Teh, “Fuzzy dynamic thermal rating system-based thermal aging model for transmission lines,” *Energies*, vol. 15, no. 12, 2022, doi: 10.3390/en15124395.
[32] S. Murphy, D. Niebur, "Solving the overhead transmission conductor heat balance equation using the Newton Raphson algorithm," *IEEE Transactions on Power Delivery*, vol. 36, no. 6, pp. 3743–3751, 2021, doi: 10.1109/TPWRD.2020.3048831.
[33] S. Kim, M. Morcos, "An application of dynamic thermal line rating control system to up-rate the ampacity of overhead transmission lines," *IEEE Trans. Power Deliv.*, vol. 28, no. 2, pp. 1231-1232, 2013, doi: 10.1109/tpwrd.2012.2234940.
[34] S. Uski, “Estimation method for dynamic line rating potential and economic benefits,” *International Journal of Electrical Power & Energy Systems,* vol. 65, pp. 76-82, 2015, doi: 10.1016/j.ijepes.2014.09.034.
[35] J. Vinklers, N. Chokani, R. Abhari, “Improved integration of European renewables using dynamic line rating in Switzerland,” International Conference on the European Energy Market, 2016, doi: 10.1109/eem.2016.7521236.
[36] B. P. Bhattarai *et al*., "Improvement of transmission line ampacity utilization by weather-based dynamic line rating," *IEEE Transactions on Power Delivery*, vol. 33, no. 4, pp. 1853-1863, 2018, doi: 10.1109/TPWRD.2018.2798411.
[37] J. Liu, H. Yang, S. Yu, S. Wang, Y. Shang, F. Yang, “Real-time transient thermal rating and the calculation of risk level of transmission lines,” *Energies*, vol. 11, no. 1233, pp. 1-14, 2018, doi: 10.3390/en11051233.
[38] A. Rodrigo, S. Rishanthi, “Real-time dynamic thermal rating method to uprate the ampacity of overhead transmission lines: a case study,” *ENGINEER*, vol. LIII, no. 3, pp. 53-61, 2020, doi: 10.4038/engineer.v53i3.7420.
[39] C. Yangchun, L. Peixuan, Z. Zhenliang, D. Yuan, “Real-time dynamic line rating of transmission lines using live simulation model and tabu search,” I*EEE Transactions on Power Delivery*, pp. 1-9, 2020, doi: 10.1109/tpwrd.2020.3014911.
[40] O. Lebedov, B. Enache, F. Argatu, "Studying the impact of dynamic line rating on the Romanian power transmission grid," International Conference on Modern Power Systems,2021, doi: 10.1109/MPS52805.2021.9492522.
[41] I. Nkan, E. Okpo, O. Okoro, “Multi-type FACTS Controllers for power system compensation: a case study of the Nigerian 48-bus, 330 kV system,” *Nigerian Journal of Technological Development*, vol. 18, no. 1, pp. 63-69, 2021, doi: 10.4314/njtd.v18i1.9.
[42] C. Ofoma, I. Okonkwo, “Line loss reduction in nigeria 330kv transmission line,” *Iconic Research and Engineering Journals*, vol. 4, no. 9, pp. 107-116, 2021.
[43] I. Okakwu, E. Ogujor, P. Oriaifo, "Load flow assessment of the Nigeria 330-kV power system," *American Journal of Electrical and Electronic Engineering*, vol. 5, no. 4, pp. 159-165, 2017, doi: 10.12691/ajeee-5-4-6.
[44] The Energy Year, *Nigeria Power Infrastructure Map 2021 free download*, 2025, https://theenergyyear.com/articles/nigeria-power-infrastructure-map-2021-free-download/
[45] European Commission, Joint Research Centre, "PVGIS 6 geospatial solar radiation and PV performance data," 2024, https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html. Accessed.
[46] M. Metwaly, J. Teh, "Fuzzy dynamic thermal rating system-based sips for enhancing transmission line security," *IEEE Access*, vol. 9, pp. 83628-83641, 2021, doi: 10.1109/access.2021.3086866.