ISSN 0511-5728
The West Indian Journal of Engineering
Vol.36, No.2, January 2014, pp.76-83

A Methodology for Dynamically Adjusting a Transmission Line Rating on an Island Grid in the Caribbean

Sanjay Bahadoorsingh [a,Ψ], Laurel Vitra Bhairosingh[b], and Chandrabhan Sharma [c]

Department of Electrical and Computer Engineering, Faculty of Engineering, The University of the West Indies, St Augustine Campus, Trinidad and Tobago, West Indies;
[a]E-mail: sanjay.bahadoorsingh@sta.uwi.edu
[b]E-mail: laurel.bhairosingh@ieee.org
[c]E-mail: chandrabhan.sharma@sta.uwi.edu

[Ψ] *Corresponding Author*

(Received 8 April2013; Revised 9 September 2013; Accepted 28 January 2014)

Abstract: *Electricity transmission along overhead power lines has traditionally been limited by the transmission lines' thermal rating, defined in terms of a fixed, static rating. Load growth and the rapid increase in distributed generation have forced network operators to challenge these static ratings as overly conservative and explore alternative methods of maximising transmission line capacity. This paper describes the development of an overhead dynamic line rating software. The developed software is then applied to the Trinidad and Tobago Electricity Commission (T&TEC) transmission network. Ampacity calculations are performed using the IEEE 738 standard and implemented in MATLAB with an accompanying GUI. Results indicate that the line usage efficiency of one circuit examined in T&TEC's transmission network can be increased, suggesting technical and financial benefits to further this study.*

Keywords: Asset management, conductors, power transmission lines, power transmission meteorological factors, software

1. Introduction

Demand for electricity has increased, resulting in transmission network bottlenecks. Established static thermal ratings have been deemed overly conservative and utilities are now exploring methods to satisfy this increased demand using existing transmission infrastructure. New technologies are emerging which enable the constant monitoring of transmission lines and their environmental conditions. This facilitates the periodic updating of maximum conductor current. Accurate monitoring enables the network operator to monitor the conductor's thermal limit and vertical clearances to prevent violations.

This paper provides an investigation into methods for improving transmission line usage efficiency and describes the development of a dynamic line rating software. The developed software was applied to part of the Trinidad and Tobago Electricity Commission (T&TEC) network.

2. Literature Review

Electrical transmission systems facilitate the interconnection of generation stations with distant loads. Transmission systems employ overhead conductors and/or underground cables. Underground cables are insulated, whereas overhead conductors, also referred to as bare conductors or overhead lines, are made of un-insulated metal and suspended on insulators. Overhead conductors are usually preferred over underground conductors due to their lower cost and ease of maintenance. Selection of a suitable overhead conductor depends on factors such as wind speed, tension that supporting structures must withstand, terrain across which lines must be constructed and ambient temperature.

The thermal rating is the conductor current which would produce the maximum allowable conductor temperature at a specific location and time along a power line (Foss and Moraio 1992). There are two internationally recognised standards for the rating of overhead transmission lines.

- IEEE 738: Standard for Calculating the Current-Temperature of Bare Overhead Conductors (IEEE, 2006)
- Cigré 144: Thermal Behaviour of Overhead Conductors

Both standards provide similar closed-form equations to calculate heat losses and heat gains. The difference in the ratings standards for most typical applications is often less than 1% (Schmidt 1999). Presently, one dynamic line rating software available on the market is LineAmps which is used by TransPower, New Zealand; Hydro Quebec, Canada and Korea Electric Company (Deb 2000).

The thermal rating of an overhead conductor is determined based on climatic factors such as ambient air temperature, wind speed and direction and solar radiation; and conductor attributes such as conductor size and resistance, conductor temperature, conductor sag and conductor tension. Table 1 shows the influence of weather changes on ratings.

Table 1. Influence of Weather Changes on Ratings

Climatic factors	**Variation**	**Conductor capacity**
Ambient air temperature	2% fluctuation 10% decrease	+/- 2% + 11%
Wind speed and direction	1 ms^{-1} increase 45˚ angle 90˚ angle	 ≈18% ≈ 23%
Solar radiation	Cloud shadowing Total eclipse	+/- a few percent + 18%

Source: Adapted from (Goodwin and Smith 2011)

2.1 Bare Conductors

Bare conductors are classified as homogenous or non-homogenous:

- ***Homogenous conductors*****:** These conductors comprise individual strands that are made of the same material and therefore exhibit electrical, mechanical and physical properties which parallel the properties of their singular-type individual wire. These conductors are made of aluminum because aluminum is lightweight and inexpensive. Conductors manufactured from relatively pure aluminum are called *All Aluminum Conductors* (AAC) and those manufactured with an aluminum alloy are called *All-Aluminum Alloy Conductors* (AAAC).
- ***Non-homogenous conductors*****:** These conductors consist of a mixture of different materials and possess properties that reflect the individual properties and relative percentages of the different materials present. The most commonly used non-homogenous conductors are *Aluminum Conductor Alloy Reinforced* (ACAR) and *Aluminum Conductor Steel Reinforced* (ACSR). In the case of ACSR, the steel-conductor supports the weight of the transmission line while the aluminum is used for its conductive properties. The construction of the ACSR conductor is referred to as *concentric-lay-stranded* (CLS), meaning that the straight centre core is surrounded by one or more layers of helically wound wires. The purpose of these conductors is to facilitate the flow of electric current through a transmission line (see Figure 1).

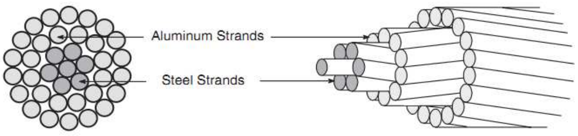


Figure1. Aluminum Conductor with Stranded Steel Core
Source: Adapted from (Hernandez, 2006)

2.2 Static line rating (SLR)

Static line rating utilises predetermined weather conditions to determine the conductor current which produces the maximum allowable conductor temperature. Environmental conditions are forecasted using historical climatic data for the geographic area of the installed line. Consideration is also given to clearance limits to ensure that in the event of conductor sag, vertical clearances are never violated. According to Hernandez (2006) conductor manufacturers suggest conductor ratings based on the following conditions:

- 75°C conductor temperature
- 25°C ambient temperature (temperate climate)
- 40°C ambient temperature (tropical climate)
- 0.61 ms^{-1} wind speed
- 0.5 coefficients of emissivity and absorption

During extreme climatic conditions, the SLR may be conservative or excessive. In cases where the SLR is too low, the conductor is not utilised to its full capacity. In cases where the SLR is too high, the conductor is over-utilised and its thermal limit may be exceeded. Severe conductor sag or even conductor breakage can eventually occur, causing damage and/or injury to both network infrastructure and personnel.

2.3 Physical approaches to optimise use of overhead conductors

Focus is now being placed on the possibility of varying the amount of current transmitted by the conductor in order to facilitate a larger net transfer of current over time. This venture is a major undertaking for any utility. Therefore, it is important that alternative methods of increasing power line capabilities be investigated before a solution is chosen. There are two approaches:

- ***Retensioning*****:** Facilitates higher current flow by increasing the horizontal tension of an existing line. It is usually performed on lines exposed to heavy electrical loading and severe weather conditions. It is limited by materials used to construct the supporting structures (tower, poles, etc.) and their maximum withstand force.
- ***Reconductoring*****:** Existing lines are replaced with larger conductors to increase the maximum operating temperature, increasing the maximum current capacity.

These approaches require line outages to perform physical modifications to the existing infrastructure. It is often difficult for utilities to schedule these costly outages.

2.4 Dynamic Line Rating (DLR)

DLR is a technique to exploit the transmission line capacity. Real-time values for ambient conditions are used to establish the dynamic operability limits of transmission lines. Wind speeds influence the conductor cooling-rate, while ambient temperature influences the conductor's operating temperature. Periodic or continuous measurement of these values allows the thermal limit of the line to be regularly updated. Operational design limits such as sag and tension are also monitored to ensure that in the event of violations, corrective action can be taken immediately. This method does not require line outage.

DLR delays reconductoring and/or installing parallel lines; optimises existing infrastructure utilisation; improves system reliability and safety; and decreases congestion. Conductors are replaced only when they have reached and exceeded their safe operational limits, resulting in reduced and/or deferred capital expenditure. Increased power is supplied using the same resources yielding increased efficiency and greater flexibility for network power-flows. DLR results in an increase in loading of existing resources and therefore affects a utility's load management system and its protection coordination system. Also, during certain operating circumstances, such as a deliberate increase in conductor ampacity, protection circuitry may recognise the current increase as an overload and operate. DLR therefore requires the adjustment of the sensitivity of protection function settings. DLR can produce very high ampacity values, but in practice rating is limited by the conductor's thermal rating as well as other circuit components such as joints and switchgear. Three DLR approaches, weather based, sag based and tension based, are described below.

1) ***Weather based*** - Instantaneous conductor temperature is obtained using environmental conditions to which a conductor is exposed and its heat balance is calculated. This value is used to determine a suitable line rating which allows the conductor to operate within the specified limits of operability. The field data needed are:

- Wind speed (measured by an anemometer) and wind direction
- Air temperature
- Solar heat intensity
- Conductor parameters such as diameter, ac resistance, rates of heat losses and heat gains

2) ***Sag based*** - This method is based on the determination of the amount of current that can be carried without exceeding the required statutory ground clearance. The field data are the same for a weather-based approach. Additional data include conductor position and sag. After the required data is collected, the conductor's actual temperature is calculated using the predetermined relationship between conductor position/ sag and temperature. The heat balance equation is then used to determine how much more current can be transferred before the maximum operating temperature of the conductor is met and exceeded.

3) ***Tension based*** - Two limits which are defined before a transmission line is installed are sag and tension limits. When a conductor is exposed to extreme conditions over an extended period of time, annealing can also occur. Annealing due to excessive line temperature is one of the most significant causes of conductor aging, which can cause critical equipment of the networks to fail permanently. Annealing due to high temperatures is one of the main reasons for permanent damage of Aluminum strands in ACSR conductors.(Bhuiyan et al. 2010)

When stranded conductors are subjected to high operating temperatures, the strands are exposed to a lot of heat. This heat relaxes the strands, causing the conductor to elongate and lose strength. In the sag/tension monitoring DLR method, a tension gauge is placed on the conductor; and the line tension and strain is measured. Sag is then calculated. This sag value, along with the ambient temperature at the line and the amount of current being carried in the line is used to estimate the ampacity of the conductor. Table 2 summarises the advantages and disadvantages of these DLR approaches.

3. Methodology

Several dynamic line rating methods have been outlined. A hybrid system accepting a combination of inputs from other DLR methods was chosen to produce a software tool with increased accuracy, superior to existing methods. Figure 2 illustrates a concept map for the development of the MATLAB based DLR software.

Table 2. Advantages and Disadvantages of DLR approaches

DLR approaches	Advantages	Disadvantages
1. Weather based	• Low purchase cost • Low installation cost • Low maintenance cost • No line outage	• Lower accuracy than other methods • Prediction of wind direction and persistence nearly impossible at low wind levels
2. Sag based	• No line outage	• High installation cost • High maintenance cost • Wind on conductor can affect sag
3. Tension based	• High accuracy for conductor sag • High accuracy for line rating	• Line outages recommended for installation • High installation cost

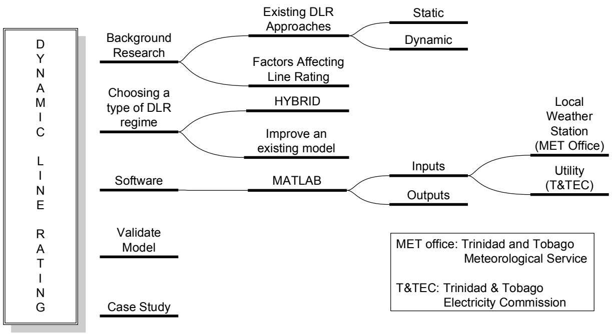


Figure 2. DLR software concept map

3.1 Design and development of software

The inputs and the outputs of the software had to be determined before designing the software. The output, rating of a transmission line, depended heavily on the conductor's electrical and mechanical properties; its environment; and its geographical location.

A Software Development Life Cycle Model was then selected. The iterative enhancement model was chosen since it allowed for early delivery of several useful components and allowed for feedback from earlier designs to be used to improve subsequent models. Figure 3 shows an iterative enhancement model.

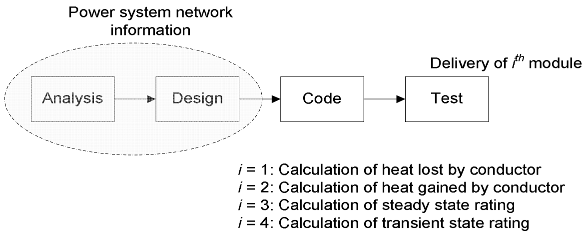


Figure3. Iterative Enhancement Model

The foundation of DLR software is the calculation of heat gained and dissipated by the conductor. The software depicted in Figure 4 requires three (3) data sets:

1) ***Conductor attributes***: dependent on conductor type and provided by conductor manufacturer.
2) ***Environmental parameters:*** dependent on the climate at conductor location and obtained from local weather stations and/or mounted conductor equipment.
3) ***Geographical parameters:*** dependent on the physical orientation of the installed conductor.

It is insufficient to assign a rating based solely on the conductor's heating and cooling rates. There are network constraints which must be considered, including but not limited to conductor sag, voltage drops and system losses. The DLR software was designed to perform ampacity calculations under steady state and transient state conditions using inputs identified in Table 3.

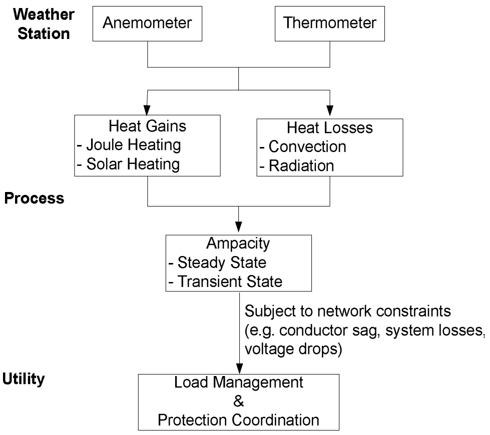


Figure 4. DLR software flow diagram

DLR results in an increase in conductor loading. In some cases, this increase may be recognised as an overload and protection circuitry operates. Furthermore, although the conductor can tolerate the increased loading without exceeding its thermal limit, the thermal limit of other circuit elements ,such as joints and switchgear, may be exceeded and they can be damaged. The calculated ampacity value can be bounded by predetermined lower and upper limits. The upper limit can be obtained from system constraints such as maximum conductor rating. Provided conductor loading stays within these limits, an increase in loading does not result in unwanted operation of protection circuitry.

Threshold time delay and trip level of protection circuitry can also be adjusted to provide flexibility for coordination with the load management system. The threshold time delay is the time during which the measured current is the product of the ampacity and trip level. The purpose of the threshold time delay is to avoid spurious tripping during temporary network faults and to provide a possible means of grading with other protection and control actions in the network (Yip, Aten, and Ferris 2009)

3.2 Steady State

An overhead conductor line is assumed to be in steady state when exposed to minimal variation in weather conditions, conductor and ambient temperatures, while it is delivering constant current, for an hour or greater. During steady-state conditions, the total heat absorbed and dissipated by the conductor are equal, that is the conductor and its environment are in thermal equilibrium. Heat losses and gains are equated to give the heat balance equation (1).

$$\begin{aligned} &\text{radiated heat loss} + \text{convected heat loss} \\ &\quad = \text{solar heat gain} + \text{joule heating} + \text{magnetic heating} \end{aligned} \tag{1}$$

Table 3. DLR software input variables with test values

Symbol	Description	Test Value	Unit
Conductor Attributes			
D	Conductor Diameter	28.1	mm
T_{low}	Minimum conductor temperature for which AC resistance is specified	25	°C
$R(T_{low})$	AC resistance at T_{low}	$7.283\text{x}10^{-5}$	Ωm^{-1}
T_{high}	Maximum conductor temperature for which ac resistance is specified	75	°C
$R(T_{high})$	AC resistance at T_{high}	$8.688\text{x}10^{-5}$	Ωm^{-1}
Geographical Parameters			
Z_1	Azimuth of line	90	°
H_e	Conductor elevation	100	m
Environmental Parameters			
T_a	Ambient air temperature	40	°C
T_c	Conductor Temperature	100	°C
α	Solar absorptivity	0.5	
ε	Emissivity	0.5	
Lat	Degrees of Latitude	30	°
V_w	Wind speed	0.61	ms^{-1}
N	Day of year (January 12 = 12)	161	
t	Time of day	11:00 am	
Sag Calculation Parameters			
w_c	Conductor weight	1.18246	$kgkm^{-1}$
S	Horizontal span length	362	m
H	Conductor tension	1758.3	kg

Source: adapted from IEEE (2006)

3.3 Radiated heat loss (q_r)

This is a function of the conductor's emissivity, diameter and temperature difference between the conductor and its environment as given in Equation (2) (IEEE, 2006). A conductor's emissivity-- ε is based on its surface "darkness", i.e., 0.23 ≤ ε ≤ 0.98. A value of 0.5 is typically used for lines with unknown surface properties.

$$q_r = 0.0178D\varepsilon\left[\left(\frac{Tc+273}{100}\right)^4 - \left(\frac{Ta+273}{100}\right)^4\right] \qquad (2)$$

3.4 Convected heat loss (q_c)

This is a function of the conductor's diameter, directional wind speed, air viscosity μ_f, air density ρ_f and thermal conductivity of air k_f (IEEE, 2006). The IEEE 738 Standard provides three equations (3), (4) and (5), as follows:

At zero wind speed (natural convection occurs)

$$q_{cn} = 0.0205\rho_f^{\ 0.5}D^{0.75}(Tc-Ta) \qquad (3)$$

Low wind speed: < $0.61ms^{-1}$

$$q_{c1} = \left[1.01 + 0.0372\left(\frac{D\rho_f Vw}{\mu_f}\right)^{0.52}\right]k_f K_{angle}(Tc-Ta) \qquad (4)$$

High wind speed: > $0.61ms^{-1}$

$$q_{c2} = \left[0.0119\left(\frac{D\rho_f Vw}{\mu_f}\right)^{0.6}\right]k_f K_{angle}(Tc-Ta) \qquad (5)$$

3.5 Solar heat gain (q_s)

This is a function of the conductor's exposure to the sun and its surface condition described by α, its coefficient of absorption (0.23≤ α ≤ 0.97). A typical value of 0.5 is used when the conductor surface is unknown (LocLe, Negnevitsky, and Piekutowski 1995) (see Equation (6)).

$$q_s = \alpha Q_{se}\sin(\theta)A' \qquad (6)$$

3.6 Steady state rating (I)

A function of Joule and magnetic heating, is influenced by the conductor's AC resistance, $R(T_c)$ (i.e., Equation (7)) and is calculated using Equation (8).

$$R(T_c) = \left[\frac{R(T_{high}) - R(T_{low})}{T_{high} - T_{low}}\right](T_c - T_{low}) + R(T_{low}) \qquad (7)$$

$$I = \sqrt{\frac{q_r + q_c - q_s}{R(T_c)}} \qquad (8)$$

4. Transient State

During the transient state, a temperature difference exists between the conductor and its environment. Ampacity varies until thermal equilibrium is achieved. This software employs calculations for transient-fault and transient-dynamic state.

1) ***Transient-Fault***: The temperature gradient between conductor and environment exists for less than five minutes. There is a significantly high step-change in conductor current during a fault. This results in an increase in conductor temperature. Increase in conductor temperature is solely a result of the increased conductor current. Ambient temperature has no effect on the conductor temperature. Conductor ampacity during a fault is a function of conductor mass, *m*, and specific heat capacity, C_p, and calculated using Equation (9).

$$mC_p \frac{dT_c}{dt} = I^2 R \tag{9}$$

Once detected, protection circuitry usually operates within a few cycles and the fault is cleared. During a fault, no heat is exchanged between the conductor and its environment. After the fault is cleared, there is a thermal imbalance between the conductor and its environment. Thermal equilibrium is not restored immediately, but progressively within minutes.

2) ***Transient-Dynamic***: The temperature gradient between conductor and environment exists for 5-30 minutes. This is the power system's response to a controlled step change (e.g. line energisation). Conductor current rises instantaneously but unlike during a fault, the change in conductor temperature is gradual as shown in Figure 5.

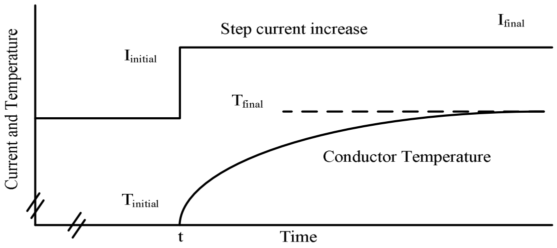


Figure 5. Conductor temperature response to instantaneous change in current
Source: Adapted from IEEE (2006)

The conductor and its environment are in thermal equilibrium immediately prior to the step change ($t = t^-$). Immediately after the step change ($t = t^+$) the conductor's resistance, temperature and heat losses remain the same. However, there is an increase in the generation rate of ohmic losses as the conductor current and the conductor temperature begins to increase. Non-steady state ampacity can be calculated using Equation (10).

$$q_c + q_r + mC_p \frac{dT_c}{dt} = I^2 R(T_c) + q_s \tag{10}$$

5. Network Constraint: Conductor Sag

Conductor loading is not limited to its ampacity. According to Brooks (2007), transmission lines are also subjected to various types of physical loading, such as:

- Weight of conductor and fittings,
- Conductor tension,
- Environmental load (e.g. wind), and
- Construction and maintenance load.

An increase in physical and electrical loading results in conductor sag. Conductor sag is defined as the vertical distance between any point on a conductor and a straight line between the two attachment points. Provided the sag is < 9% of the span length, there is < 1% difference in the parabolic and catenary profiles (Brooks, 2007). The relatively simpler parabola formula was used to calculate sag using Equation (11).

$$D = \frac{9.81 w_c S^2}{8000H} \tag{11}$$

As conductor temperature increases, the unstretched conductor length will increase according to Equation (12) (Brooks, 2007).

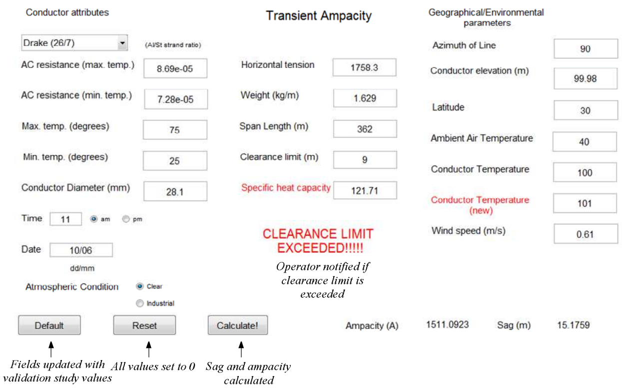
$$\Delta L = \alpha \Delta TS \tag{12}$$

The new span length is then used to recalculate conductor sag, identifying any sag limit violation.

7. DLR Software Implementation

7.1. DLR Software Functionality

The DLR software was implemented in MATLAB and applicable to all bare overhead conductors. The conductor library currently contains ACSR conductors with the facility to manually input additional conductor attributes. Wind speed and temperature data can also be imported from a spreadsheet. The manual input window for transient dynamic ampacity calculation is displayed in Figure 6.



Drake (26/7) (Al/St strand ratio)
AC resistance (max. temp.) 8.69e-05
AC resistance (min. temp.) 7.28e-05
Max. temp. (degrees) 75
Min. temp. (degrees) 25
Conductor Diameter (mm) 28.1
Time 11 ● am ○ pm
Date 10/06 dd/mm
Atmospheric Condition ● Clear ○ Industrial
Horizontal tension 1758.3
Weight (kg/m) 1.629
Span Length (m) 362
Clearance limit (m) 9
Specific heat capacity 121.71
CLEARANCE LIMIT EXCEEDED!!!!!
Azimuth of Line 90
Conductor elevation (m) 99.98
Latitude 30
Ambient Air Temperature 40
Conductor Temperature 100
Conductor Temperature (new) 101
Wind speed (m/s) 0.61
Ampacity (A) 1511.0923 Sag (m) 15.1759

Operator notified if clearance limit is exceeded

Fields updated with validation study values

All values set to 0

Sag and ampacity calculated

Figure 6. Transient state calculation window of software illustrating input fields

7.2 Validation

The DLR software was validated using values provided in a sample calculation from the IEEE 738 Standard (IEEE, 2006) for a drake conductor. Sag results were validated using a sample calculation, from Rahim et al (2010), for a zebra conductor. Table 4 shows the parameters of the DLR software output.

A case study was performed on the 66 kV Chaguanas East - Chaguanas West circuit of the transmission network at T&TEC (illustrated in Figure 7). Conductor parameters were obtained from Hernandez (2006). Load demand values for this circuit were recorded every 15 minutes. Hourly values for ambient air temperature and wind speed were obtained from the Trinidad and Tobago Meteorological Service for Piarco,

Table 4. DLR software output

Symbol	Description	IEEE 738	System	Unit
q_r	Radiated heat loss per unit length	24.44	24.44	Wm^{-1}
q_c	Convected heat loss per unit length	82.3	82.3	Wm^{-1}
q_s	Heat gain rate from sun	14.1	14.1	Wm^{-1}
$R(T_c)$	AC resistance of conductor at temperature T_c	9.39×10^{-5}	9.39×10^{-5}	Ω
I	Ampacity	994	994	A
D	Sag	11.016	11.016	m

Trinidad. It was assumed that wind speed and temperature were similar at Piarco and Chaguanas.

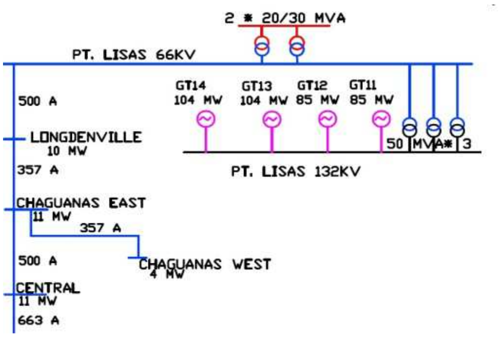


Figure 7. Chaguanas East - Chaguanas West circuit used for case study

On July 18th 2012, there was a 2.7°C variation in the ambient air temperature. The lowest wind speed was 2.4 ms^{-1} and the highest was 8.5 ms^{-1} as shown in Figure 8. Observations of weekly trends in wind speed and ambient temperature before and after the specified date were similar to that in Figure 8, suggesting the conductor experienced similar environmental cooling and heating. For the entire 24-hour period, neither the calculated ampacity nor the actual conductor loading exceeded the manufacturer's rating of 512 A. The lowest ampacity calculated, at 10:00am, was 727 A, approximately 42% higher than rated. The highest ampacity calculated was 1060 A, at 12:00am, was 107% higher than rated. This is illustrated in Figure 8. These results were expected.

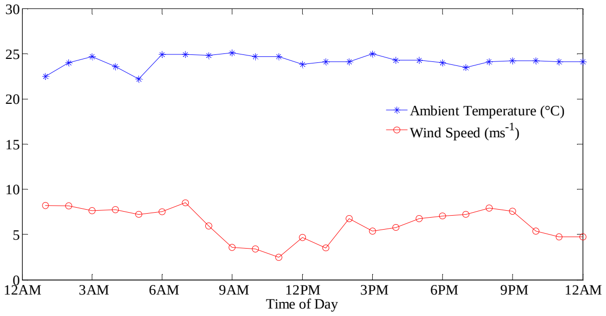


Figure 6. Hourly readings for wind speed and ambient temperature

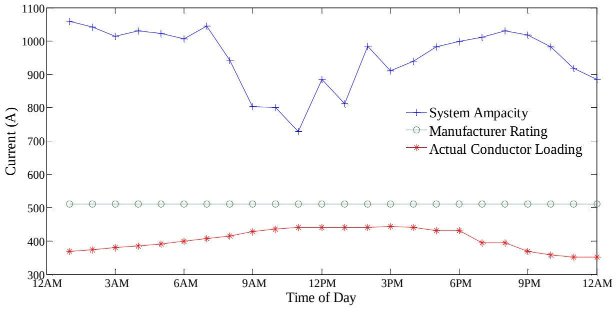


Figure 7. Actual conductor loading for July 18th 2012 and calculated ampacity

The manufacturer's test condition for ambient air temperature was 25°C; approximately the same as the Chaguanas East - Chaguanas West circuit. Wind speeds were different. The manufacturer's rating was determined using wind speed of 0.61ms^{-1}, significantly lower than the wind speeds experienced at the site. Figure 9 suggests that the Chaguanas East - Chaguanas West circuit was conservatively loaded.

8. Conclusion and Further Work

This paper briefly described methods of increasing the usage efficiency of transmission resources and provided an overview of the development of a MATLAB based DLR software tool. This developed software calculated ampacity of overhead conductors under steady state and transient conditions using (IEEE, 2006) and was validated using a case study (Rahim et al., 2010). A case study was conducted on an ACSR Wolf conductor and the results showed that the circuit was conservatively loaded. Further work is planned to assess the predetermined limits for selected lines to ensure that protection schemes are not compromised by employing DLR. The software tool will also be expanded to include the effect of constraints, such as transmission line losses; and steady state and transient state voltage stability levels to allow the selection of current loading.

References:

Bhuiyam, M.M.I., Musilek, P., Heckenbergerova, J. and Koval, D. (2010), "Evaluating thermal aging charactersitics of electric power transmission lines", *Proceedings of the Canadian Conference on Electrical and Computer Engineering (CCECE)*, Canada, Vol.1, pp.1-4

Brooks, J. (2007), *Network Lines Standard Guidelines for Overhead Line Design*, Ergon Energy Corporation Limited, Queensland.

Deb, Anjan K. (2000), *Powerline Ampacity System: Theory, Modeling and Applications*, CRC Press, Florida

Foss, S., and Moraio, R. (1992), "Evaluation of an overhead line forecast rating algorithm", *IEEE Transaction on Power Delivery*, Vol.7, No.3, pp.1618 - 1627.

Goodwin, T, and Smith, C. (2011), *Smart Grid Demonstration Project- Dynamic Line Rating (DLR),* Available at: http://www.texasre.org/CPDL/Smart%20Grid.pdf

Hernandez, Manuel (2006)(ed), Line Parameters, Taylor and Francis Group, available at: http://www.unioviedo.es/pcasielles/uploads/proyectantes/cosas_lineas.pdf.

IEEE (2006), *IEEE 738: Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductor*s, The IEEE Standards Association, Piscataway, NJ 08855

LocLe, T., Negnevitsky, M. and Piekutowski, M. (1995), "Expert system application for the loading capability assessment of transmission lines", *IEEE Trans. on Power Systems*, Vol.10, No.4, pp.1805-1812.

Rahim, A., Abidin, I., Tarlochan, F. and Hashim, M. (2010), "Thermal rating monitoring of the TNB overhead transmission line using line ground clearance measurement and weather", *Proceedings of the International Power Engineering and Optimisation Conference*. Malaysia, Vol.7, No.10, pp.274-280

Schmidt, N. (1999), "Comparison between IEEE and Cigre Ampacity Standards", *IEEE Trans. on Power Delivery*, Vol.14, No.4, pp.1555 - 1562.

Yip, T., Aten, M. and Ferris, B. (2009), "Dynamic Line Rating Protection for Wind Farm Connections", *Proceedings of the 20th International Conference on Electricity Distribution*, Prague, Prague, Czech Republic, June 8-11

Authors' Biographical Notes:

Sanjay Bahadoorsingh *completed the B.Sc. degree from The University of The West Indies in 2003 and the M.Sc. degree from UMIST in 2005. In 2009, he completed the Ph.D. degree at The University of Manchester. Dr. Bahadoorsingh is currently Lecturer in the Energy Systems Group at The University of the West Indies. His areas of research are power systems, asset management and dielectric ageing.*

Laurel Vitra Bhairosingh *completed the B.Sc degree in Electrical and Computer Engineering from The University of the West Indies, St. Augustine in 2013. She is currently employed at the Trinidad and Tobago Electricity Commission. Her research interests include power systems analysis and operation; and application of advanced technologies to improve transmission efficiency.*

Chandrabhan Sharma *is the Professor of Energy Systems with the Faculty of Engineering, The University of West Indies. He is the Head of the Centre for Energy Studies and the Leader of the Energy Systems Group. He has served as a member of the Board of Directors of the local Electric Utility for over 10 years and is also a member of the Board of Directors of the largest bank in the country. Prior to joining the Academic staff at the university, Professor Sharma was attached to the petrochemical industry in Trinidad. His interests are in the area of power system operations and control.*

■