Dynamic Line Rating Current Calculation without Ambient Parameters Inputs

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Agenda

- Introduction
- Proposed Algorithms
- Validation and Testing Results
- Conclusions

Introduction

- The power transfer capacity of a transmission line is primarily constrained by stability limits and thermal limits
- Stability limits are reliability requirements and thermal limits, however, are mainly restrained with safety requirements in order to maintain line minimum clearance (sag limit) and to avoid conductor annealing
- Typically, the ampacity of long lines is primarily determined by the stability or voltage limits and the ampacity of short lines is determined by line thermal limits

Introduction

- Traditionally, thermal limit is applied with static line rating (SLR), which provides the maximum allowable current-carrying capacity based on certain environment assumptions and won't be altered frequently, such as summer line rating and winter line rating
- However, with renewable energy penetration, a line that was originally designed to supply a relatively small load, now may carry more current because of the large reverse power, and could exceed its winter and summer line ratings
- Rather than applying fixed summer and winter line ratings based on the "worst-case" weather assumptions, a dynamically derived line rating can be adopted

Introduction

- With dynamic line ratings (DLR) applied, transmission facilities can be operated up to their actual physical capacity rather than a conservative estimate of line capacity
- Conventional method for dynamic line rating current calculation requires ambient parameters inputs, such as ambient temperature, wind speed, wind direction and sun radiations, however, extra cost will be incurred for measuring these ambien parameters
- In order to avoid the extra costs for these additional measuring devices, several new techniques based only on the measuring voltage and current without ambient inputs have been propose including

Introduction

1. Calculate conductor temperature based on the conductivity characteristics respective to temperature. However, the coefficient of the temperature characteristic is too small to accurately calculate the temperature
2. Calculate conductor temperature based on the line sags, which significantly improved the accuracy of temperature calculation, however, no rating current can be given out

- This paper proposes a new method for calculating the dynamic rating current based on voltages and currents of both terminals of a line without any ambient parameter inputs
- The instantaneous temperature is estimated by calculating the variation of the line parameters, and then the steady state conductor temperature is calculated accordingly

Introduction

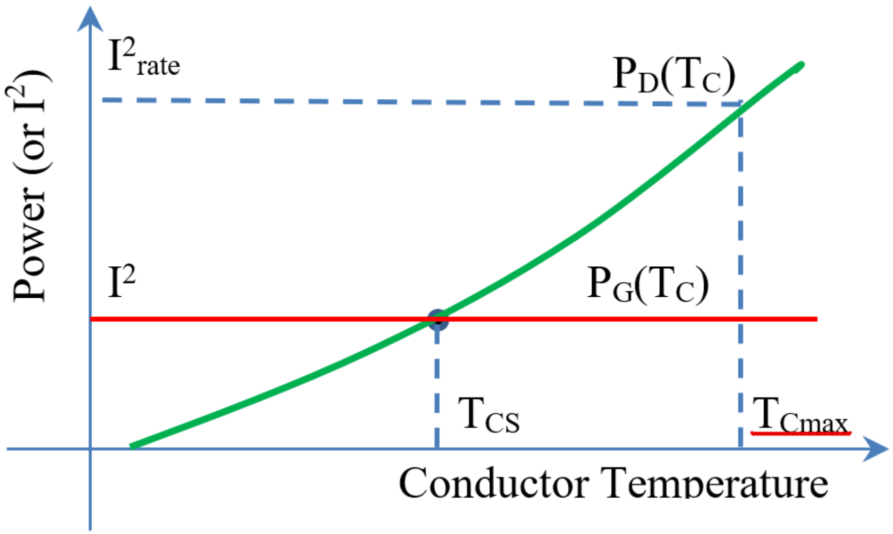
- With the calculated steady state conductor temperatures and the corresponding currents, the dissipating heat curve can be obtained by curve fitting method
- The dynamic rating current can be calculated based on the dissipating curve at the maximum allowed conductor temperature

The Proposed Algorithm

$$M_C \frac{dT_C}{dt} = P_G(T_C) - P_D(T_C),$$

$$P_G(T_C) = I^2 R(T_C)$$

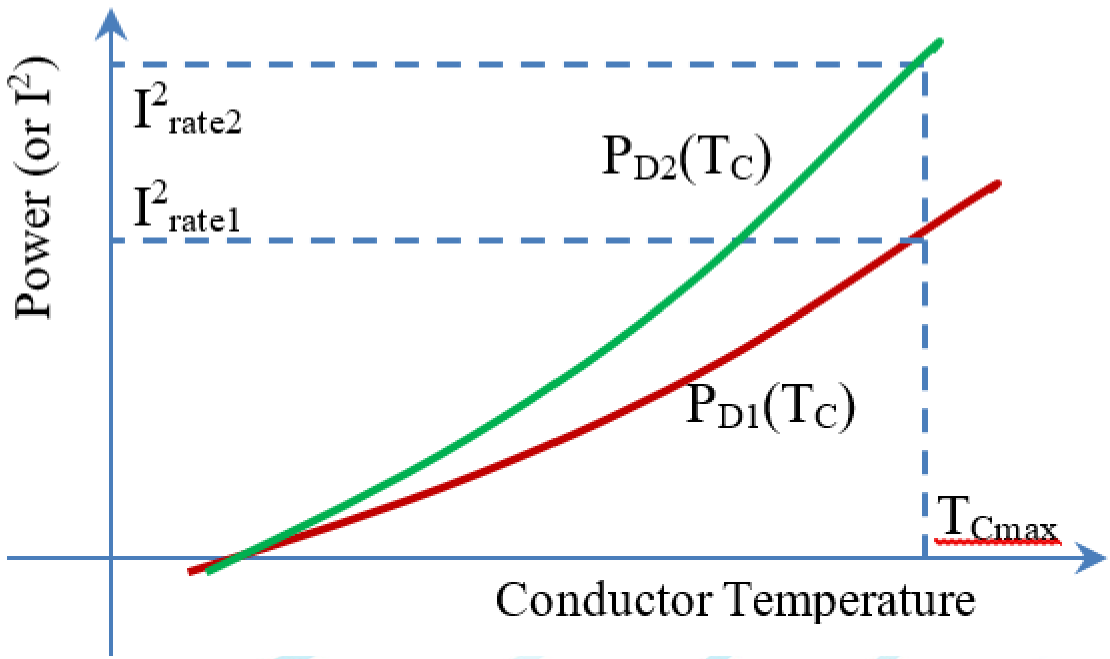
Mc	total heat capacity of conductor
T_C	conductor instantaneous temperature
$P_G(T_C)$	heat generating power
$P_D(T_C)$	heat dissipating power
$R(T_C)$	conductor resistance



$$I_{rate} = \sqrt{\frac{P_D(T_{Cmax})}{R(T_{Cmax})}}$$

The Proposed Algorithm

- If the ambient parameters are dynamically changing, the dissipating power curve dynamically changes accordingly, and so does the rating current, as shown below



The Proposed Algorithm

- Conductor heat dissipating power can be expressed as $P_D(T_C)=p_c+p_r-p_s$, where p_c is the convection heat loss, p_r is radiation heat loss, and p_s is solar heat gain
- The details for the dissipating power (P_D) calculation are defined in IEEE standard 738, in which a lot of ambient parameters and inputs are required
- In this study, power dissipating curve is expressed in polynomial terms

$$P_D(T_C) = a_0 + a_1 T_C + a_2 T_C^2$$

Where a_0, a_1 and a_2 are the coefficients to be determined

The Proposed Algorithm

- At the balance point, the dissipating power equals to the generating power, we can obtain the dissipating power by calculating the generating power

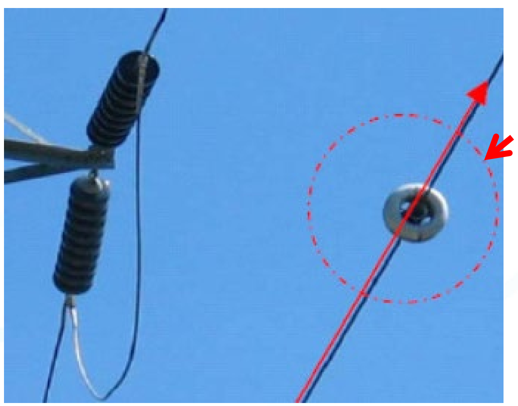
$$P_D(T_C) = a_0 + a_1 T_C + a_2 T_C^2, \qquad P_G(T_C) = I^2 R(T_C)$$

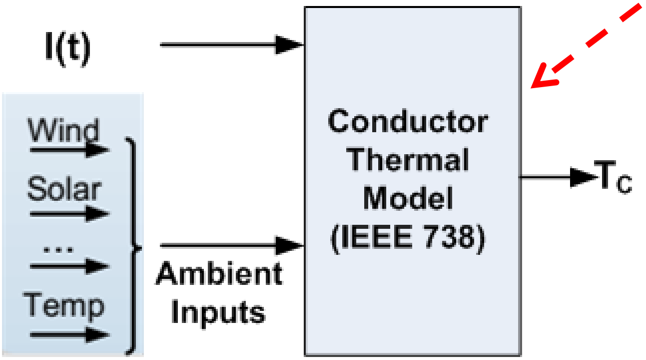
- Assuming N pairs of heat generating power and temperature values are obtained, coefficients (a_0, a_1, a_2) can then be solved, and rating current can be calculated accordingly

$$\begin{bmatrix} P_{G1} \\ P_{G2} \\ \cdots \\ P_{GN} \end{bmatrix} = \begin{bmatrix} 1 & T_{C1} & T_{C1}^2 \\ 1 & T_{C2} & T_{C2}^2 \\ \cdots & \cdots & \cdots \\ 1 & T_{CN} & T_{CN}^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} \qquad I_{rate} = \sqrt{\frac{a_0 + a_1 T_{Cmax} + a_2 T_{Cmax}^2)}{R(T_{Cmax})}}$$

The Proposed Algorithm

- The difficulty is how to obtain the conductor temperature?
- Conventional methods include (1) direct measurement, and (2) calculation based on ambient parameter inputs

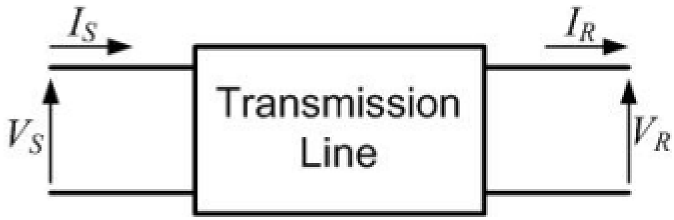




- However, extra cost will be incurred for both methods

The Proposed Algorithm

- In our approach, the conductor temperature is calculated based on voltages and currents from both terminals of a line, but without any ambient parameter inputs
- Conductor temperature change will result in the line length change, which will lead to line parameters change



$$\begin{bmatrix} \dot{V}_S \\ \dot{I}_S \end{bmatrix} = \begin{bmatrix} A(T_c) & B(T_c) \\ C(T_c) & D(T_c) \end{bmatrix} \begin{bmatrix} \dot{V}_R \\ \dot{I}_R \end{bmatrix}$$

$A(T_c) = D(T_c) = \cosh(\gamma l);$

$B(T_c) = Z_c \sinh(\gamma l);$

$C(T_c) = \sinh(\gamma l)/Z_c;$

$l(T_c) = l_0[1 + \alpha(T_C - T_{REF}) + \beta(T_C - T_{REF})^2]$

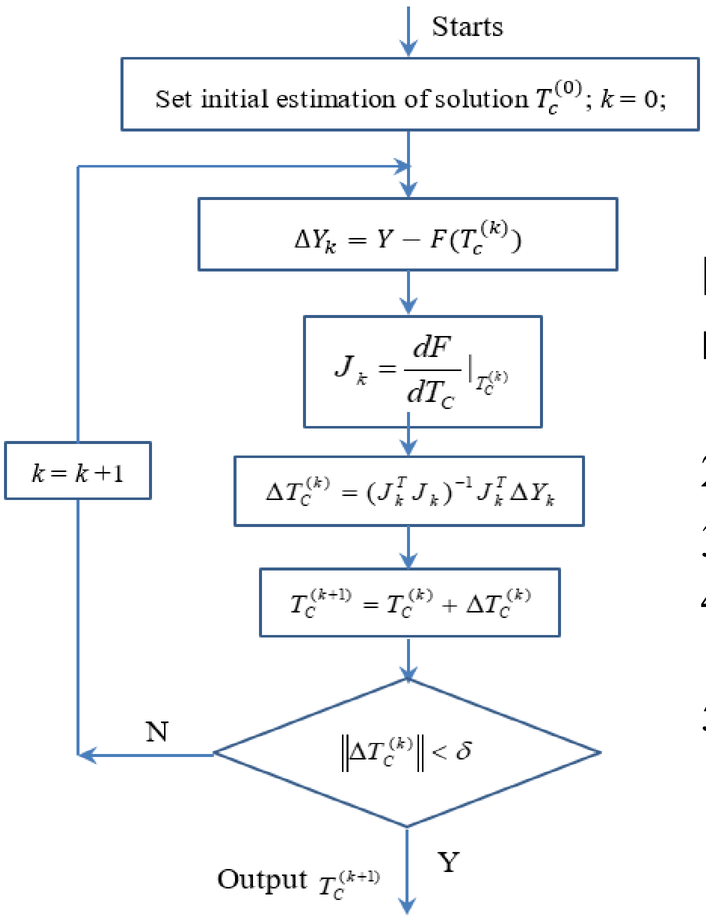
$\gamma = \sqrt{(r + j\omega L)(j\omega C)}$

$Z_c = \sqrt{(r + j\omega L)/(j\omega C)}$

The Proposed Algorithm

$$\begin{bmatrix} \dot{V}_S \\ \dot{I}_S \end{bmatrix} = \begin{bmatrix} A(T_c) & B(T_c) \\ C(T_c) & D(T_c) \end{bmatrix} \begin{bmatrix} \dot{V}_R \\ \dot{I}_R \end{bmatrix}$$

$$\mathrm{Y} = \begin{bmatrix} Re(\dot{V}_S) \\ Im(\dot{V}_S) \\ Re(\dot{I}_S) \\ Im(\dot{I}_S) \end{bmatrix} = \mathrm{F}(T_c) = \begin{bmatrix} Re\left(f_1(\dot{V}_R, \dot{I}_R, T_c)\right) \\ Im\left(f_1(\dot{V}_R, \dot{I}_R, T_c)\right) \\ Re\left(f_2(\dot{V}_R, \dot{I}_R, T_c)\right) \\ Im\left(f_2(\dot{V}_R, \dot{I}_R, T_c)\right) \end{bmatrix}$$



Newton's algorithm is employed for solving this non-linear equation:

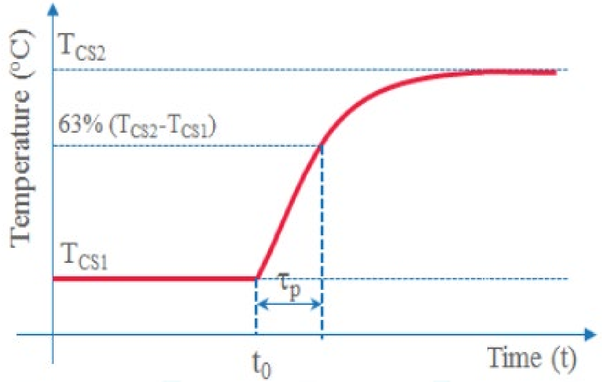
1) Set an initial solution, substitute it into $F(T_C)$, set k=0
2) Calculate the difference between Y and $F(T_c^{(k)})$
3) Substitute $T_c^{(k)}$ into Jacobian matrix
4) Calculate the difference between k^th solution and real root value by means of least square method
5) Correct the k^th solution

The Proposed Algorithm

Calculation of Steady State Temperature

- Steady state conductor temperature can be estimated with 1st order differential equation, where τ_p is thermal time constant

$$T_C(t) = T_{CS} + \tau_p \frac{dT_C(t)}{dt}$$



- It can be further digitized

$$\frac{T_C(n) + T_C(n-1)}{2} = T_{CS} + \tau_p \frac{T_C(n) - T_C(n-1)}{T_s}$$

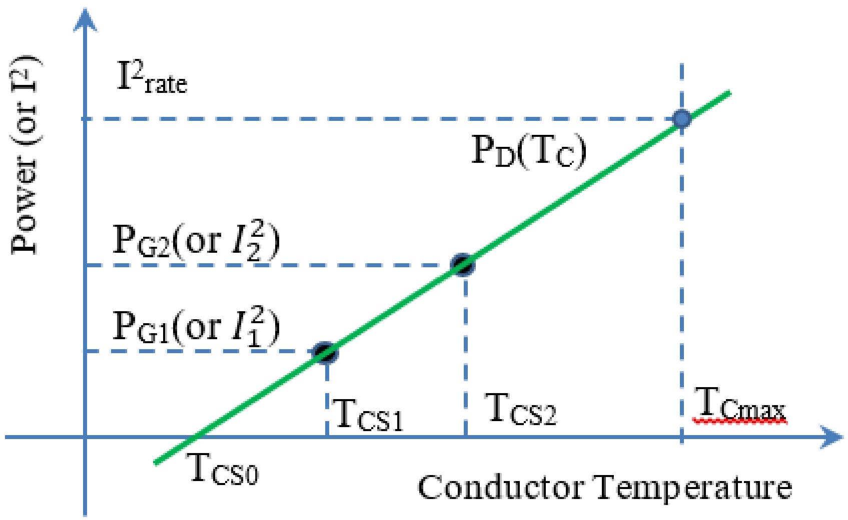
- Use at least two equations to solve T_{CS} because of 2 unknowns. Assume one equation is at time n, another one is at time m:

$$\begin{cases} \dfrac{T_C(n) + T_C(n-1)}{2} = T_{CS2} + \tau_p \dfrac{T_C(n) - T_C(n-1)}{T_s} \\ \dfrac{T_C(m) + T_C(m-1)}{2} = T_{CS2} + \tau_p \dfrac{T_C(m) - T_C(m-1)}{T_s} \end{cases}$$

The Proposed Algorithm

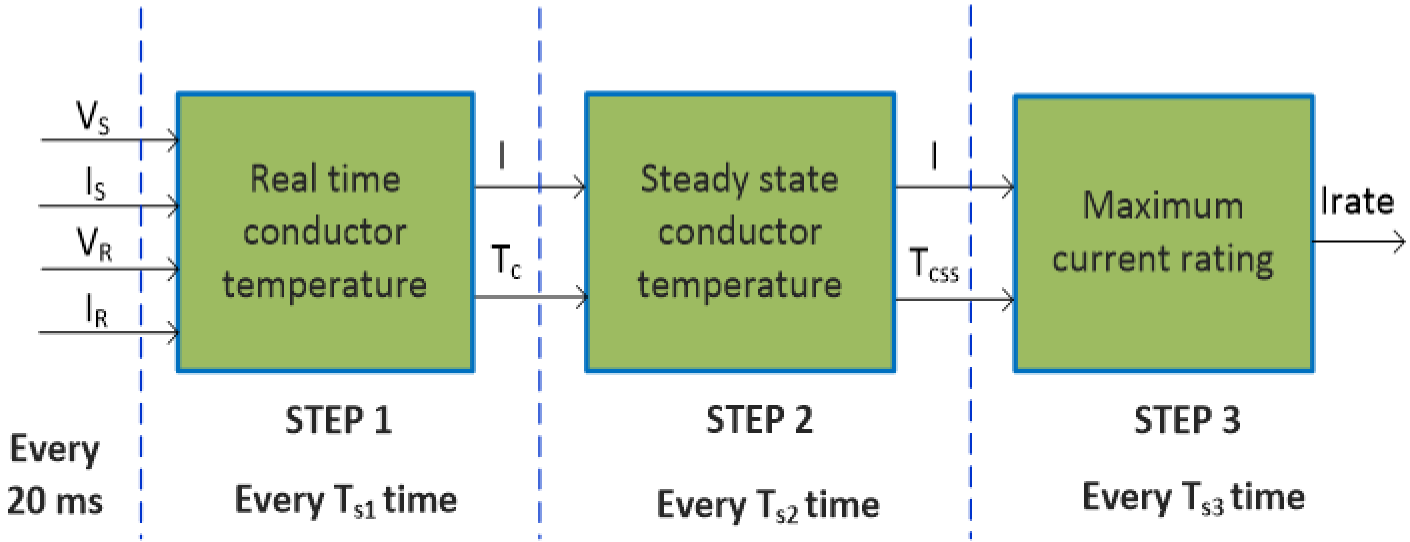
Calculation of Rating Current

- For simplification, linear polynomial is used for curve fitting the heat dissipating power curve



The Proposed Algorithm

THE SCHEME AND ALGORITHMS FOR REALIZATION



Ts1 = 20ms (for 50Hz system);
Ts2 = 100ms;
Ts3 = 1000ms;

The Proposed Algorithm

- How to deal with the scenarios where the measured conductor temperature points and conductor current points (or heat generating power) are on different dissipating power curve

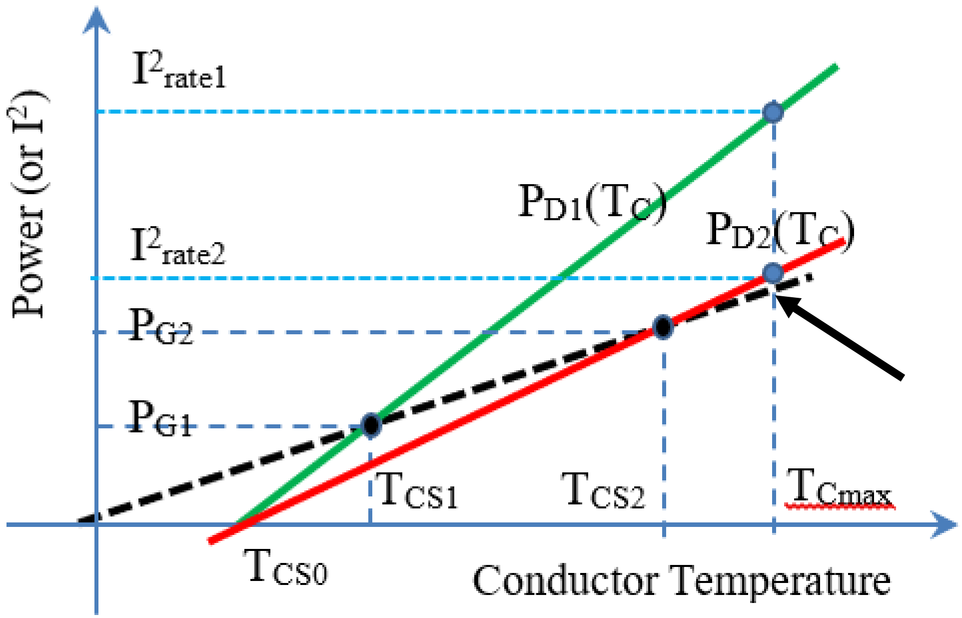


Figure 7. Both the current and ambient condition change

The Proposed Algorithm

- The solution for overcoming the scenario where the two points are not in the same dissipating curve is that these scenarios should be identified by checking the initial conductor temperature
- Before the algorithm is running, in the initialization stage, the inception conductor temperature T_{CS0} is set as the possible minimum value of the ambient temperature

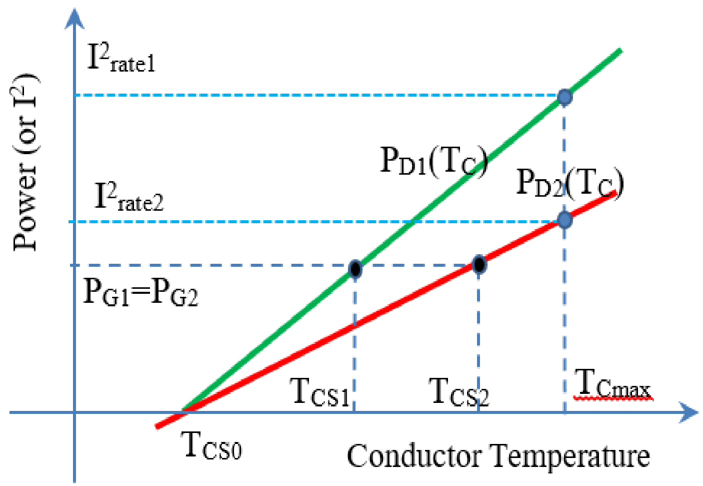


Figure 8. Current does not change but conductor temperature changes due to the change in ambient conditions

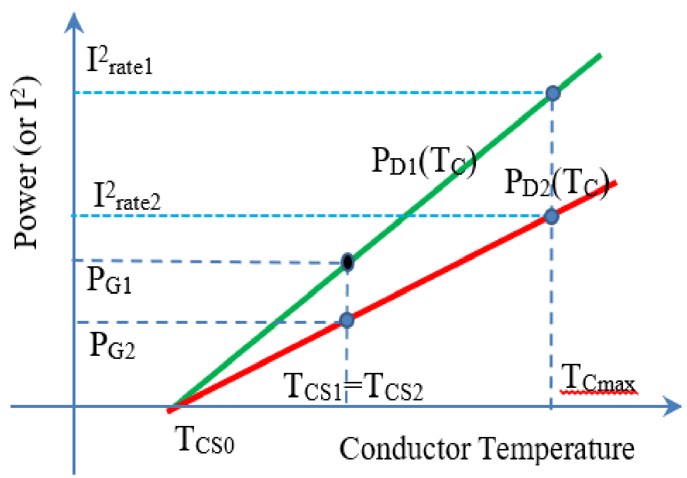
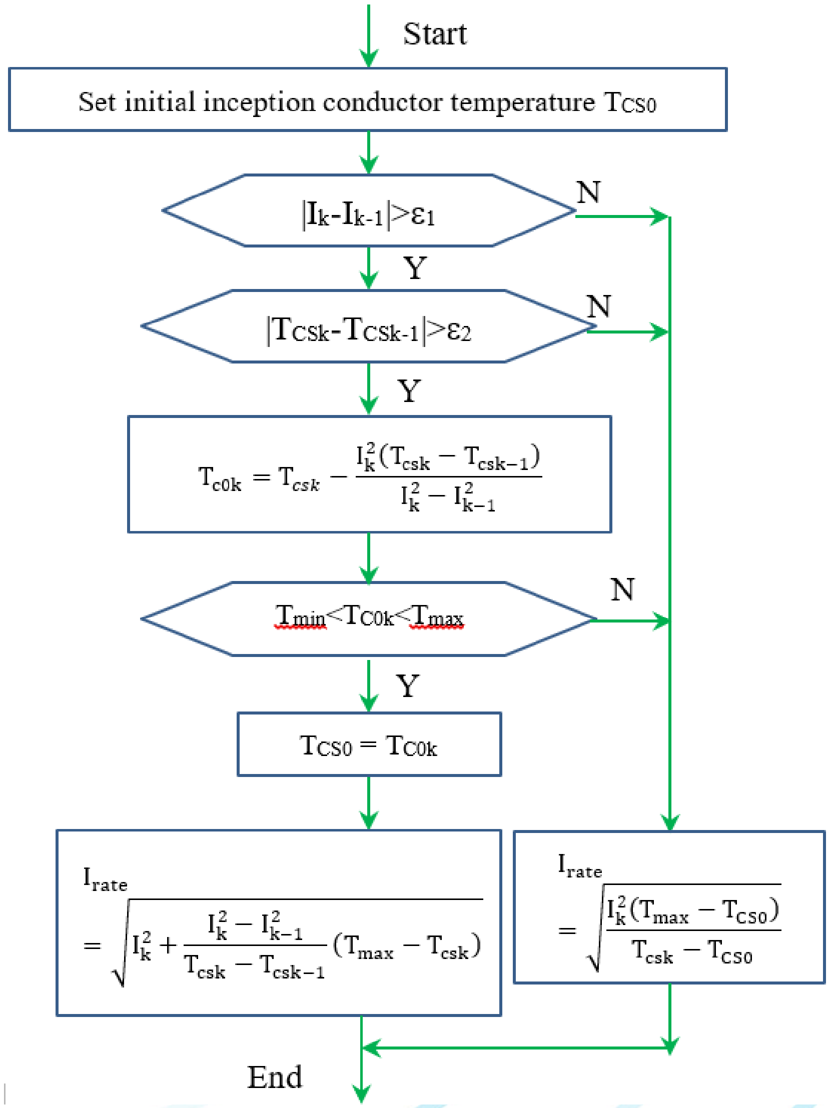


Figure 9. Current changes however conductor temperature does not change due to ambient condition changes

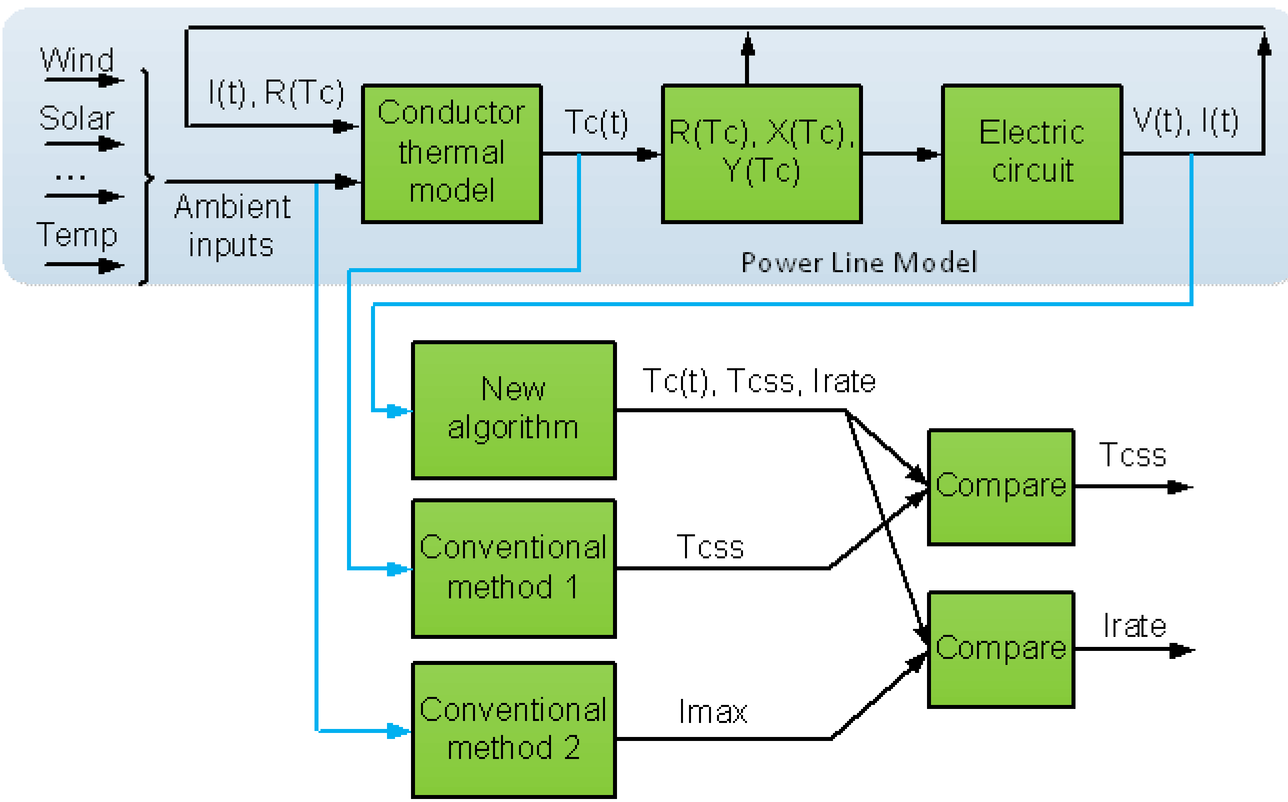
The Proposed Algorithm

Flow chart of calculating rating current



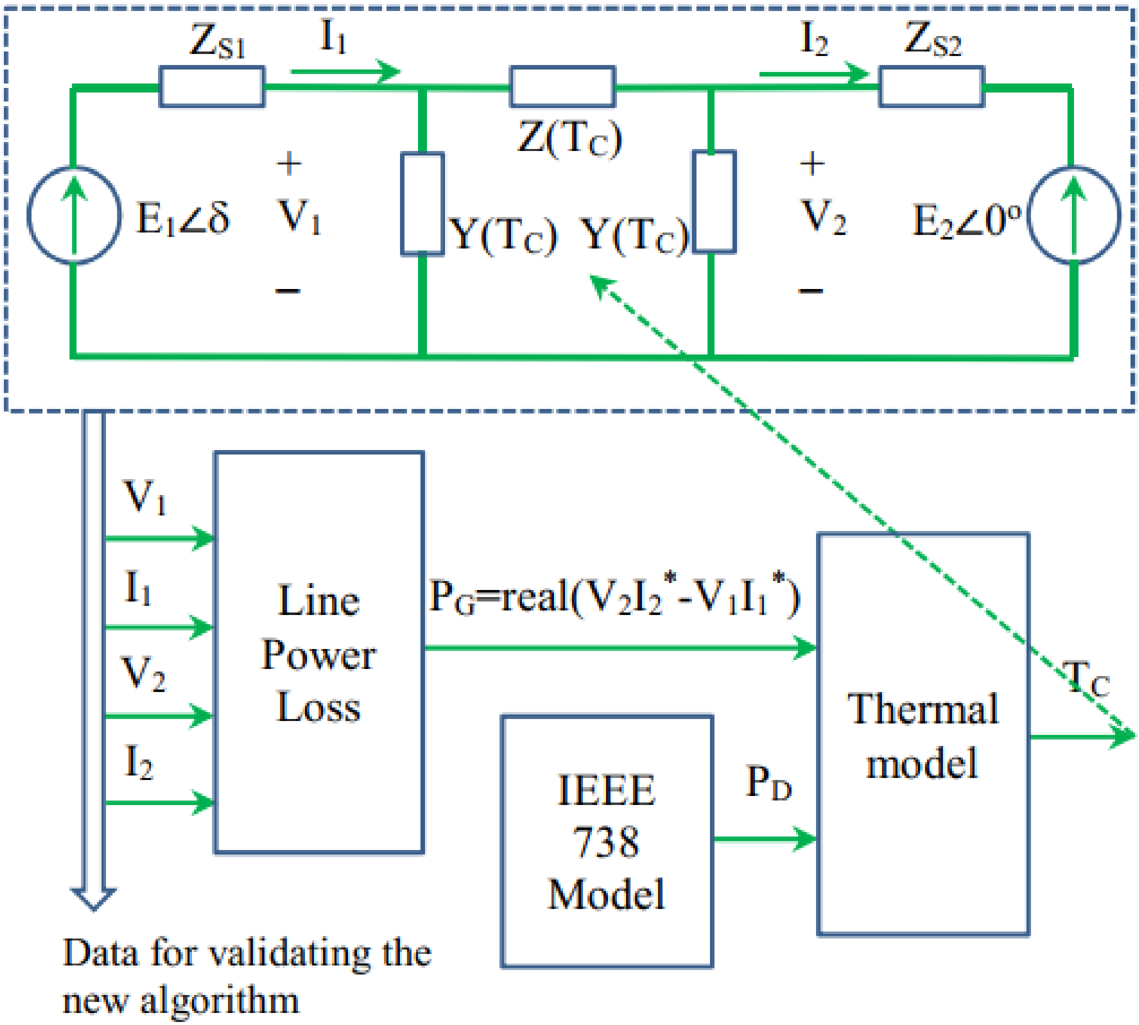
Validation and Testing Results

- The data for validating the new algorithm are generated by simulations inMatlab/Simulink



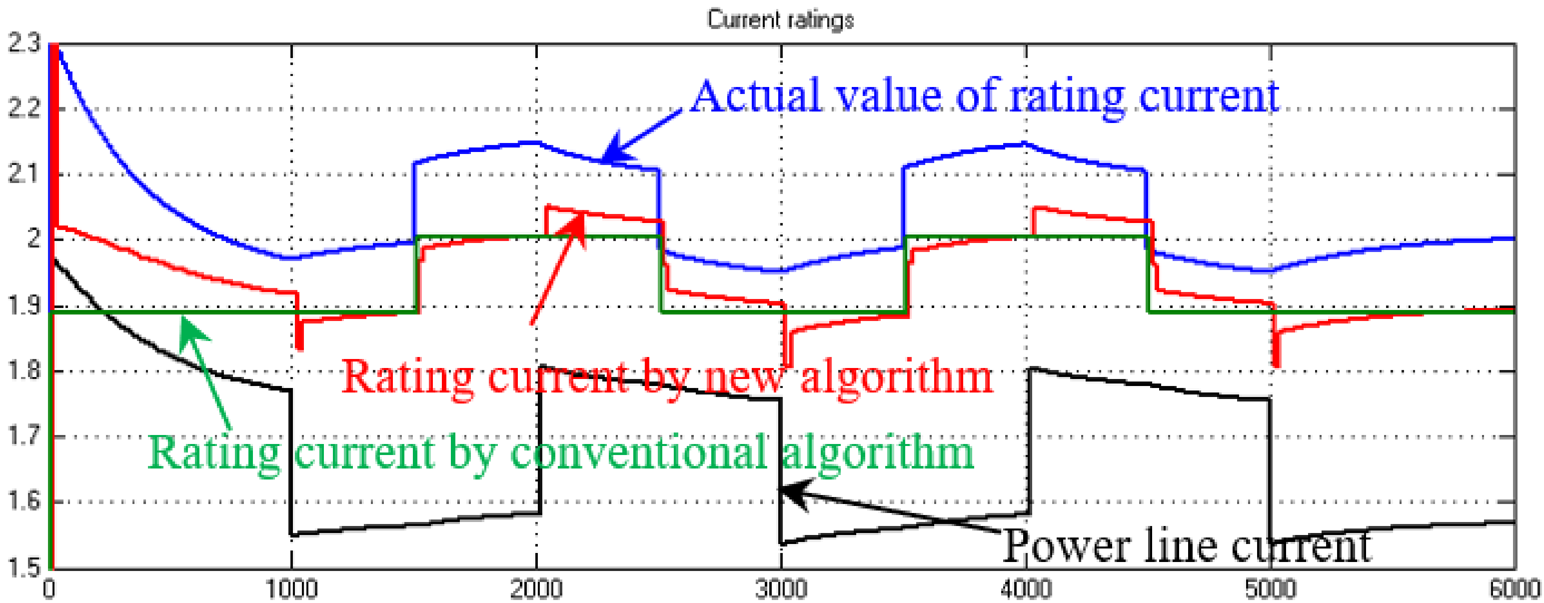
Validation and Testing Results

- Simulation Model In details



Validation and Testing Results

- Validation Results



Conclusions

- This paper proposes a method for calculating the dynamic line rating current without ambient inputs
- The conductor temperature is calculated by the variation of the line parameters
- The rating current is calculated from the dissipating power curve, generated by curve fitting method, at the maximum allowed conductor temperature

Conclusions

- The results of the validation show that this method is reliable and the difference between the new method and the conventional method which requires large amount of ambient inputs is less than 4%

Thank You

Questions?