Impact of rain on transmission lines’ ampacity: Scotland as a case study

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Impact of Rain On Transmission Lines' Ampacity: Scotland as a Case Study

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***Abstract*— The increase in volume of embedded generation, particularly wind farms in the United Kingdom coupled with change in nature of connected load (growing number of electric vehicles and domestic PV) will require system operators to look for ways to reduce network constraints. Increasing the current carrying capacities of transmission lines while ensuring that safety margins are not encroached will result in significant improvements to overall transmission efficiency and reduction in operational costs. It is possible to increase transmission lines transfer capacities through monitoring of conductor temperature in real time; however, there are conditions that will necessitate limitations. One of these is the effect of conductor shading (due to trees for example), another is the temperature overshoot effect (mainly relevant to new conductors running at 90° Celsius). This paper will focus on studying the cooling effect of rain on conductor ampacity. A close relationship (rain Vs conductor temperature) often ignored in studies concerned with ampacity measurements and computation.**

***Index Terms*— Ampacity of bare power lines, dynamic thermal ratings, generation dispatch, ruling span of transmission line, temperature overshoot effect and thermal time constant.**

I. INTRODUCTION

Traditional approach to compute power line ampacities involves calculation using assumed static parameters where generally worst case scenario parameters are chosen. Although this approach will result in safe line operation but this will be at the expense of costs. According to [1] during high wind conditions, employing a dynamic line rating system (DLR) will create an extra margin in the transfer capability of transmission lines. This in turn will allow more generation particularly wind power feed-in with minimum reinforcements in capacity of the grid. While wind contributes to enhance overhead lines rating, rain also have an impact on transmission line ratings, this study conducted an experiment to analyse impact of rain on conductor ampacity. Researchers in [2][3][4] suggested to employ line temperature sensing technologies combined with real-time weather data and a custom built routine software to enhance ratings of transmission lines and other system components in a real time. Research team working in [5] also stated that rate of conductor temperature increase exceeds that of corresponding current increase

It was found that in a clear day rate of conductor temperature increase in relation to current applied through it is linear in nature, unlike during rainy days where this rate tends to develop a non-linear relationship. This relationship to the best knowledge of this document authors was not given the necessary attention in engineering literature. The main purpose of this study is to analyse it in some details and propose ways to utilise it. However, there are limitations as outlined by [6] obtained from practical experience such as temperature variation in spans of a very long transmission line. These are caused by factors such as topography example; altitude of tower line, shading due to trees, river crossings, railway or motorway crossings and way-leave restrictions. Other limitations to be considered include material; dimension and geometry of the conductor, ageing effect, surface condition of conductor tend to exhibit emissivity and absorptivity changes for older conductors. Researchers in [7] found that temperature and rainfall were positively correlated during January and May and negatively correlated between June and December. The tendency of hot conductor to conduct heat through the thermal gradient to air that manifests itself when rain is applied will be studied during course this experiment.

Part of this study will focus on another parameter well known to electronics manufacturing and thermal generation industries but often overlooked in transmission and distribution, it is the thermal time constant of bare overhead line conductors. Researcher in [8] defines it as a measure of the speed at which a material heats up or cools down as thermal load increases or decreases; it is a representation of thermal inertia of the conductor. Researchers in [9] stated that it is important to distinguish between transient and steady state thermal rating of a power cable.

II. METHODOLOGY

A. *Test setup*

Prior to undertaking conductor temperature measurements, detailed calibration of the sensors and feedback sensors was conducted using iced and boiling water. The following equipment will be used to conduct the experiment:

- ➔ Cartridge heater, (temperature range 10°C to 250°C, powered by domestic mains electricity).
- ➔ Thermocouple wires, temperature range -30°C to +120°C
- ➔ An AAAC clipped conductor, (37.5 millimetre diameter, stranded Araucaria conductor)
- ➔ Water pressure sprayer (mechanical pump).
- ➔ Environmental Chamber

B. Method statement

A cartridge heater is used to heat the conductor up to its maximum design temperature for a stranded AAAC Araucaria cable it is 90°C. To achieve homogenous heat distribution throughout the conductor, the specimen is drilled and a metal sleeve is inserted through the conductor. Temperature of the conductor will be measured and logged in at different points of the experiment. To achieve the main objective described earlier, it is essential that the following steps be conducted;

- ➔ Initial measurements are undertaken using thermo-couple prior to heating up the conductor.
- ➔ It is also essential to calibrate the temperature measurement equipment above before commencing the experiment to check for any discrepancies/ unusual outputs.
- ➔ The bare cable will have to be;
    - i. Visually inspected for any damage.
    - ii. Its initial temperature will have to measure just before commencement of the experiment.
- ➔ Repeat steps above following simulation of rain to check impact of rain droplets on the conductor temperature at different pre-loading conditions to simulate the impact of combination of rain and summer average temperatures on a loaded transmission conductor.

To mimic precipitation, rate the mechanical water pump pressure is adjusted to discharge required water spraying rate, calibration of the water pump is done prior to undertaking the spray using a digital stopwatch and volume scale markings on the pump. To measure impulsive effect of rain on conductor temperature water having different levels of pressure to reflect different precipitation rate is applied for 1 minute at a time to two different cases. This step is important to help research team mathematically linearize the relationship between rain and conductor temperature as much as possible.

III. Analysis

A. Heat balance equation [10]

Heat balance equation computes available thermal capacity of overhead power lines.

$$Q_C + Q_R = Q_S + Q_{EM} \quad (1)$$

Where,

Q_C – Convective heat loss per unit length, in W/m

Q_R – Radiant heat loss per unit length, in W/m

Q_S – Heating from solar insolation per unit length, in W/m

Q_{EM} – Losses from AC current per unit length, including joule loss, in W/m

$$Q_c = N_U * \lambda * \pi * (T - T_a) \quad (2)$$

$$N_{U\ low} = 0.32 + 0.43 * Re^{0.52} \text{ low wind speeds} \quad (3)$$

$$N_{U\ hi} = 0.24 * Re^{0.6} \text{ high wind speeds} \quad (4)$$

$$R_e = \nu D \gamma / \eta \quad (5)$$

where

ν –Wind speed

D – Diameter of the cable

γ – Specific mass of air

η – Dynamic viscosity of air

λ – Thermal conductivity of air

N_U – Nusselt number

T – Conductor temperature

T_a – Ambient temperature

Heat convection happens when a bulk flow of fluid or gas carries heat along with the flow of matter. Nusselt number defined by [11] as the ratio of convection heat transfer to fluid conduction heat transfer under the same conditions.

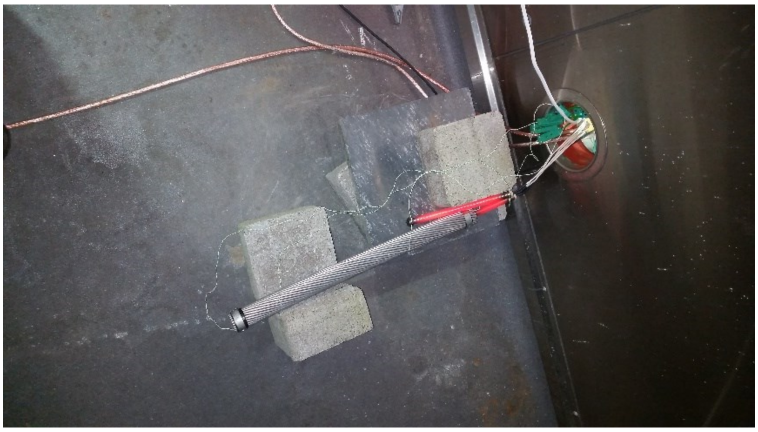

Fig 1- Calibrating the cartridge heater feedback thermocouple

Fig 2- Digital Data logger software and environmental chamber computer control

This ratio is different for different wind speeds. Conductors with high grease contents (used mostly near coastal areas where corrosion resistance is a requirement) generally retain heat more when compared with lower grease contents / grease grade conductors.
Cable manufacturers offer three main categories of grease grade, each suitable for different application. For the higher grades, more consideration needs to be given to mechanical loading on towers cross arm members and this has profound effect on thermal ratings of transmission lines.

Fig 3- Pre-test setup; AAAC cable, stranded Araucaria conductor

B. *Results*

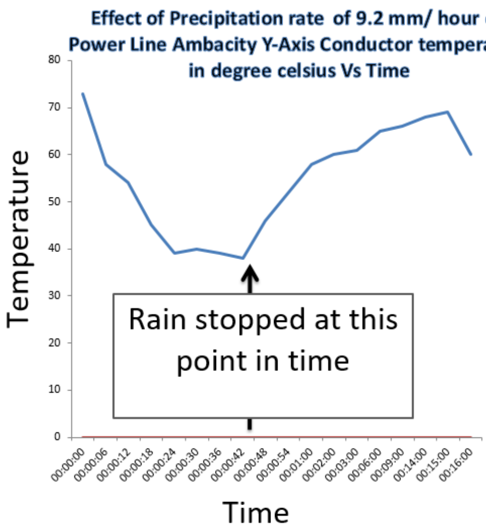

Fig 4 – Conductor Temperature Vs Time during rain application, precipitation rate 9.2 mm/ hour

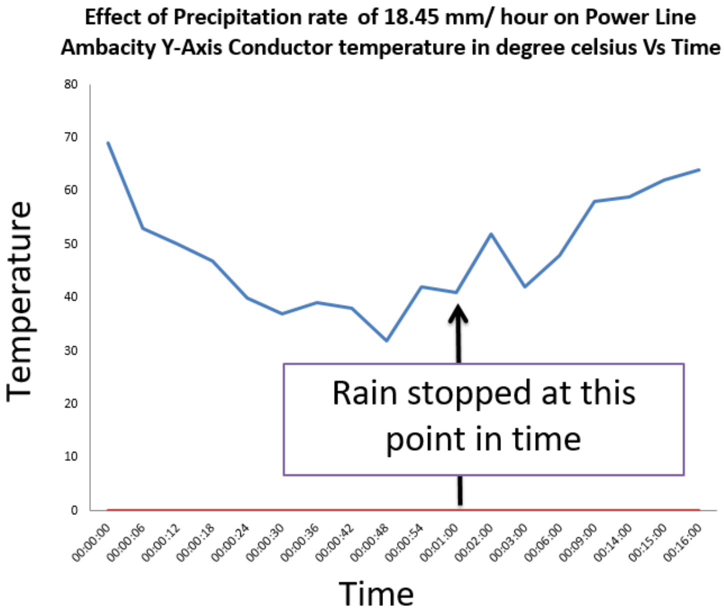

Fig 5 – Conductor Temperature Vs Time during rain application, precipitation rate 18.45 mm/ hour

The graph in figure 4 and 5 measurements was conducted at an ambient temperature of 25°C with the intent of identifying and quantying behaviour patterns of conductors during a wet summer seasons. This season was chosen because it offers a challenging time in Scotland for system operators from a thermal demand and high loading standpoint, particularly in touristic areas. Also the choice of ambient temperature of 25° C is consistent with typical hot summer day average in Northern Scotland.

The three patterns observed during course of this experiment were.

1. Temperature overshoot effect

Findings of these measurements are consistent with what researchers in [12] reported, temperature overshoot effect can cause newly conductors designed to run at 90°C to overheat. Reaching extremely high temperatures exceeding 100°C at times increasing risk of conductor annealing and dangerous sagging encroaching electrical safety clearences. Conductor's grease retains heat long after line is deenergised leading to intemittant overheating. After hours of heating the conductor and application of rain, the conductor grease eventually gets removed.

2. Thermal time constant

Thermal time constant is an important parameter in the design of power line cables, it took the specimen in this experiment 700 seconds to reach its maximum temperature after heat was applied . Importance of this parameter manifests itself when considering the generation dispatch response times. It is also particularly useful to offset supply outages risks during adverse weather conditions when temporar system overload becomes inevitable. Research team in [13] stated that overlooking this parameter can have serious financial costs to utilities because it removes the needed flexibility during adverse weather conditions.

3. Effect of rain

The graphs 2 and 3 above shows the profound and fast impact rain has on rate of temperature drop of power lines, in under 1 minutes conductor temperature dropped to 54% of maximum peak temperature and remained between 80% and 54%. Temperature of the conductor never really fully recovered for full 15 minutes despite rain source being removed after 1 minute following rain application in both cases. Rain can thus be considered a thermal reset button of bare aerial power lines. These results are significant as they clearly show impulsive lasting effect of rain on conductor temperature, to put these results in system operational context, consider a heavily loaded power line operating close to it's design temperature during a rainy day. As soon as it starts raining, immediately after the first minute of the rainfall conductor temperature will fall by anything between 20% and 50% loading and precipitation rate dependant.And further remain well below the maximum design temperature long after the rain has stopped for no less than 15 minutes.This not only inceases network reliability but offers the system operator so many other benefits such as..

- Flexibility when its most needed.
- Reduction in transmission cost resulting from flexibility.
- Maximise system utilisation.
- Enhanced secuirty of supply.
- Enhanced system inertia and power quality.
- Reduced generation curtailment.

IV. Discussions And conclusion

The conductor used in this experiment was a AAAC Aracuria, it is (installed with high density anti-corrion grease) designed to operate in and around coastal areas where corrosion is endimic. This characteristic lead to higher heat retention rate at 40°C (slower convective heat loss).

Researchers proposes to BS EN 50182 committee to include the following tests to the lists of recommended standard

Manuafcturers type tests BS EN 50182 (subject to request of purchaser)….

➔ Temperature overshoot rate test; responsible technical committee to create a suitable testing regime.

➔ Identify and quantify based on grease category used the conductor thermal time constant at rated conductor temperature.

Main purpose of this phase of the study was to replicate a worst case scenario [within the tolerences of the conductor design temperature] and measure effect on rain on adding additional thermal capacity headroom to the heat balance mix of the conductor under investigation. The study outlined the long term risk consequences of running new conductors at or near their design temperature without having any form of remote conductor temperature monitoring. Risks are speeding up the process of cable annealing due to temperature overshoot effect , (chemical deformation leading to losing electrical and mecahnical properties of the conductor). Generally in the UK the design temperature is 90°C. The study also outlined that the key to enhance transmission line ratings is by acquiring accurate conductor and ambient temperature data of all critical spans. It is also vital to improve our understanding of the conductor behaviour in response to current and climatic loading conditions.

Possible countermeasures reccomended by researcher to transmision system operators is to develop a thermal profile for every circuit in the network on a case by case basis. Circuits forming bottlenecks as determind by network planning engineers to be considered first. Once Bottlenecks are identified there is no substitute for line surveys to check for tree felling requirements, motor way crossing, oversailing circuits and motorway crossings. Engage with conductor manufacturers to include thermal time constant and temperature overshoot type testing regimes. Another recommended countermeasure to reduce possibility of new conductors overheating is to ask conductors manaufacturers to sand blast the newely manaufactured conductors to remove any impurities and excess grease that could retain heat for longer and effect the thermal capacity of the line intermittantly. The immediate plan for future work is to look at conductor behaviour during high wind winter season times, with a view to record rate of temperature overshoot and measure cooling effect of sub-zero temperatures on thermal time constant.

References

[1] Jiao Fu et al, "Impact of Dynamic Line Rating on Power Systems" *in 46th International Universities Power Engineering Conference, Soest, Germany2011*

[2] K.E.Holbert and G.T.Heydt Department of Electrical Engineering in Arizona State University Arizona, "Prospects for dynamic transmission ratings" , IEEE International Symposium on Circuits and Systems , May 2001.

[3] Stephen.D.Foss and Robert.D.Maraio , "Dynamic line rating in the operating environment", IEEE transactions on power delivery , Vol. 5 , No. 2 , August 2002

[4] J. F. Hall and A. K. Deb, Member, "Prediction of overhead transmission line ampacity by stochastic and deterministic models" , IEEE transactions on power delivery, Vol. 3, No. 2, April 1988

[5] Elvira Fernandez, Igor Albizu, A. Javier Mazon, Agurtzane Etxegarai, Garikoitz Buigues and Rafael Alberdi "Power Line Monitoring for the Analysis of Overhead Line Rating Forecasting Methods" 2016 IEEE PES Power Africa Conference

[6] J.Teh & I.Cotton, "Critical span identification model for dynamic thermal rating system placement" *IET Gener. Transm. Distrib., 2015, Vol. 9, Iss. 16, pp. 2644–2652.*

[7] Heinz Herwig, "What Exactly is the Nusselt Number in Convective heat transfer problems and are there alternatives?" Entropy 2016, 18, 198, http://www.mdpi.com/1099-4300/18/5/198 Online Accessed 11/06/2017

[8] Xiaoli LU et al, "Research on Measurement Method of Temperature sensors thermal time constant based on constant power injecting*" 2011 International Conference on Electrical and Control Engineering, Yichang, China*

[9] S.D.Foss et al, "Dynamic line ratings in operating environments", IEEE Transactions on Power Delivery, Vol. 5, No. 2, April 1990

[10] *Standard for calculating current-temperature relationship of bare overhead conductors*, IEEE738, 1993

[11] Rong-Gang Cong and Mark Brady, " The Interdependence between Rainfall and Temperature: Copula Analyses" The Scientific World JournalVolume 2012, Article ID 405675,

[12] Scottish Power Energy Networks, "Flexible Network Closedown Report for a low carbon future" Online ,Accessed https://www.spenergynetworks.co.uk/userfiles/file/Flexible%20Network%20Closedown%20Report27.10.pdf Accessed 03/06/2018

[13] A.Abdaelbaset, M.E.Farrag, D.Hepburn, S.Farokhi "Overview of On-line and Off-line Ampacity Identification Techniques of Bare Overhead Transmission Line" in 51 International Universities Power Engineering Conference, Sep.2016, Coimbra, Portugal