Pure Mathematical DLR Model for Implementation in Embedded IT Systems – Modelling Principles and Accuracy

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ABSTRACT

The paper presents the Danish transmission system operator's development of Dynamic Line Rating algorithm which allows full integration with the SCADA system. When fully developed, the model can be directly built into the SCADA system, thereby allowing SCADA-integration of the operational criteria set out by the DLR. The DLR algorithm is based on a bilinear autoregressive moving average (ARMA) model representing the dynamics of the cables. The model shows good accuracy compared to the expected results obtained via IEC methods.

KEYWORDS

Cables, high-voltage, dynamic, rating, DLR, system, Real Time Thermal Rating, RTTR, identification

INTRODUCTION

In the transition towards a more digitized electrical network, transmission system operators and utilities are looking to the Dynamic Line Rating (DLR) of cable lines as a tool to enhance optimization and maximize the usage of their existing assets. Several commercial DLR software are currently available on the market, most of them relying on the calculation methods proposed in the IEC 60287 and 60853 standard series. As these solutions are being developed by third parties, integrating DLR into the grid operator's SCADA system poses a great challenge to IT and cyber security. the Danish transmission system operator thus chose a different path in order to be able to implement DLR and its dynamic operational limits in the Danish transmission system, by developing a DLR algorithm internally and thereby integrating it directly into SCADA. SCADA systems are generally not designed for DLR calculations performed with the traditional, IEC-based calculation methods. It was on this background chosen to use as simple mathematics as possible i.e. a bilinear autoregressive moving average model resembling the dynamics of the cables.

DLR MODELING PRINCIPLE

General

DLR algorithms aim at dynamically calculating the operational limits of the asset in operation, given some initial conditions. In the case of power cables, it is of interest to be able to determine, based on the current cable loading, how much power can be transferred for a specific amount of time in the future. This shall be without exceeding the cable insulation's temperature limits. In order to do this, DLR relies heavily on distributed temperature sensing (DTS) along the cable, as this gives essential information on the temperature in the immediate surroundings of the cable conductor.

This means a DLR algorithm is generally required to : (1) estimate the conductor temperature at the present time ($t0$), based on the measured temperature and loading of the cable ; (2) calculate the conductor temperature at a certain time in the future ($t1$), based on the results of (1) and on the expected load between $t0$ and $t1$. In order to achieve (2), the DLR needs to be able to accurately predict the conductor temperature development in time without relying on measurements.

Objectives

It is of interest to be able to:

1. Estimate the conductor temperature at present time ($t0$)
2. Predict the conductor temperature 15 minutes, 1 hour and 40 hours ahead
3. Predict the jacket temperature 15 minutes, 1 hour and 40 hours ahead (relevant for land cables only)

It is in general assumed that the cable system be equipped with DTS. In this case the DLR is normal operation mode. However, in case of loss of DTS, DLR shall be able to achieve the same objectives for up to the following 10 hours. In this instance, the DLR is in emergency mode.

The desired performance of the DLR can be summarized in the following points:

- Prediction horizon: up to 40 hours
- Target accuracy for Model 1: ±2,5 ºC
- Target accuracy for Model 2: ±0,5 ºC
- Target accuracy for Model 3: ±2,5 ºC

Modelling Theory

For the DLR model to be directly integrated in SCADA, this shall be as mathematically simple as possible. In achieving this, a bilinear autoregressive moving average model is proposed. It is also assumed that cables operated with this DLR algorithm are equipped with DTS measurement. The fibre optic cable, where the temperature is measured, is always placed adjacent to the warmest of the three cables. Under these assumptions, and in order to be able to fulfil both requirements (1) and (2), the model consists of the following three functions, or models:

Model 1 - Calculation of the conductor temperature (y) as function of conductor current. It is expressed as:

$$y[n] = T_{amb.} + T_{corr.} + \sum_{k=1}^{N} a_k.(y[n-k] - T_{amb.}) + \sum_{k=1}^{M} b_k.u[n-k]$$

Model 2 – Calculation of the conductor temperature y as function of both load current and measured temperature. It is expressed as: