REAL TIME LOAD OPTIMISATION OF CABLE BASED TRANSMISSION GRIDS

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ABSTRACT

Energinet.dk has launched an investigation of dynamic current ratings of cable based transmission grids, where both internal and external parameters are variables. The first topic was to investigate state of the art within calculating the current carrying capacity (ampacity or loadability) of cables embedded in larger cable systems. Some recently published research has been concerned with dynamic loadability, but such researches are based on many assumptions. It is shown in the paper, that only limited research has been concerned with larger cable grids, and no remarkable work could been found which is concerned with optimising loadability of such systems.

KEYWORDS

Ampacity, Loadability, Current Carrying Capacity, Transmission, Cable Grid, Power System.

INTRODUCTION

The present paper discusses state of the art within current rating calculations and technologies of transmission cables. The authors have addressed the issue by searching for publications which go beyond the standardised methods of current rating. This includes conference papers and journal articles, as well as other published research, documentation on commercial products, etc.

International Standards

In order to obtain knowledge on state of the art research, one must know the work on which this is based, that means the present method of current rating transmission cables. For this purpose, a number of organisations publish standards, which prescribe specific methods for addressing different scenarios within current rating of transmission cables. The method described in this section is mainly taken from [1], however standards such as [2] are based on the same basic principles.

The basic assumption in all literature available to the authors of this paper is, that it is the temperature at either the conductor (causing thermal ageing of the insulation), or the outer covering (due to moisture migration), which is the limiting factor for the current carrying capacity of transmission cables. The temperature in such cables rises in relation to the surroundings, as both resistive and dielectric losses in the cable generate heat.

The international community has, through standards such as [1], decided to utilise the resemblance between heat flowing through the layers of a transmission cable, and current flowing through resistances in an electric circuit. In the electric equivalent of the thermal behaviour (seen in figure 1), heat sources (resistive and dielectric losses) are modelled as current sources, heat capacities are modelled as electric capacitors and thermal resistances are modelled as electric resistances. In this way, the temperature is automatically modelled as the voltage. The electric equivalent is, as seen on the figure, a lumped model describing the temperature of a cable in 1D from the conductor centre, which is assumed equal to the conductor surface, to the surface of the ground. The international standards give suggestions to each of the physical quantities of figure 1, for different cable designs, laying configuration and surrounding conditions.

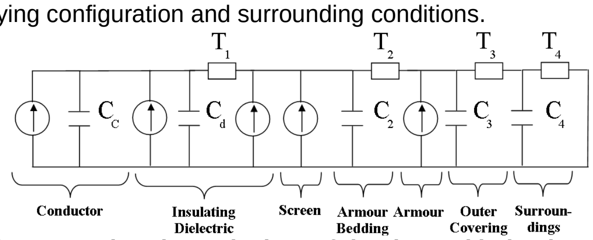

Fig. 1: An electric equivalent of the thermal behaviour of transmission cables.

[1] suggests, that cables should be rated according to their steady state capabilities, which means the current which the cable is capable of carrying continuously without exceeding the thermal limitations. Using figure 1, the loadability can be determined easily by using equation [1].

$$I = \left(\frac{\Delta\theta - W_d\left(0.5T_1 + n\left(T_2+T_3+T_4\right)\right)}{R\left(T_1 + n\left(1+\lambda_1\right)T_2 + n\left(1+\lambda_1+\lambda_2\right)\left(T_3+T_4\right)\right)} \right)^{\frac{1}{2}} \qquad [1]$$

Here *I* is the rated current. *Δθ* is the temperature rise above ambient caused by the resistive losses, which originates from the current *I* flowing through the resistance *R*. W_d is the dielectric losses. *n* is the number of conductors. λ_1 is the ratio between the losses in the metal sheath and the losses in the conductors. λ_2 is the ratio between the losses in the armour and the losses in the conductors. The physical parameters are determined under worst case conditions, such as high air temperature, etc. It should be noticed, that as the model only determines the temperature distribution in 1D, one should apply the model to expected bottlenecks of the cable track.

It is recognised by IEC, that only few transmission cables carry a constant current for long periods of time, and the following three cases are therefore taken into special consideration: Cyclic operation, Transient operation and Emergency operation.

Cyclic operation is the inclusion of the normal daily (24 hours) load cycle in the evaluation of the loadability of cables. Cyclic operation, as well as transient and emergency operation, is dealt with by multiplying a correction factor (*M*) to the ampacity obtained by the steady state ampacity equations. [3, 4] states that the cable operator, by visual inspection of the load curve, should determine the highest temperature during the load cycle. The mean of the loss-load factors (*μ*) should be calculated (the loss-load factor is defined as $Y=I_i/I_{max}$), on the basis of one hour mean current values (I_i). This value and the current of the six hours leading up to the time of maximum conductor temperature is the only information utilised in calculating the cyclic correction factor (*M*). As they are too extensive, the equations for determining *M* are not restated in the present paper, however it should