THERMAL BEHAVIOUR OF NETWORK COMPONENTS DEPENDING ON OUTDOOR WEATHER CONDITIONS

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ABSTRACT

The liberalization of the power market and the increasing number of regenerative energy producers (esp. wind parks) cause an increasing current load on existing transmission systems. As a result, power utilities and system operators are currently looking for opportunities to increase the capacity of the existing overhead lines (OHL) without increasing the risk of equipment or system failure due to higher loading and an accelerated aging of the transmission infrastructure. Several monitoring systems to increase the capacity of the existing Transmission lines are in service [1]. But all components of the electrical circuit have to be able to carry the increased current load. It is also necessary to take care on ageing behaviour of existing joints and terminations in transmission and distribution systems [2].

Most previous investigations concentrate on the ampacity of overhead lines depending on varying weather conditions like ambient temperature, wind speed and direction and solar radiation. This paper will present a contribution to the thermal behaviour of other components in transmission systems, especially circuit breakers, disconnectors, current transformers and line connectors depending on weather conditions. Therefore thermal network calculations are compared and equalized to experiments with real equipment. Increase or decrease of maximum allowable current load of the several components is discussed.

The investigations show, that the ampacity of the components depending on the ambient conditions are varying. So the ambient temperature can easily be used, because all components react alike and the ambient temperature does not change so frequently in time and region. The wind speed in contrast changes very fast, is regional very volatile and the components react very divers.

INTRODUCTION

The liberalization of the power market and the increasing number of regenerative energy producers (esp. wind parks) cause an increasing current load on existing transmission systems. Additionally it is increasingly difficult to build additional transmission circuits. As a result, power utilities and system operators are currently looking for opportunities to increase the capacity of the existing OHL. But in the most papers only the ampacity of the overhead lines depending on varying weather conditions is discussed. During the operation all components of the electrical circuit have to be able to carry the increased current load. So it is also necessary to evaluate the thermal behaviour of the other components in the current path, like circuit breaker, disconnectors, current transformers and also to take care on the accelerated ageing behaviour of existing joints and terminations in transmission and distribution systems [2].

THERMAL NETWORK APPROACH

The rated current for overhead transmission lines and other components is normally given for defined ambient conditions (e.g. 35°C ambient temperature and 0,6 m/s windspeed), wich only for a few hours a year occur. Most time of the year it is possible to load the equipment with higher currents without exceeding the temperature rise limit, because the cooling by the wind is better or the temperature difference between ambient and maximum allowed temperature is higher than the temperature rise limit (Figure 1).

![Figure 1: Ampacity depending on the ambient conditions (principle)]
To be able to load an overhead line and the concerned equipment in a current path with higher currents, it is necessary to know the thermal behaviour of all components depending on the environmental conditions (ambient temperature, wind speed and solar radiation). To find these dependencies thermal network calculations were used [3]. Thermal networks use the analogy between the electrical and the thermal flow field. That means that for example the voltage in the electrical network represents the temperature in the thermal network (Table 1).

<table>
<thead>
<tr>
<th>Electrical Network</th>
<th>Thermal Network</th>
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<tbody>
<tr>
<td>Potential difference [V]</td>
<td>Temperature difference [K]</td>
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<tr>
<td>Current [A]</td>
<td>Heat flow [W]</td>
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<tr>
<td>Electrical Resistance [V/A]</td>
<td>Thermal Resistance [W/K]</td>
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Table 1: Analogy between electrical and thermal flow field

By using the network simulation program PSPICE for all components in the current path thermal networks were built. All thermal networks were verified with experiments in the laboratory carried out on the real equipment. Then by changing the environmental conditions, like ambient temperature, wind speed and solar radiation, in the simulation the real ampacity could be calculated. The real ampacity was defined as the ampacity, when the component or the critical part of a component reached its maximum temperature rise. That could be for example the temperature of the contacts or the temperature of the insulation material.

As an example the thermal network of an overhead conductor will be described (Figure 2). The thermal network of the overhead conductor consists of a heat source for the Solar radiation and one heat source for the current losses.

Figure 2: Thermal network of an overhead conductor

The heat in the conductor can be released by one radiation resistance and one convective resistance toward the ambient temperature and by one radiation resistance toward the colder temperature of the sky.

Experiments in the laboratory on different overhead conductors were carried out to evaluate the emission coefficient of the conductor and to verify the static and dynamic thermal behaviour of the conductors.

This proceeding was carried out for different overhead lines, for a 220-kV-circuit breaker, a 515-kV- disconnector and a 220-kV combined current and voltage transformer.

RESULTS

As expected the simulation of the thermal behaviour shows, that the components can be loaded with higher currents depending on the ambient conditions (Figure 3 and Figure 4). But at the same time it has to be considered, that if the ambient conditions are worse for the thermal behavior of the components, that means for example the windspeed is lower than 0.6 m/s or the ambient temperature ist higher than 35°C, the ampacity is lower than during standard conditions.

Figure 3: Ampacity of an overhead conductor depending on the ambient conditions

Most publications to this subject focus on the ampacity of the overhead conductor. The possibility to increase the ampacity for this component is very high, as it can be seen in Figure 3. So for example at a wind speed of 5 m/s and an ambient temperature of 10°C the current can be more than doubled without overheating the overhead conductor.

But it should considered that all components have to carry the same current in the line. So for example the circuit breaker can be loaded only with 160% of the rated current at the same ambient conditions (5 m/s, 10°C) (Figure 4).

Figure 4: Ampacity of an encapsulated circuit breaker

Because of the enclosure of the circuit breaker the wind speed has much less influence on the cooling of the current path and so on the ampacity as for example of the overhead
The influences of the ambient conditions are almost the same for all components. The simulations on the disconnector also showed that there the influence of the wind speed is almost the same as for the overhead conductor, whereas the SF6–insulated combined current and voltage transformer react alike the circuit breaker.

So for loading the lines with higher current depending on the wind speed the components have to be divided into two categories: with an encapsulated and a non-encapsulated current path.

The run of the resistance $R_C(t)$ is calculated from the ageing speed of the connection resistance. As a general reference value for describing the connection resistance the relation $k_a$ of the connection resistance to the resistance of an equivalent conductor of the same length is used. Is a connection according to the rules installed, the relation $R_{Connection}/R_{Conductor}$ can be lower than 1. For the calculations, which were carried out, a ratio $k_a$ of 1, was chosen. That means that the connection resistance has the same value as the resistance of an conductor with the same length. Depending on the time the resistance of the connection increases, because the connection is ageing and the contact areas will decrease.

The influence of the current can be seen in Figure 6. All values are calculated for the case, that the maximum allowed temperature of the conductor will not be exceeded. If the overhead conductors and so the connections are loaded with 40% of the rated current, the life time of the connections is much higher than 45 years. That’s the situation which is now the normal case on high voltage transmission lines. If the overhead conductors will be loaded all their lifetime with the rated current, the life time will decrease to 16 years. If the conductors and the connections will be loaded even higher than 100% of the rated current for a longer time, the life time will decrease much more (Figure 6). In these scenarios the maintenance time and effort will increase.

Another consideration is the dynamic reaction of the components on changing loads and/or changing ambient conditions. Because of their less dimensions the overhead conductor and the disconnector have time constants of about 10 to 30 minutes. That means for example for the overhead conductor, that if the load or the ambient conditions are changing the conductor will reach its new static state temperature after app. half an hour.

The time constant of the circuit breaker is about two to three hours, that means that it reaches its new static state temperature after about six to nine hours. For the same parts of the current transformer it can even take a day to reach the static state temperature.

The research also showed that normally the current transformers are not a problem for higher current loads, because they normally can be thermally overloaded with at least 120% up to 200% [4].

Another point of interest is the aging behaviour of the connectors within the overhead conductor. Although the overhead conductor will not exceed its maximum allowed temperature, for example 80°C, the aging of the connectors will increase, due to the higher current load. Using a mathematical model, which is based on long term experiments on bolted connectors [2][5], the change in resistance of the connections was estimated.

The wind speed changes very fast and is regional very
There are many volatil. Although the consideration of the wind speed holds the biggest gains for increasing the current, it’s very complicated to define the correct allowable load current for different components and components in different places. So system operators should be careful with increasing the load current depending on the wind speed.

Another important point is the lifetime of the connections. With an increasing load current the ageing of the connection is accelerated, although the maximum allowable temperature of the conductor will not be exceeded. Especially if already aged connectors (e.g. 10 years old) will be loaded with a higher current, some connections can fail within a short time. So before loading the overhead conductor with higher currents all connections should be checked.

REFERENCES


[3] C. Gramsch, A. Blaszcyk; H. Löbl; S. Großmann Application of the thermal network method for prediction of temperature rise in components of electric power systems CMD 2006, International Conference on Condition Monitoring and Diagnosis, Korea, 02.-05.04.2006
