EXPANDING HIGH VOLTAGE NETWORK CAPACITY USING A WEATHER CONDITION BASED INDIRECT MONITORING SYSTEM

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ABSTRACT

The increasing generation out of decentralized energy resources, which can be observed since several years, will become even faster in Germany due to the „Energiewende“ throughout the next years. First of all the development of wind energy and solar power has to be mentioned. The classic network expansion by means of conventional assets deals with the well-known disadvantages of long-term realization periods and has to be critically scrutinized regarding economic aspects.

Hence this paper describes a weather condition based indirect monitoring system ensuring the efficient and rapid capacity expansion of high-voltage overhead line networks. In general the classic transfer capacity extension of existing high-voltage networks is linked with a number of construction measures on the same level as a complete renewal. The network integration of decentralized energy, especially wind energy, is usually connected with weather conditions that differ from standard (worst-case) conditions. The related higher transfer capacities of existing overhead lines can be used by means of a focused weather condition monitoring system.

INTRODUCTION

The maximum operating current of a high-voltage overhead line is limited by the maximum permitted temperature of the used transmission line conductor as well as by the minimum allowed space between conductor and ground. Provided that the current weather conditions differ from the extreme standard values (35°C outdoor temperature, 0,6 m/s vertical wind flow, 900 W/m2 global solar radiation), higher operating currents are also permitted. The given combination of extreme standard values is very rarely observed in Germany, with the result that the maximum conductor temperature is not exceeded in general. Furthermore areas with wind dominated feed-in are characterized by higher wind speed in those periods when the feed-in requires an adequate network capacity.

MAIN IDEA

Principally the described monitoring of weather conditions can be provided by a direct or indirect observation. Direct monitoring systems measure directly the conductor temperature or derive this value from measurements of the conductor (tensile force, currents). These methods cause the equipment of the transmission line conductors with corresponding measuring technology requiring a system-dependent exchange of primary technology (conductors, isolators) or even a pole-oriented renewal. So far the related high costs have mainly prevented an extensive rollout of such systems.

In contrast the approach of an indirect line conductor temperature monitoring by means of the observation of relevant weather conditions can be realized in a cost-efficient way. The weather condition monitoring will be ensured by a close-meshed application of inexpensive climate measuring stations. The central module of this monitoring system is realized by an expansion of the central network control system in the form of a “climate formula” which describes the relationship between weather conditions and the dynamically permitted line conductor capacity:

$$I = \sqrt{\frac{P_W + P_A - P_S}{R'_{ac}(T_L)}}$$

I = Maximum permitted dynamic conductor current [A]
P_w = Cooling by convection (wind) [W/m]
P_A = Cooling by line conductor radiation [W/m]
P_S = Heating by global solar radiation [W/m]
R'_{ac} (T_L) = Temperature dependent AC resistance [Ω]

It is obvious that large values of the parameters P_W and P_A lead to an increase of the permitted maximum current capacity. Exemplarily figure 1 shows the effects with an example of a typical line conductor cross-section 243-AL1/39-ST1A:

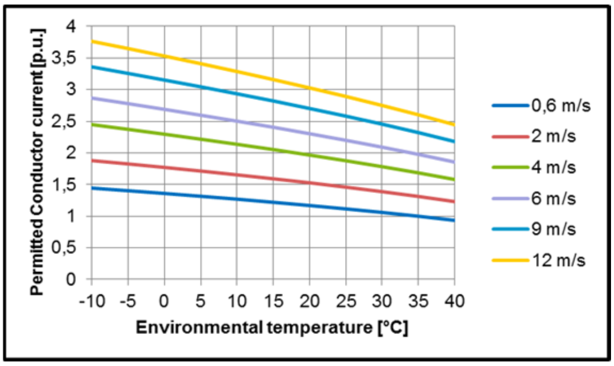

Fig. 1: Influence of temperature and wind speed on the permitted conductor current

SETUP OF THE DEMONSTRATION AERA

Chosen test area

The described weather condition based monitoring system was developed and implemented within the scope of a R&D project of Westnetz GmbH, the largest distribution system operator in Germany. A test area with about 380 MW of installed decentralized wind energy resources in the high-voltage network was chosen. In extreme feed-in scenarios the high voltage line sections are already loaded with approx. 100%.

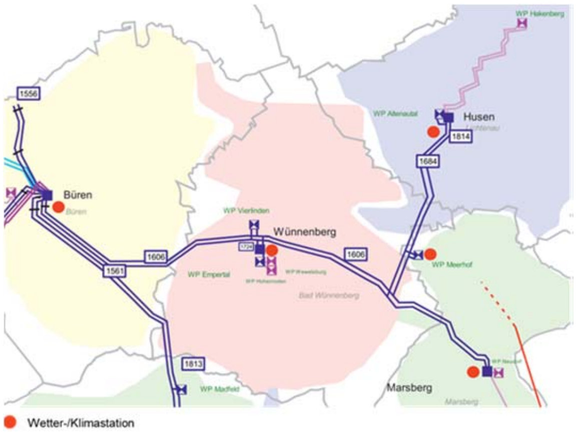

Fig. 2: Chosen test area

The test line section is oriented in north-south as well as west-east direction enabling a verification of the different parameter influences (global solar radiation, temperature, wind direction and wind speed). Another advantage of this test area is the fact, that the geographical conditions along the test line sections allow for a consideration of hill and valley situations.

Upgrade of the test HV overhead lines

In advance the high-voltage transmission lines under test were checked thermographically by flight and selectively upgraded for the higher current capacity. Fig. 3 shows exemplarily the thermo-check of an overheated current terminal:

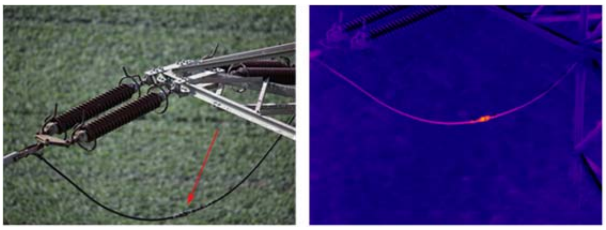

Fig. 3: Thermo-check of a current terminal

Based on the results of this check a restoration resp. an upgrade of critical components was executed. The tube current clamps were bypassed by additional auxiliary conductors. Furthermore the loop connections at junction poles were upgraded with additional current clamps.

Choice and installation of the climate stations

The gained experience of climate stations used in a former project lead to the choice of the installed station type. The requirements of this project determined the measurement parameters global solar radiation, temperature, atmospheric density, wind speed and wind direction. In this area an appropriate number of five climate-measuring stations was installed and connected to the central network control system. Fig. 4 shows a typical setup:

Fig. 4 : Setup of a climate station

Offline temperature measurement for calibration

Additionally an offline conductor temperature measurement was performed using simple sensors directly attached to the line conductors. These offline sensors were installed at the beginning of the test phase and de-installed at the end. This additional measurement was used to calibrate the climate formula according to the practical environment conditions of the high-voltage network.

Approach to data evaluation

The calculation module for the evaluation of the maximum permitted conductor current was verified by this additional temperature measurement. The “climate formula” was resolved towards the conductor temperature and resulted in this correlation:

$$T_{Ber(k+1)} = \frac{R'_{TAC(k)} \cdot I^2 - P_{A(k)} + P_S}{\pi \cdot \lambda_{(k)} \cdot N_{U\delta(k)}} + T_U$$

$$for\ k = 0,1,2, \dots$$

$T_{Ber(k+1)}$ = Conductor temperature [°C]
$R'_{TAC(k)}$ = Temperature dependent AC resistance [Ω]
I_{akt} = Present value of the current [A]
$P_{A(k)}$ = Cooling by line conductor radiation [W/m]
P_S = Heating by global solar radiation [W/m]
T_U = Ambient temperature [°C]
$\lambda_{(k)}$ = Thermal conductivity [W/(Km)]
$N_{U\delta(k)}$ = Nusselt number
k = Number of iterations

The conductor temperature $T_{\_Ber\_1}$ is evaluated depending on the measured values for minimum wind speed (vw_{min}), maximum ambient temperature ($T_{U,max}$) and maximum global solar radiation (S_{max}). In the next step this computed value is compared to the maximum measured conductor temperature $T_{\_iBut\_max}$ of the offline measurements. To validate the computation model $T_{\_Ber\_1}$ should follow the measured temperature. If this condition is not kept the possible failure causes have to identified and evaluated according to the practical implementation of the monitoring system.

For safety reasons the maximum conductor current is additionally computed by means of a more conservative current temperature $T_{\_Ber\_2}$ that uses a worst case maximum global solar radiation value.

Results of data evaluation

The comparison between the described conductor temperatures showed some faults of the measurement recording procedures. The fault reasons will be avoided by means of the further on described dynamic limit value concept. Furthermore the practical implementation of the monitoring concept will not be restricted. Fig. 5 shows the expected curve shape of the conductor temperatures.

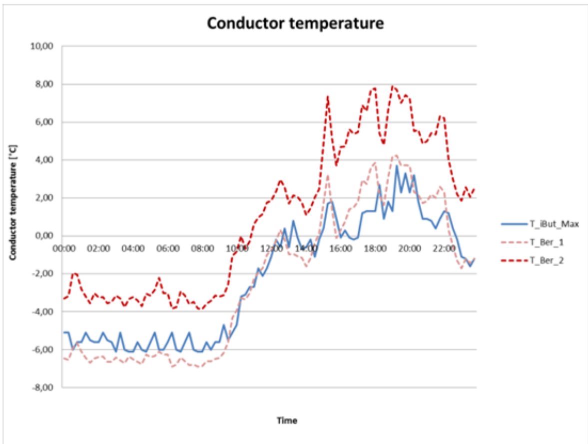

Fig. 5: Comparison of conductor temperatures

After filtering the incorrect measured values and under consideration of the accuracy of the measuring instruments the expected curve shape of conductor temperatures can be observed for the complete measurement duration. Hence the calculation model can be considered as verified.

Fig. 6 illustrates the potential of the indirect monitoring method. The standard maximum current ($I_{\_Max\_nach\_Norm}$) and the calculated dynamic maximum current ($I_{\_Max\_Berechnet}$) are shown in relation to the climate conditions of the same example day as in fig. 5. A considerable increase of the maximum permitted current value is obvious.

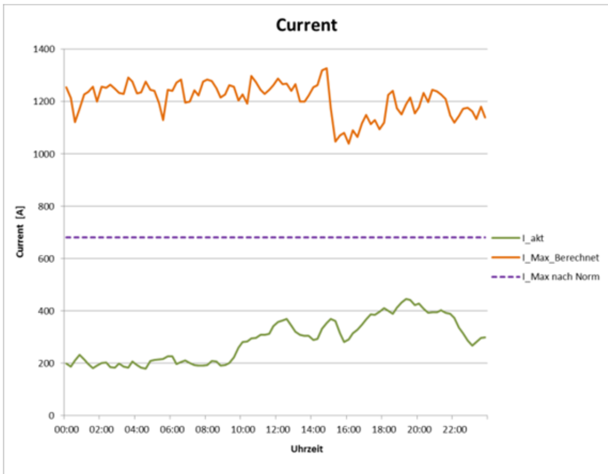

Fig. 6: Comparison between the standard and the dynamically permitted line conductor capacity

After this calibration procedure the shown climate formula was implemented in the central network control system.

Network control system integration

Furthermore the control system is currently expanded by additional modules to enable a dynamic calculation of the permitted current capacity as well as the handling of dynamic threshold values. The dynamic calculation of the present maximum permitted current values is implemented within the scope of the periodic as well as the event-oriented calculation of higher decision and optimisation procedures within the network control system.

HANDS-ON EXPERIENCE

After the implementation of the monitoring module and an additional analysis tool the calculation results of the climate formula could be reproduced by means of the online measurement values. The network security calculation enables the validation of network assets that are not directly measured. Hence the current values of line sections can be calculated by the estimation method without using direct measurements. An asset-related alarm is initiated in the network control system in case of violating a limit of the present network state as well as in case of a network fault variation.

In case of both violating the limits of the present network state and the fault variation the alarm with highest priority is initiated. Highest priority means the highest exceedance of a limit with higher values for alarm limits than warning limits. The alerting and confirmation of limit value findings is operated by acoustical signals, collector indicators and an adequate network condition list in a system compliant way (see Fig. 7).

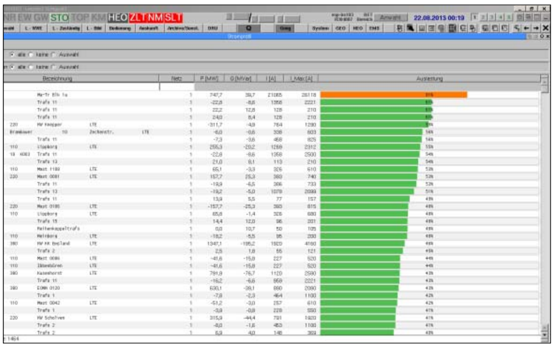

Fig. 7: Overview of dynamic limit values

The transmission of the climate station measurements is performed from the beginning of the operational phase of these stations. The climate data acquisition is handled by a cost efficient GPRS connection that is not implemented in a redundant way. This connection type is typical for other development projects.

The assignment of the weather condition values to single line sections was provided by the data preparation. A block of five measurement values regarding the environment temperature T_{Ui} and wind speed v_{wi} (corresponding five climate stations) was assigned to each single line section. The selected parameters for the limit value calculation are T_U = Max (T_{U1}, T_{U2}, …, T_{U5}) and v_w = Min (v_{w1}, v_{w2}, …, v_{w5}) with T_{Ui} and v_{wi} as mean values of a 15 min. period.

These evaluations are completely based on validated measurement values regarding updated values also as validated. Even with validated values the parameters T_U and v_w will be limited to these boundary values:

$$-10°C <= T_U <= +40°C$$

$$0,6 \text{ m/s} <= v_w <= 10 \text{ m/s}$$

In case of no valid measurement values equivalent replacement values can be used and imported into the network control system. This process can by handled by an additional block of five values for temperature and wind speed. This value block can consist of 15 min. mean values that are separately delivered by an external provider.

This strategy for the use of replacement values for missing measurement values, the validation of the boundary values and the averaged weather condition values were successfully tested in the operational environment of the network control system without any problems.

DYNAMIC LIMIT VALUE CONCEPT

In consequence the introduction of the above described dynamic limit values for single assets lead to a methodic review of the implemented limit value concept of the existing network control system.

Historically the SCADA alarm system (depending on measurement values) and the network safety calculation alarm system (depending on the safety calculation results) are operating independently from each other and thus generate simultaneously status signals of limit value violations. The dynamic results of the new module “Overhead line monitoring” do not fit to the static limit value control method of the SCADA system (Fig. 8).

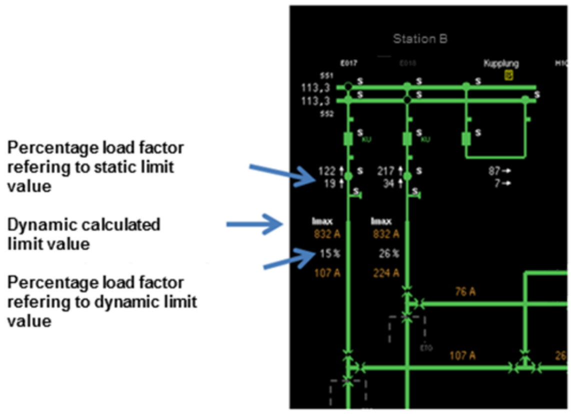

Fig. 8: Different limit values in the SCADA system

Implementing a new limit value concept enables the possibility of supervising assets that are not directly measured. This new concept only needs the limit values of the assets. The alarm concept and protocolling method are consistent for the operator. The problematic nature of a possible inconsistency between measurement values and limit values of single assets is solved. The asset shows the weak point in contrast to the measurement value.

Furthermore the asset related calculated values of the estimation method statistically own a better quality as the measured values. Additionally the estimated values are available at all network areas where no measurements exist (e.g. regarding the calculation of single line sections). Therefore the asset oriented alarm concept is more valuable in this context.

OUTLOOK

The present experience with this simple method shows a high potential of an efficient and fast expansion of existing high-voltage overhead line networks without requiring the expensive and time-consuming classic network expansion measures.