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Experiences with the Weather Parameter Method for the use in Overhead Line Monitoring Systems

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SUMMARY

Overhead lines are essential components of high voltage power systems worldwide. The performance of this network element is important for a save and reliable transmission of electrical energy. The load capability of a line is related basically to the line design itself and takes centre stage of the economic operation whereas the sag behaviour and the technical condition of the conductor and their components are more related to the line and network safety.

Based on this situation overhead line monitoring systems are actually under discussion in many committees worldwide. This auxiliary equipment for overhead power lines helps to evaluate the actual transfer capability and/or to increase the system reliability. Therefore a number of systems using different measuring methods and monitoring techniques are available on the market. More or less all methods are based on physical data and process information to achieve a suitable output to control the line stress. One of these methods is called the Weather Parameter Method, which uses local metrological weather data and system load information to estimate the conductor temperature.

In a research project running over years an overhead line monitoring system was set up in cooperation with the Austrian transmission utility APG. After these years of experience a number of information and data based on the principle of the Weather Parameter Method is available and gives the scientific basement for this contribution. Three observation stations are collecting data all over the year; two stations are at a 220kV overhead line and one station at the open air test field of the IHS in Graz in use.

This contribution focus on the coherences of the different parameters collected for the evaluation of the conductor temperature and it is not the main goal to discuss the improved performance by using a thermal management system, as mentioned in many other papers. By the knowledge of the punch-through of significant parameters in combination with the appearance probability a more accurate scheduling of the utilisation of the line under observation will be possible. A well prepared processing of many significant parameters for an overhead line monitoring system and a scientific approach based on some years of practical experience is presented in this contribution.

KEYWORDS

Weather Parameter Method, overhead line monitoring, transmission lines, IEEE738, field report

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1 Introduction

Overhead lines are essential components of high voltage power systems worldwide. The performance of this network element is important for a save and reliable transmission of electrical energy. The load capability of an overhead line is related basically to the mechanical and electrical design of the line itself. The most important factors are the system voltage (in most cases given) and the rated current of the conductor. Especially for long lines, the voltage drop and the stability of the line are additional critical parameters for the line performance. The transmitted electrical power, the transmission losses, the maintenance and construction costs affect the operation and the profitability of the line. Beside the economic, the safety aspects have to consider for the utilizable capability of a line. One criterion is the reserve buffer inside the integrated network (n-1 criteria) which (should) prevent a chain reaction of line disconnection by over load caused by a single unplanned line shut-down. Another criterion is a limitation caused by aging of the line components. Thereby are the line sags and the remaining safety distances between line conductors and objects or surface areas the limitation. So the sag behaviour and the technical condition of the conductor and their components dominate the line safety whereas the (n-1)-criterion affects the network safety. Both, line and network safeties, decide the power quality and reliability for the end-users. With the opening of the free market of electrical energy, the transferred energies increased during the last period and the utilisation of the lines is increasing. For an optimised and secure power transmission a demand of online monitoring systems is given.

2 Overhead line monitoring systems

Actually overhead line monitoring systems are in many committees worldwide under discussion. This auxiliary equipment for overhead power lines helps to evaluate the actual transfer capability (thermal rating) and/or to increase the system reliability (thermal protection). Therefore a number of systems using different measuring methods and monitoring techniques are available on the market [1]. These systems can be divided into direct and indirect methods.

Direct measurement

Systems on the base of direct measurements use technologies, which evaluate the sag or the conductor temperature directly from measurement points of the object under observation. Principles are sag evaluation via optical, ultrasonic or GPS measurement and conductor temperature measurement via distributed and punctual thermal probes or infrared based systems. Except the contactless temperature measurement in most cases a direct intervention on or in the conductor is necessary.

Indirect measurement

The disadvantage of a direct intervention can be avoided by using technologies, which evaluate the sag or the conductor temperature indirectly from measurement points of the object under observation via suitable physical indicators. Commercial systems use rope tension, temperature of clamps or phase angle measurement for evaluate the conductor temperature and/or the sag of a line section or punctual or integrative of the whole line. Another method uses metrological data and system current for evaluation of the conductor temperate [2][3][4]. It is the so called “Weather Parameter Method” which is the base for the following system.

3 Weather Parameter Method

The temperature of an overhead conductor depends on the thermal balance of incoming and outgoing thermal heat. The incoming thermal heat results in the sum of I^2R-losses and incoming solar radiation. These heats are at overhead conductors always positive and can not be negative (no cooling effects by conducting current or absorbing radiant energy of a hot body (5800 K sun surface temperature)). Thermal heat can be outgoing by thermal radiation to cooler body in the surrounding, thermal conductivity of the surrounding material, heat transfer by mass exchange and melting/solidify or vaporizing/condensing heat of adherence ice or water on the surface of the conductor. These energies can be negative (outgoing) or positive (incoming) depending on the temperature of the conductor and the medium. The sum of the individual energies is stored in the conductor mass and determines the temperature of the conductor (see equation 1, legend in Fig. 1).

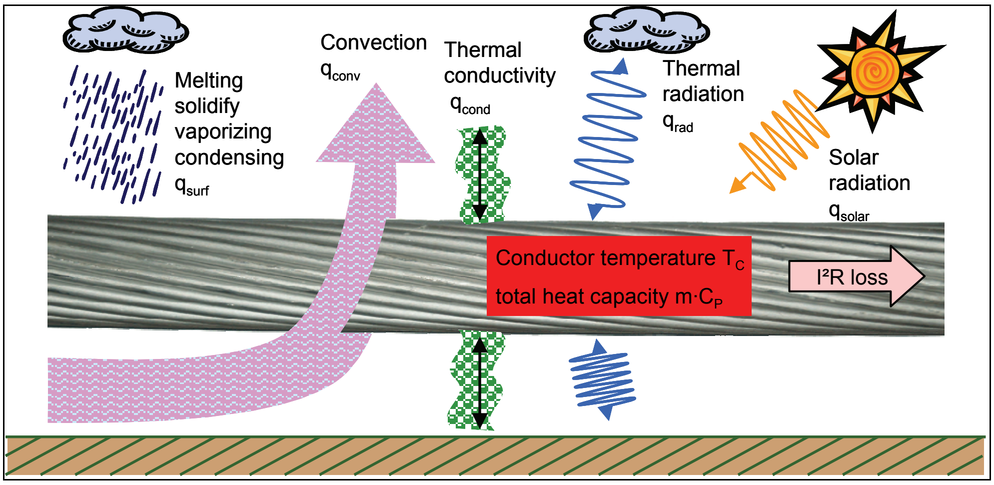

Fig. 1: Incoming and outgoing thermal heat of an overhead line conductor

$$\frac{dT_C}{dt} = \frac{1}{m \cdot C_p} \cdot \left[I^2 \cdot R(T_C) + q_{solar} - q_{conv} - q_{rad} - q_{cond} - q_{surf} \right] \quad (1)$$

I^2R Loss

The thermal losses caused by the load current can be calculated by the knowledge of the conductor resistivity which depends on the temperature and especially at thick and steel cored conductor on the frequency of the current (eddy losses and skin effect). With aging of the conductor surface, the oxide layer of the aluminium wires grow and the conducting cross section is reduced.

Solar radiation q_{sol}

The sun emits radiation energy from ultraviolet, visible, near and far infrared in a wide spectrum whereby the high frequency dominates the power spectrum. The incoming solar radiation depends on the absorption coefficient of the surface, the diameter of the conductor, the position of the sun relating to the conductor axis and the transmissibility of atmosphere. The transmissibility of atmosphere is affected by the degree of latitude of the location (air mass factor) but mainly by the cloudiness of the sky. Clouds, fog and shroud of mist keep the radiation from sun partial away.

Thermal radiation q_{rad}

Based on the natural law, that radiation energy flows from the hotter to the cooler surface, a thermal energy exchange between conductor and surface takes place. In most cases the energy flows from the hotter conductor to the ground or the sky. The transmitted power depends on the emission coefficient and the diameter of the conductor and the temperature difference between the media. The absorption and the emission coefficient depend on the condition of the surface. With proceed aging and darkening of the conductor, the coefficients increase and can shift to similar conditions of a "black body" surface.

Thermal conductivity q_{cond} and convection q_{conv}

Thermal power can also transmitted by elastic impulse of the atoms and molecules. This effect is called thermal conductivity. At gaseous media, an increasing of the media temperature causes also a density decrease. The density gradient leads to a fluctuation of the gas particles. The hot particle drift upwards and cooler will reach the surface and this process is called natural convection. The differentiation of thermal conductivity and natural convection is difficult. In most cases a simplification of both effects is practicable. In open-air situation the external winds produce an enhancement of the convection and dominate the transferred heat.

Surface Effects q_{surf}

Heating and cooling effects on the surface are given by melting of ice, solidify or vaporizing of water drops and condensing of fog on the conductor. These heats have effect on the thermal balance of the conductor but are difficult to evaluate. Incoming condensing and solidifying energy takes place at lower temperature (freezing point of water) and outgoing melting and vaporizing energy cools the conductor additional and gives an additional safety margin. In most cases a high conductor temperature is point of interest for uprating the line and so the surface effects are unaccounted for (thermal) monitoring systems.

4 Developed line monitoring systems

In a research project in cooperation with the network provider APG, a line monitoring system based on the Weather Parameter Method was developed. The system uses a modified algorithm of [2] for the calculation of the conductor temperature. Instead of the calculation of solar incoming power via the air density and air pollution type, the measured global radiation was taken in combination with a sun position algorithm from actual date and time stamp.

4.1 Monitoring system at APG

The monitored line was constructed in 1962 and is actual one of the three important North-South 220kV transmission line systems in Austria. For the line monitoring system, two weather stations were installed along the line. The choice of the positions was affected on sag critical spans also on topographically aspects.

The weather stations are equipped with a photovoltaic power supply. For the metrological instrumentation, standard sensors for temperature and global radiation were chosen. For the wind evaluation, an ultra sonic wind speed and direction sensor combination was an optimal device for the monitoring system. Main focus of the instrumentation equipment was on low power consumption and a reliable and a solid design for a maintenance-free operation. The data communication was implemented by public mobile radio over GSM-network. Other possible solution via fibre optic cable in the Overhead Ground Protection Wire (OGPW), beam radio or cable network are too extensive in installation or have a higher power requirement. The transmitted weather data come in the net distribution centre together where the data bank and the evaluation are processed. The grid operator gets information about the actual conductor temperature and the theoretical load capability of the line in time a period of three minutes, which was a compromise between heating time constant, data volume and power consumption of the stations. Both positions are located in the northeast of Austria at the foothills of the Alps and 5.7km air-line distanced.

Fig. 2: Weather stations at the 220 kV transmission line
(left: position flat country, right: position hill sided in the forest,
middle: weather station platform)

4.2 Prototype monitoring system at IHS

For the implementation of the line monitoring system, a test platform for evaluation and development was installed at the test laboratory of the IHS in Graz. The position of the weather station is on an arm on the test portal in a comparable height to an overhead line. The station is equipped with a mechanical anemometer and a conductor model for detailed investigation. The model was build of a used, aged overhead conductor from the investigated line. In the centre of the core is a thermal sensor located for conductor (core) temperature measurement. On the surface of the core is an artificial heating coil casted for simulating the load current. The aluminium wires were original from the conductor. The data transmission is realised with Ethernet and powered by means supply.

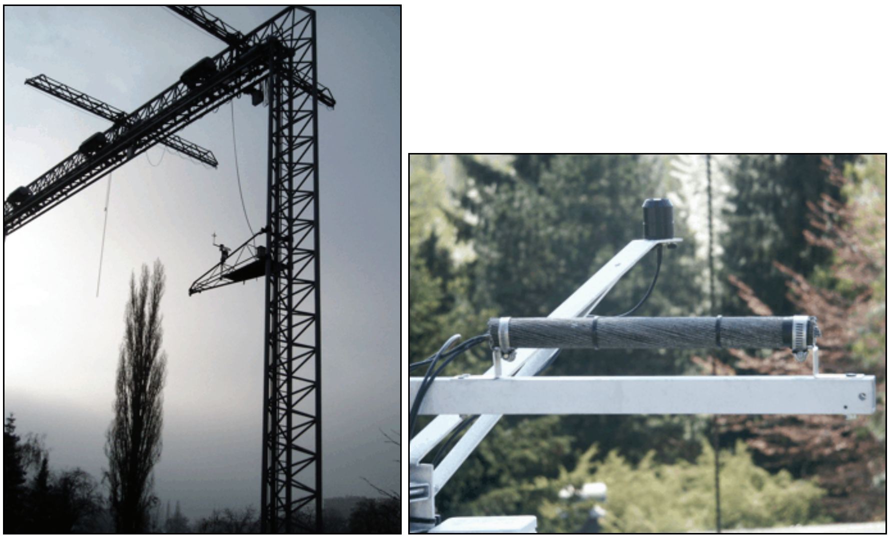

Fig. 3: Weather station at the test laboratory in Graz with the conductor model

5 Results

The monitoring systems are working at IHS since two years and at APG since 1.5 years. The design of the weather stations allows an assembling without powering off the line and also a maintaining is possible during normal operation. The data logger of the onside weather stations worked until now without any noticeable problems. In the first concept of the monitoring design, the system should be an auxiliary tool for the operator during the warm summer period. A power supply which is working over the whole years was not intended. Actually a year-round redesign of the power supply is in progress.

The system reliability depends on the transmission path of all devices. The significant parameter is there the availability of the public mobile radio service. In the investigated location the availability and response time varies. The location in the flat country has a good connection and from sending weather data till supply for the temperature computation the delay is in 99% below 14s. The broadcast station is about 900m distanced from the weather station. At the hill sided location, the broadcast station is a little more distanced from the station (approx. 1.2km) but the terrain is densely wooded with pinewood and is hilly so a line-of-sight link is not given. The result is that the connection is not very good and the response is only in 77% of the time below 30s. An improvement with a high-capacity antenna is also in planning.

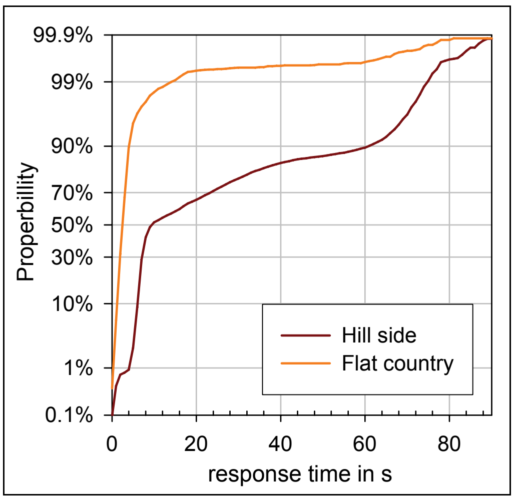

Fig. 4: Response time of the data transmission

Actually two summers are observed and temperatures up to 37°C were recorded. In Fig. 5 are the probabilities of the wind speed versus the ambient temperature of both line monitoring stations shown.

With increasing ambient temperature, an increasing wind speed is recognisable for all three stations. Although both onside locations are relative close together, the wind speed profile is quite different. At the hill site location the average speeds are almost the half of the flat country location. The probability to record a speed below 0.6m/s at 30°C ambient temperature is less than 1% and at the hill side less than 7%. These results can be used for a risk based line capability forecast to optimise the utilization. In the town location, the recorded data have to be handled with care. The installed mechanical anemometer has a poor accuracy at low wind speed and a high digitalising step (0.186m/s per step) and can not compared with the ultra sonic anemometer, but the tendency also given.

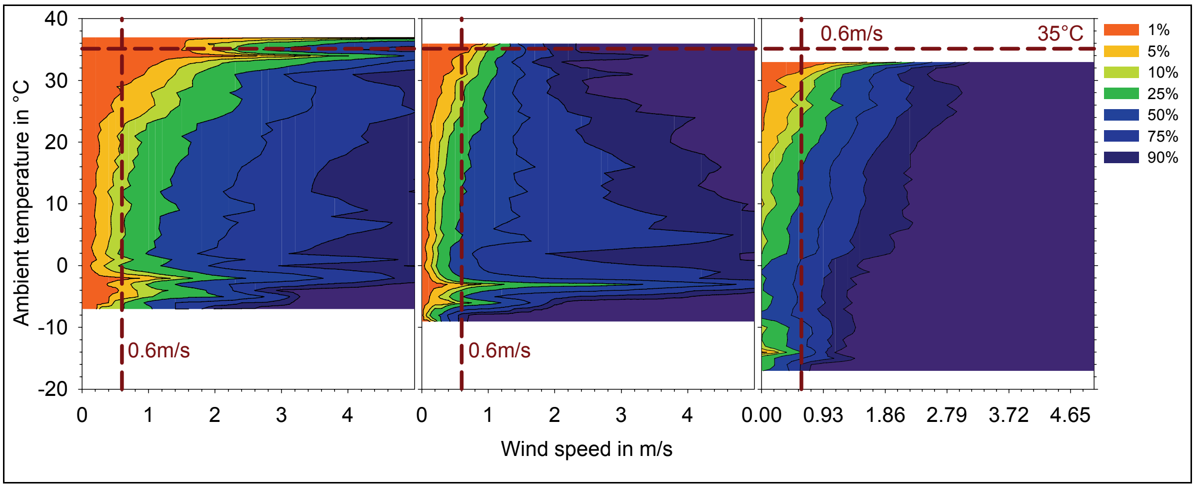

Fig. 5: probability of wind speed versus ambient temperature
(left flat country, middle hill side, right Graz Town)

The most interesting topic of an overhead line monitoring system based on an indirect method is the accuracy of the temperature evaluation. Therefore a temperature sensor was built in the core of a conductor model at the investigation platform in Graz. So the measured conductor temperature can be compared with the computed of the monitoring system. Over the whole observation time, a mean value error of -0.12K and a standard deviation of 1.2K could achieve. High differences occur at low wind speed which is a problem of the accuracy and digitalising step of the sensor. More precision will be achieved by more accurate wind measurement systems.

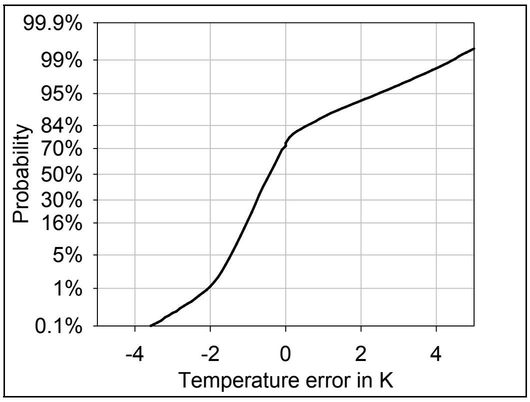

Fig. 6: Accuracy of the monitoring system

6 Conclusion

In cooperation with the APG, an overhead line monitoring system based on the Weather Parameter Method according to [2] was developed. The system was designed as auxiliary tool for the operator for observing the thermal condition of the line. The realised data transmission with GSM-network shows that a 100% transmission rate is not gettable. For a thermal rating controlled system a reliable and trusted data transmission is mandatory. Public networks do not perform these requirements at the moment. The other key factor is the resolution and accuracy of the installed sensors especially the wind speed and direction measurement. Systems without moving parts and high accuracy at low wind speeds are preferred.

At the observed locations the occurrence probability of high ambient temperature (>30°C) in combination with calm or low wind speeds is very low but depends on the topography. The standard values for nominal current (35°C, 0.6m/s [5]) are conservative assumptions which contain reserves for operation. More critical are conditions at moderate temperatures (15÷30°C) where probability of windless is significant higher. An overheating of the conductor is there more probably.

The accuracy of the used algorithm is acceptable of the thermal condition evaluation. More important is the transferability of the results of one location to other sections of the line. There are the local conditions decisive like topography, shadowing effects for wind and sun or natural cover of forest. For a reliably and trusted monitoring system the whole overhead line has to be account.

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