Operation ideas for overhead transmission lines (OHTLs) by using information of online temperature monitoring systems

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Abstract: In Europe the economic conditions for the energy sector change according to the unbundling regulations of the European Union. Therefore the generation, the operation of the power grid and the trade of electrical energy must be strictly separated. The organizational units of power generation and trading of electrical energy could earn money by dealing electrical energy directly. The organizational units of the electrical power grid gain the money only with fees of the transmitted energy. These fees could not be chosen free, but are fixed by a regulator, because the power grid is in the market economy of electrical power engineering still a monopole.

Furthermore, due to the unbundled system, the power network companies do not have any power plants controlling the power flow in their systems. The needed and of course sometimes very expansive balance energy, must be bought from other companies.

Additionally, according to the general ambitions regarding the increased use of regenerative energy sources, a lot of new power plants - like wind power plants - grow up in areas with sometimes historical structurally very weak power grids. Hence the weak power grid must additionally transport the generated regenerative electrical energy to the consumer. Furthermore, the environmental protection laws have often been changed in the last time and the erecting of new overhead lines is more complicated than in the past. Getting a positive administrative decision will take longer as well due to that fact. Another aspect is that a high percentage of the European overhead lines are already in service for a certain time and constructed according to older laws. Not all of these overhead transmission lines could be fully loaded whilst fulfilling all current security standards.

To overcome this situation some options are possible. For the near future - besides the building of new overhead transmission lines - the temperature based up-rating of overhead transmission lines might be possibility. There are different methods for online monitoring of overhead transmission lines. For a sound usage of the information gathered by such monitoring systems, modified approaches for controlling the power flow, must be developed. These ideas focus on the new situation of overhead transmission lines in the changed market of electrical energy. Not only economic strategies for benefit maximization might be included. These strategies must also include risk management and the secure supply of electrical energy in compliance with the relevant security standards. In the following paper some ideas for the operation of overhead transmission lines by using information of temperature online monitoring systems will be presented and discussed.

1 INTRODUCTION

The situation in the electricity market is changing in the last few years. On the one hand the electrical energy market in continental Europe was deregulated some years ago and at the other hand the electrical energy consumption is still increasing at an average level in Europe of approx. 2 % per year. Due to the deregulated electrical energy market the EHV (extra high voltage) transmission lines are increasingly used as transportation utilities for the “delivery” of electrical energy across the European transmission network (UCTE).

Fig 1. EHV overhead lines

Challenging for instance are situations where a lot of generation power is located in one part (e.g. in the north of Germany), where power consumption is relatively low, while there is a bottleneck in the south of Europe (especially Italy). Furthermore less new OHTLs were built in the last few years, because it takes more time to fulfil the environmental and governmental laws. Additionally the regulated fees for energy transfer in the network decreases constantly. Hence the existing EHV overhead lines must sustain higher upcoming energy transfer at lower compensation prices. The EHV overhead transmission lines were mainly built in the early 60s and in the 70s of the last century according to the national and international standards. The sag of overhead lines are dimensioned at a specific temperature, which is commonly 60°C for standard ACSR (aluminium conductor steel reinforced) conductor, because the reversible tension of the conductor depends mainly on the temperature, when no additional external load e.g. ice on the conductor is present. The rated current at a conductor temperature for e.g. 80°C is defined by specified environmental conditions like 35 °C, 0,6 m/s wind and usual solar radiation [1]. The approx. 40 - 50 years old aged conductors have been creeping by several mechanisms, which are discussed in several papers [2], [3].

In the past the grid was loaded with approx. 30%…50% of the rated current and the rated temperature was reached only in specific cases. But in the last few years the load of the OHTLs is increasing due to the above discussed points up to the rated values. Consequently the knowledge of the overhead line temperature is necessary for the decision of the possible transmission line loading. Due to the increasing load of overhead lines the sag is maximized and the clearance is minimized respectively.

2 UPRATING METHODS OF OHTLS

For the satisfaction of the higher load of the existing OHTLs (with a defined transmission capability) various methods of uprating are possible [4]. Four uprating methods are mainly discussed, (i) the deterministic, (ii) probalistic methods, (iii) real-time monitoring and (iv) re-conductering.

By using the **deterministic method** the load of the transmission line is calculated with the rated or design temperature of the conductor. This design temperature could be increased by re-tensioning of the conductor, because the clearance at a specific load increases also. Also the usage of the worst-case surroundings of a transmission line, like lowest wind speed, highest ambient temperature, highest solar radiation and maximum load currents, which depend on the area, could be calculated. The minimum clearance doesn't fall below a certain value. Risk management doesn't takes place at this method. Due to this method an exceeding of the design temperature of the conductor might occur. This method could be used for transmission lines with low rated temperatures and when lots of weather data of the area of the transmission line exist.

The **probalistic method** uses the probabilities of the occurring surrounding conditions along a transmission line including the occurring load profiles. For this calculation also weather data with an approx. 10 min time interval should be available. By using this data it is possible to calculate the dynamic temperature behaviour of an OHTL. The load profile of OHTL depends sometimes on the season, so there are some different possibilities of higher line loading depending on winter, spring, summer and autumn. By the calculation of the possible current, also some risk analyzes are done and an exceeding of the rated temperature should only take place in a very limited and a restricted time span. This method is also suitable method for uprating OHTLs with a low design temperature and high peak loads.

When using **real-time monitoring systems** for OHTLs the actual load as a combination of current, weather conditions and condition of the conductor can be measured. For the online condition evaluation of OHTLs various methods and products are used. The methods can be classified in direct and indirect methods. Direct methods measure a specific characteristic of the conductor, like force or conductor temperature, directly. Indirect methods compute the conductor temperature or the sag from other parameters. With such systems the operator knows online the situation of the overhead line and the highest possible load of existing OHTLs can be achieved. Furthermore the locations, where such monitoring systems are installed, are very essential for observing the worst-case points of an OHTL.

The transmission capability can also be increased by **re-conductoring** the OHTL. The new conductor should feature the same mechanical behaviour as the replaced one, because the mechanical design of the towers should stay unchanged. Mainly the design temperature and hence the transmission capability can be increased by the usage of e.g. TACSR (thermal resistance ACSR) conductors. This method is the most expensive one.

Furthermore there are other methods for uprating of OHTLs. The increasing of the system voltage is only possible if the other system components like switches, transformers, current and voltage transformers and strings fulfil also the ratings. Also the conductor must be checked for using at higher system voltage according to the emissions of corona losses and audible noise. With the variation of the suspension height the clearance could be increased. For increasing clearance the sag could be also increased and so a higher conductor temperatures and higher loads are possible.

3 LOAD PROGNOSIS BASING ON REAL TIME MONITORING OF TEMPERATURES

For all presented methods - excluding the real time monitoring method - the load of the OHTL is calculated during the planning or research phase and gives the system operator and the protection system the necessary information for the highest load and the switch off values as fixed levels. By using online monitoring systems the operator get the measured variable temperature values and has to interpret these values for planning the operation of the OHTL.

For the operator are the respective measured values of the real time monitoring systems, like temperature, act solely as kind of side information and can not be usually used as operation value. The interesting information for the operator at the substation is how much a line can be further loaded. Hence, for supporting the operator adequately a load prognosis should be available from the real time monitoring system.

The key requirement is that the sensor temperature is measured in short time intervals, like 60 s, which are smaller than the thermal time constant of the conductor.

The sensor temperature incorporates all load determining parameters of the environment, of the conductor and of the current load.

The results of the online measurement are generally (Fig. 2)

1. the present temperature level,
2. the temperature time functions with typical courses within the last 200…1000 seconds

Few typical temperature courses are possible:

a. progressive increase or
b. linear or degressive increase or
c. constant or
d. decrease

The observation interval of the temperature courses should be in the same order as the expected time constant T of the heating up or cooling down process of the conductor (approx. T=200 s at wind velocity of approx. 5 m/s up to approx. T=1000 s at no wind, additionally influenced by the conductor cross section).

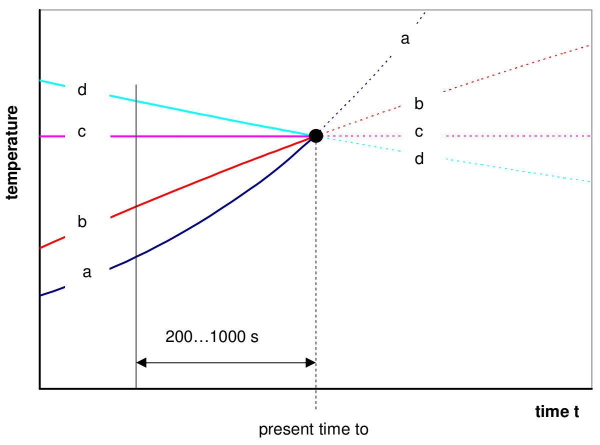

Fig. 2 Typical temperature courses

Considered might be the following details.

1. A sensor at the conductor is a heat sink and therefore the measured sensor temperature is lower than the real conductor temperature.
2. The permissible current load of a conductor is limited by a permissible conductor temperature like 40°C or 60°C or 80°C or.

3.1. Prognosis method A:
Only the sensor temperature is known

The difference between sensor and conductor temperature is ignored and the measured temperature is used as a rough estimation of the conductor temperature.

The experience shows: As soon as a sensor is installed the operator tries to draw conclusions concerning the overhead line-conditions and permissible current load basing on the assumptions above.

Only qualitative conclusions are possible.

If the measured sensor temperature is “low” (in comparison to the permissible temperature of the conductor) the conductor can be loaded higher. A rather “high” sensor temperature requires careful considerations when loading the conductor higher, especially when the temperature course is characterized by type a or b (Fig. 2)

A quantitative threshold between “low” and “high” can not be determined analytically and has to base on experience.

3.2. Prognosis method B:
Sensor temperature and typical thermal steady state properties of sensor and conductor are known

The sensor temperature data are known. These data have to be combined with results coming from systematic investigations of the steady state over-temperatures of the sensor and the conductor using thermal networks.

The findings are:

The ratio of “the over-temperature of the conductor $\Delta\vartheta_C$” divided by “the over-temperature of the sensor $\Delta\vartheta_S$” is less than 1,4 in the field of the wind velocity 0…5 m/s and nearly independent of the wind direction, the solar radiation, the ambient temperature, the load current and the absorption and emission properties of the conductor.

Remark: It is unnecessary investigating higher wind velocities than 5 m/s. The relation of the above described over-temperature ratio is in fact higher at higher velocities but the temperature level depending on the load current is so low, that a possible (very) high over load current for other than thermal reasons will be out of practical application.

Assuming a certain value for the (not measured!) ambient temperature ϑ_A one gets the over-temperature of the sensor $\Delta\vartheta_S$ and an evaluation of the conductor temperature.

The lower we estimate the ambient temperature, the higher is the difference between conductor temperature $\Delta\vartheta_C$ and sensor temperature $\Delta\vartheta_S$ and the estimation is on the safe side. An initial assumption could be the well known average ambient temperature over a year: e.g. ϑ_A =10°C.

The conductor temperature ϑ_C can than be estimated with

$$\vartheta_C = (\vartheta_S - 10°C) \cdot 1{,}4 + 10°C \qquad (1)$$

Assuming the limit of the conductor temperature is $\Delta\vartheta_{Cg}$ =80°C.

In that case the sensor temperature must be lower than

$$\vartheta_{Sg} = \frac{\vartheta_{Cg} - 10°C}{1{,}4} + 10°C = 60°C \qquad (2)$$

From a practical point of view for instance, if the sensor temperature is $\Delta\vartheta_{Sg}$ < 55°C, the load current can be increased.

A sensor temperature around 55°C (or even higher) needs attention concerning further increase of the load current, especially in combination with temperature courses a or b (Fig. 2).

Of course, a better load prognosis can be made basing on the same procedure as described above, when the real time ambient temperature is known.

3.3. Prognosis method C: Sensor temperature, ambient temperature, load current and the thermal properties of the sensor and the conductor are known

Prerequisites are that the sensor temperature $\vartheta_S(t)$ (level and course), the ambient temperature $\vartheta_A(t)$ (level and course) and the load current $I^*(t)$ (level and course) are known.

Basing on these sensor temperature and the ambient temperature courses the conductor temperature can be estimated (concerning the algorithm see [5])

1.1.1. Prognosis method C1:
Load prognosis basing on steady state conditions

The over temperature of the conductor $\Delta\vartheta_C^*$, the corresponding load current I^* and the possible conductor over-temperature $\Delta\vartheta_{Cg}$ are known. The possible steady state load current I_i can be estimated with

$$I_i = I^* \cdot \sqrt{\frac{\Delta\vartheta_{cg}}{\Delta\vartheta_c}} \qquad (3)$$

The better the temperature course follows the course type c (Fig. 2) at constant current I^* the more accurate is the predicted load current I_i will be.

Taking realistic deviations from the temperature behaviour of the HV line the periodical sensor temperature measurement every 60 s is used for continuous adaptive corrections.

1.1.2. Prognosis method C2:
Load prognosis for short prediction intervals using the dynamic thermal properties of the conductor

The load prognosis C2 allows higher dynamic load current in comparison to the steady state prognosis C1, when the prediction interval is shorter than the heating up or cooling down process of the conductor. A prediction interval of 900 s is a suitable value from the physical point of view as well as from practical needs.

The load current prediction (Fig. 3) starts from the values for the load current I^* and the conductor over-temperature $\Delta\vartheta_C^*$, which represent steady state conditions as good as possible, proven by the calculated conductor temperature course.

An assumption must be made regarding the time constant T of the heating up and cooling down process of the conductor valid for low wind velocity (in order to be on the safe side).

The superposition of the cooling down process under "no load" (step function to load zero) and the heating up process by a current step function generating the permissible conductor temperature at the end of the prediction interval results in the current I_i, the permissible load during the prediction interval.

Depending on the real current course and the real time constant (depending e.g. on the wind velocity) the conductor temperature will be calculated every 60 s. So the predicted current can be corrected and adapted every 60 s. (example see Fig. 4)

$$I_i = \frac{I^*}{\sqrt{\Delta\vartheta_C^*}} \cdot \sqrt{\frac{(\vartheta_g - \vartheta_A) - (\vartheta_{Start} - \vartheta_A)\exp\left(-\frac{t_i}{T}\right)}{1 - \exp\left(-\frac{t_i}{T}\right)}} \qquad (4)$$

I_i	possible current within the prediction interval, can be corrected every 60s
I^*	steady state current; generates the conductor over temperature
ϑ_g	permissible conductor temperature
ϑ_A	ambient temperature
ϑ_{Start}	conductor temperature at the begin of the prediction interval
t_i	duration of the prediction interval, the conductor temperature at the end of

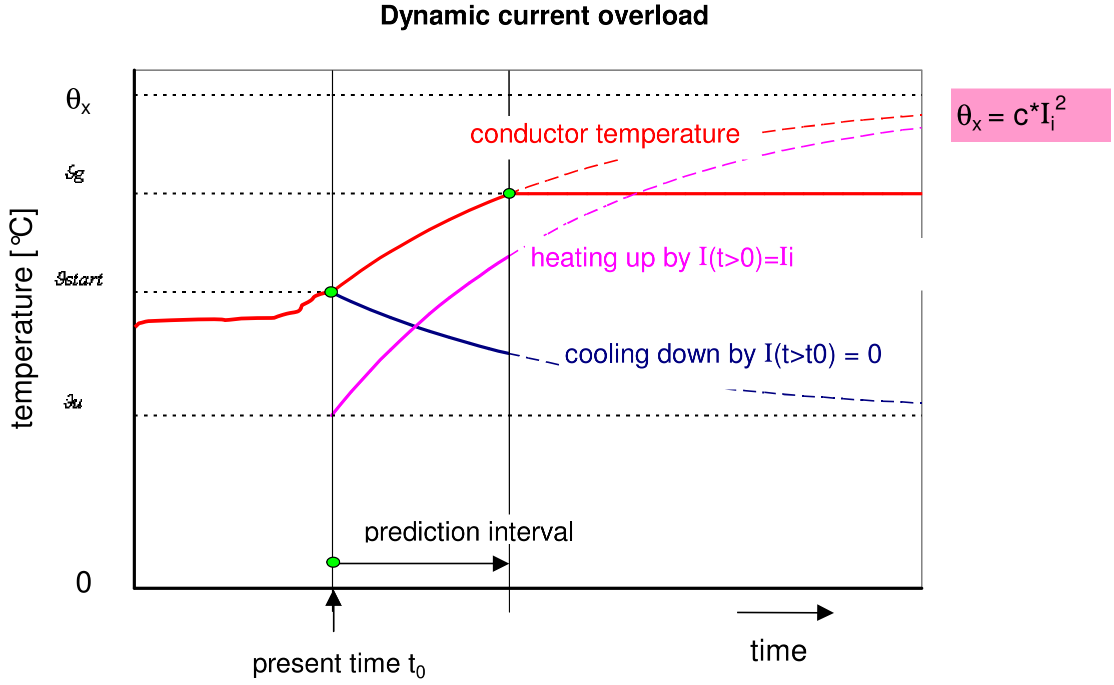

Fig. 3 Dynamic current over-load; temperature courses

this interval is equal to the permissible temperature

T Time constant of the heating up and cooling down process of the conductor

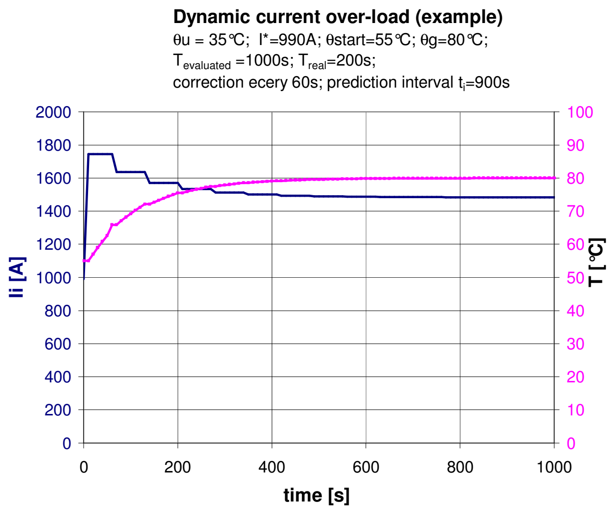

Fig. 4 Dynamic current over-load; current and conductor temperature courses; example

4 USAGE OF UPRATING

The results of the load prognosis can be used in various areas of load control for transmission grids. The possibility of increasing the load includes affects both the economic and the technical aspects of the power grid operation in the deregulated market of electrical energy.

The static load prognosis could be used for increasing the steady state power of transmission lines. At the one hand an increased transmission capability is possible, while the secure operation is not questioned. On the other hand increasing fees and lower costs for load control energy are possible. A further effect is that the increasing demand on transmission load could be satisfied by using the existing transmission lines for a specific time. Hence a lot of capital expenditure might be suspended or even omitted [6].

By using regenerative energy sources for generation of electrical energy especially by using wind, high peak transmission loads occur depending on the behaviour of the wind speed. In Germany the power of the wind parks is increasing rapidly in a landscape, while at the same time the power grid is not prepared for this high loading at high wind speeds. With online monitoring systems controlled uprating resulting in higher transmission capabilities for high wind speed periods is possible. The generated electric power of the regenerative sources could be transported to the load more flexible.

Additionally during grid problems the results of the dynamic load prognosis could be helpful regarding a secure delivery of electrical energy when operating over the calculated rated current. This high loading situations of a HV overhead line arises normally only in a short time span, because during problems various regulation mechanisms are initialized. Nevertheless during this short time period the loaded transmission lines could be overloaded in a controlled manner by using the information of the load prognosis and power outages might be avoided.

5 RISKS OF UPRATING

In addition to the positive effects of uprating of OHTLs also some risks are introduced. An increased load could have some impacts to the conductor, the overhead transmission line and also on the electrical power system. Higher loading of the transmission line stands also for a higher conductor temperature up to the rated temperature of the overhead line. The irreversible elongation of the transmission line depends mainly on the temperature of the conductor. As well the aging of conductor and clamps depends on the system temperature. A high loaded transmission line has influences on the (n-1) safety criteria, so sometimes this criteria and sometimes this criteria might not be satisfied any longer, especially if transmission lines with the same power grid function are loaded up to their rated temperature. Depending on the length of the line and the loading, also the steady state and the dynamic stability of the power grid (voltage stability) is influenced.

Before using methods for uprating of transmission lines investigations for checking the suitability of the conductor, the line and also the effects to the scheduled power grid part should be done.

6 SUMMERY

Due to the circumstances at the changed market of electrical energy new monitoring systems for overhead lines are necessary. The important information for an operator are usually not directly the measured values of the monitoring system. Rather derived information regarding the possible loading of the monitored line are necessary and valuable. The time span for the forecast of the load prognosis could be divided into static (steady state) and dynamic prognosis. Both can be used differently for uprating the load at OHTL. While uprating as well risks might be introduced, which can be evaluated and the probability of exceeding rated levels can be decreased to a minimum level. For an efficient and effective operation of existing OHTLs and a satisfaction of the increasing energy demand with the existing HV lines uprating methods – in particular real time monitoring with an appropriate load prognosis - are necessary and helpful.

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