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Influence of the conductor temperature error on the overhead line ampacity monitoring systems

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Abstract— **Many real time overhead line ampacity monitoring systems are based on the calculation of the wind speed. The wind speed is obtained from the conductor temperature. The conductor temperature can be measured directly or it can be obtained indirectly from other magnitudes such as the tension or the sag. An error in the temperature difference gives as a result an error in the calculated wind speed and ampacity values. This paper analyzes and quantifies the influence of the temperature difference error in the obtained ampacity value. As a result, a method for the evaluation and the correction of the ampacity error that can be used in the monitoring systems is proposed.**

***Index Terms*— ampacity, overhead line, rating, real time monitoring**

1. INTRODUCTION

Currently, many overhead lines are close to their ampacity limit. The ampacity or thermal rating is that current which will meet the design, security and safety criteria of a particular line. Therefore, there is great pressure to increase the power flow in existing right of ways using existing infrastructure as far as possible. For this reason, methods without the need to strengthen the towers that allow increasing the line power flow securely and safely have been developed [1]. Among these methods, the conductor replacement is found. The new conductor needs to have better properties, such as lower sag-temperature relation [2]. Another option is to increase the ampacity of the line by real time monitoring [3-4].

The real time ampacity monitoring systems give the actual ampacity value, which usually is underestimated because it is calculated from conservative weather conditions (low wind speed, high ambient temperature and high solar radiation). Hence, these systems allow the utilities making use of the actual transmission capacity of the existing assets. During the last years, many commercial real time ampacity monitoring systems have been developed.

The simplest systems monitor the weather magnitudes (wind speed and direction, solar radiation and ambient temperature). Making a thermal calculation [5-6], the ampacity is calculated as the current intensity value that equals the conductor temperature to the conductor maximum allowable temperature. There is some uncertainty in this option due to the variation of weather conditions along the line and between the line and the weather monitoring station. Hence, an alternative is the direct monitoring of the surface conductor temperature, the sag or the tension.

Many real time ampacity monitoring systems are based on the wind speed calculation. The wind speed is obtained from the conductor temperature. The conductor temperature can be measured directly [7-10] or it can be obtained indirectly from other magnitudes such as the conductor tension [11-15] or the sag [16-19].

When the conductor temperature is obtained, an error in the temperature difference between the conductor temperature and the ambient temperature gives an error in the calculated wind speed and ampacity values. This paper analyzes and quantifies the influence of the temperature difference error in the obtained ampacity value.

2. AMPACITY MONITORING SYSTEMS

The ampacity monitoring systems based on the wind speed calculation calculate the ampacity value following the diagram represented in Figure 1. From the conductor temperature, the current intensity and the weather conditions (ambient temperature and solar radiation) the wind speed value is calculated. Then, from the conductor maximum allowable temperature, the ampacity is calculated. The ampacity is the current that with the existing weather conditions (ambient temperature, wind speed and solar radiation) gives as a result a conductor temperature value equal to the maximum allowable temperature.

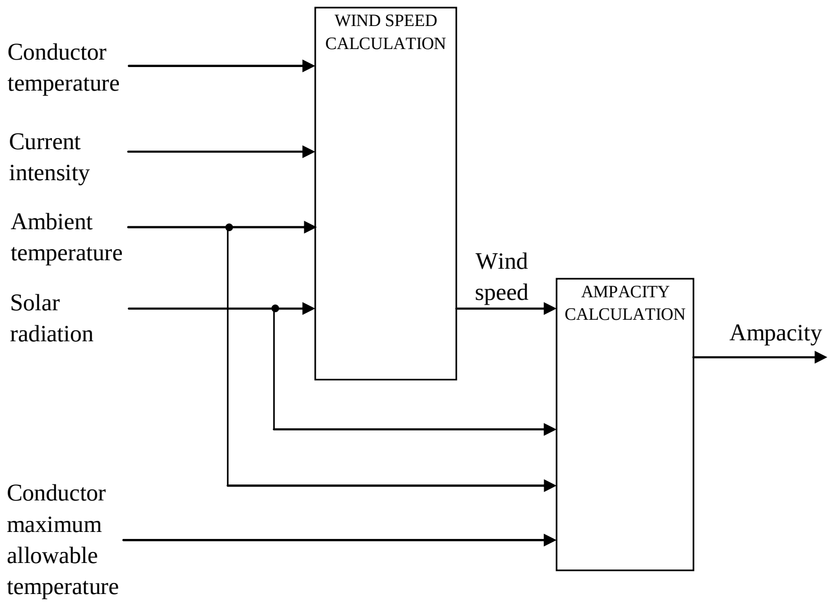


Fig. 1. Ampacity monitoring systems based on the wind speed calculation

2.1. Conductor temperature monitoring systems

The conductor temperature monitoring systems measure directly the conductor surface temperature. The uncertainty of these systems is related to the uncertainty of the measurement and the variation of the temperature between the measured point and other points within the monitored span.

The first commercial system based on conductor temperature monitoring, the Power Donut, was developed in the early eighties [7-8]. Besides monitoring the conductor temperature, the Power Donut monitors the current intensity. To calculate the ampacity, the system needs the ambient temperature and the solar radiation values. These magnitudes can be obtained from weather station nearby. In case this is not possible, the system offers the possibility of installing a weather station that measures the ambient temperature and the solar radiation in the tower that is closest to the temperature sensor. It can measure the conductor temperature up to 250 ºC with an uncertainty of 0,5 %.

Recently, a similar temperature monitoring system has been developed [9]. It is called SMT (Temperature Monitoring System) and it monitors the conductor temperature and the current intensity. This system measures the conductor temperature up to 120 ºC with an uncertainty of 2 % or 1 ºC.

Another option is the monitoring of temperature by devices based on surface acoustic wave (SAW) [10]. The system comprises a radar that sends and receives high frequency electromagnetic waves and a passive SAW sensor installed on the conductor. With this system the conductor temperature up to 150 ºC can be obtained with an uncertainty of 0.5 ºC.

2.2. Conductor tension monitoring systems

The conductor tension monitoring systems calculate the conductor temperature value from the measured tension values. A tension-temperature calibration curve is obtained and this curve is used in order to calculate the conductor temperature. To calculate the ampacity, these systems also need the ambient temperature, the solar radiation and the current intensity values. There is an uncertainty in the obtained conductor temperature due to the uncertainty of the tension monitoring system and the uncertainty in the calibrated tension-temperature curve.

There is one commercial tension monitoring system called CAT-1 [11-12]. This system is calibrated in order to establish the relation between the conductor tension and the conductor temperature. Besides, it has a special system in order to measure the weather values indirectly. Regarding the calibration, it is based on measuring pairs of tension-temperature values. On the one hand, a reference for the tension and the conductor temperature is established. On the other hand, the value of the ruling span is obtained. The special system that measures weather values indirectly is known as Net Radiation Sensor. It is an aluminum tube with the same emissivity and absorptivity values as the conductor. It is installed in the same tower where the load cell is installed. The tube is situated parallel to the conductor. A temperature sensor measures the temperature of the aluminum tube. This temperature represents the temperature that the conductor has with no current intensity. If the Net Radiation Sensor is used, there is no need to know the ambient temperature and the solar radiation values in order to implement the thermal equations. The ambient temperature is substituted in the thermal equations by the temperature measured by the Net Radiation Sensor.

Recently, a new monitoring system based on tension has been developed by the University of the Basque Country UPV/EHU [13]. This system, known as TAM System, monitors the mechanical tension, the ambient temperature, the solar radiation and the current intensity. The tension-temperature calibration curve is obtained from mechanical calculation [14-15] and a tension-temperature reference value. The tension-temperature reference value is updated in order to take into account the conductor creep.

2.3. Conductor sag monitoring systems

The conductor sag monitoring systems calculate the conductor temperature value from the measured sag values. A sag-temperature calibration curve is obtained and this curve is used in order to calculate the conductor temperature. To calculate the ampacity these systems also need the ambient temperature, the solar radiation and the current intensity values. There is an uncertainty in the obtained conductor temperature due to the uncertainty of the sag measuring system and the uncertainty in the calibrated sag-temperature curve.

The first commercial sag monitoring system, the Sagometer, is based on image processing [16]. A target is connected to the conductor in the middle of the span and a camera situated in the tower locates the target and calculates the sag. Additionally, a weather measuring system is added in order to obtain the ampacity.

There is another commercial sag monitoring system, developed by Promethean Devices, which is based on the measurement of the line magnetic field and it calculates the line current intensity, the sag value and the conductor temperature [17]. The uncertainty in the conductor temperature is ±4.5 ºC.

Recently, the University of Liège has developed a system that determines the sag value indirectly by conductor vibration analysis [18-19]. This system is known as Ampacimon.

3. ANALYSIS OF THE INFLUENCE OF THE TEMPERATURE ERROR

A theoretical analysis where the wind speed is assumed to be known has been carried out in order to analyze the conductor temperature error influence on the ampacity calculation (Fig. 2). The conductor temperature is calculated from the current intensity and the weather conditions (wind speed, ambient temperature and solar radiation). Theoretically, this value is the actual conductor temperature. The conductor temperature error value is added to the actual temperature in order to analyze its influence. As a consequence, the calculated wind speed (with error) will differ from the actual wind speed. Therefore, the ampacity value obtained from the calculated wind speed (with error) will differ from the actual ampacity value calculated from the actual wind speed. The difference in the ampacity value (ampacity error) has been analyzed as a function of the conductor temperature error.

Obviously, the conductor temperature is not the only value that affects the calculated ampacity value. Errors in the current intensity, the ambient temperature, and the solar radiation values also influence the final result and should be taken into account in the evaluation of the accuracy of the monitoring system. However, the analysis carried out has intentionally neglected these errors in order to analyze the influence of the conductor temperature error without the interference of other errors.

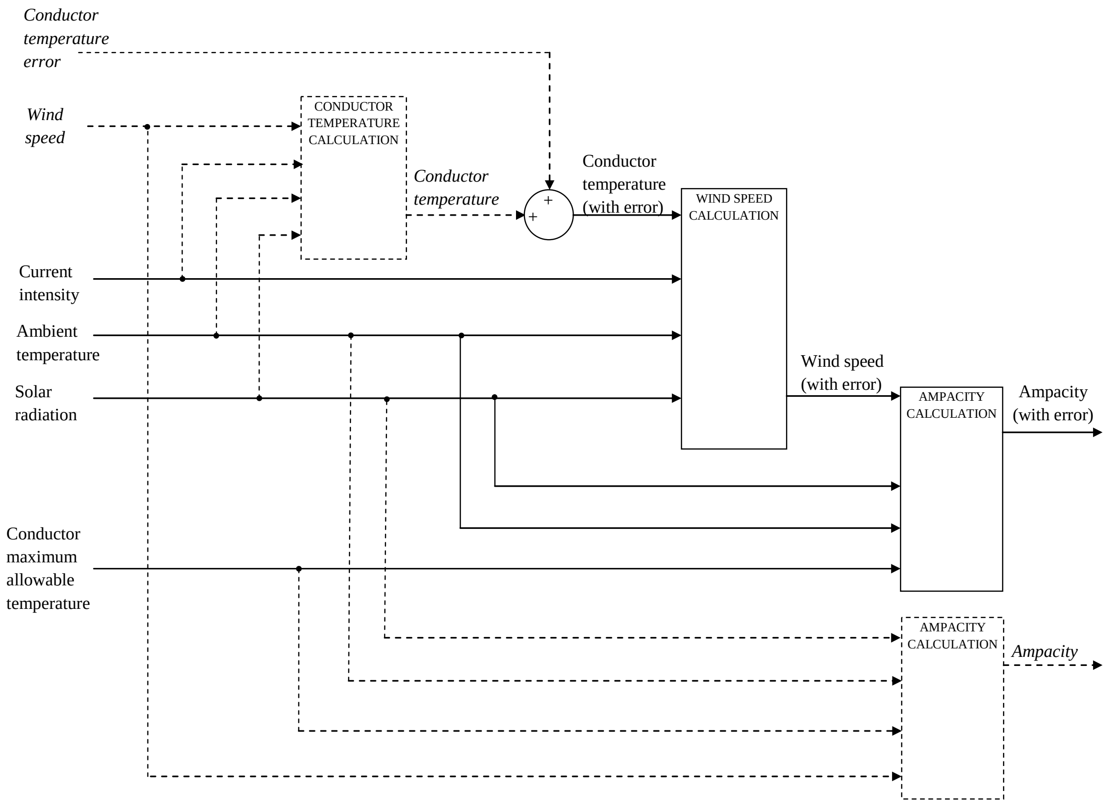
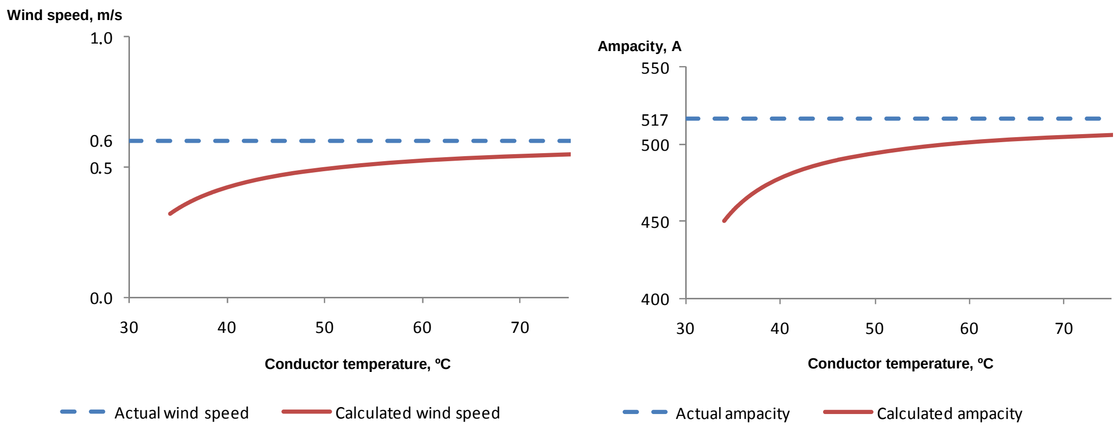
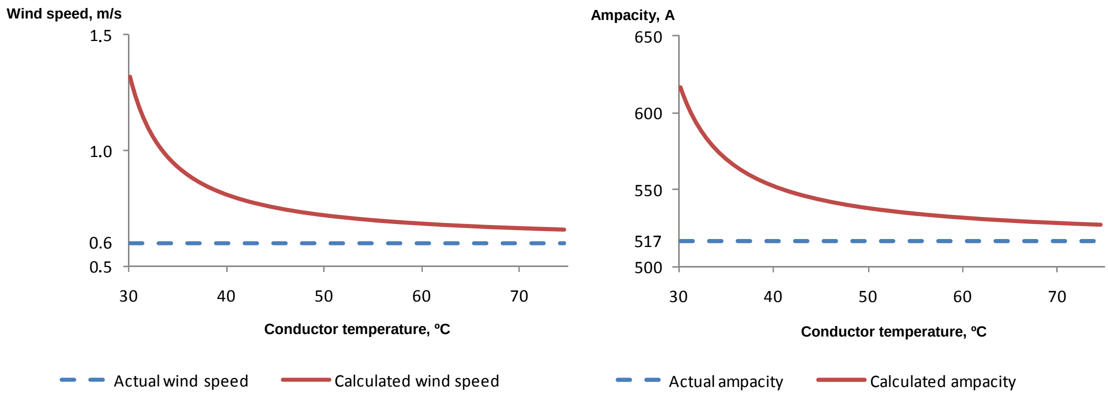


Fig. 2. Simulation of the temperature error

An example of the analysis carried out is shown below. The conductor is the ACSR LA-180 (147-AL1/34-ST1A) conductor [20], the ambient temperature is 25 ºC, the solar radiation is 1000 W/m^2, the wind speed is 0.6 m/s and the conductor maximum allowable temperature is 80 ºC. These values give an actual ampacity value of 517 A. Figure 3 shows the calculated wind speed and ampacity as a function of the conductor temperature assuming a conductor temperature error of 2 ºC (Fig. 3.a) and -2 ºC (Fig. 3.b). The different conductor temperature values correspond to different current intensity values. The Figure shows that the calculated wind speed and ampacity values approach the actual values when the conductor temperature increases. In other words, when the difference between the conductor temperature and the ambient temperature is low the influence of the conductor temperature error in the ampacity calculation is higher and vice versa. A positive conductor temperature error (calculated or measured temperature higher than actual temperature) underestimates the wind speed and the ampacity values (Fig. 3.a). On the contrary, a negative conductor temperature error (calculated or measured temperature lower than actual temperature) overestimates the wind speed and the ampacity values (Fig. 3.b). Hence, from the point of view of security the conductor temperature negative errors are more dangerous because the actual ampacity value is lower than the calculated value.



a)



b)

Fig. 3. Wind speed and ampacity calculation
a) Positive conductor temperature error (2 ºC)
b) Negative conductor temperature error (-2 ºC)

3.1. Temperature difference and temperature error

The influence of the temperature difference between the conductor temperature and the ambient temperature on the ampacity calculation has been analyzed (Fig. 4).

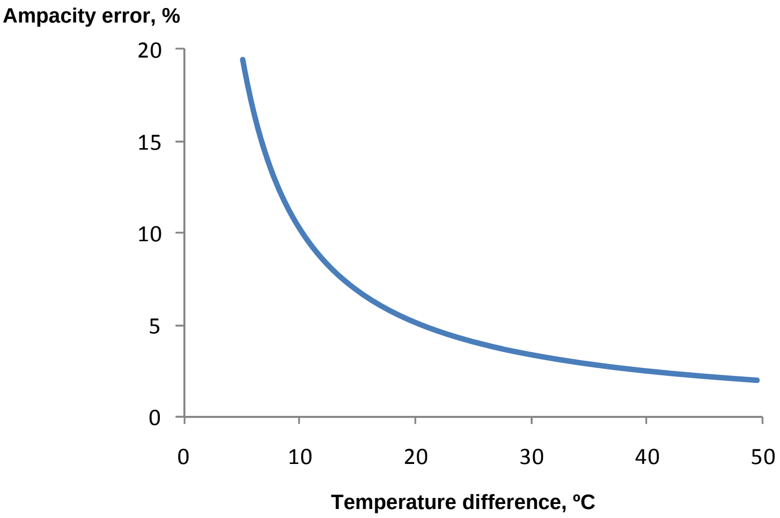
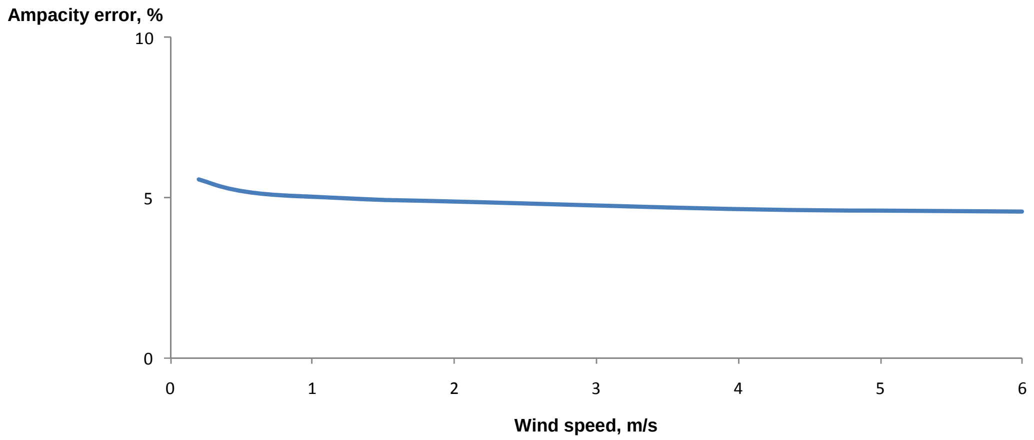
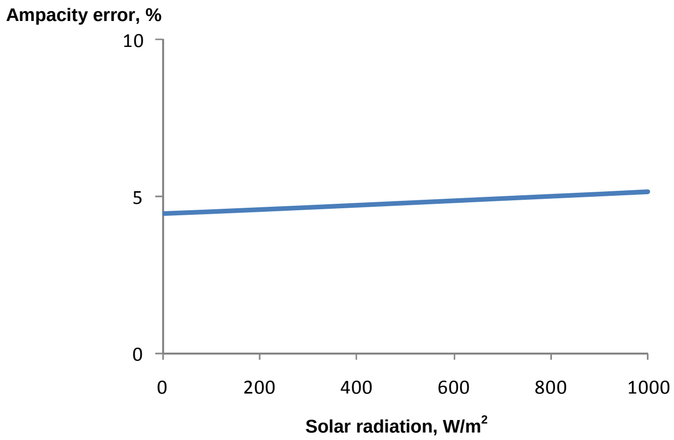


Fig. 4. Ampacity error as a function of the temperature difference (cond. temp. error: -2 ºC)

The curve represented in Figure 4 has been calculated from the weather conditions given above (25 ºC, 1000 W/m^2, 0.6 m/s). The analysis carried out has shown that for other weather conditions the change in the curve is small. In Figure 5 the ampacity error is given for different values of wind speed (Fig. 5.a), solar radiation (Fig. 5.b) and ambient temperature (Fig. 5.c) when the conductor temperature error is -2 ºC and the temperature difference is 20 ºC. These curves show that the ampacity error given as a percentage is almost constant for different weather conditions for a given conductor temperature error and a given temperature difference.



a)



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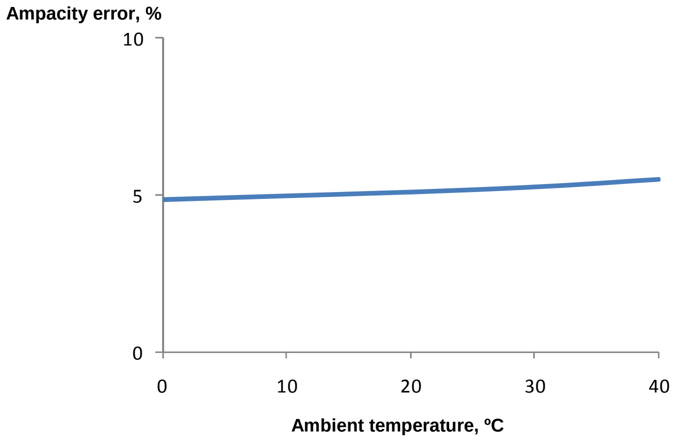


c)

Fig. 5. Ampacity error (cond. temp. error: -2 ºC; temp. difference: 20 ºC)
a) As a function of wind speed
b) As a function of solar radiation
c) As a function of ambient temperature

Although the ampacity error is almost constant, there is a slight dependence on the weather conditions. The curves show that the ampacity error given as a percentage is higher for low wind speeds, high solar radiation and high ambient temperature. In other words, the error is higher when the weather conditions are unfavourable from the point of view of the ampacity. For example, when the ambient temperature is 25 ºC, the solar radiation 1000 W/m^2 and the wind speed is 0.6 m/s the ampacity error is 5.15 % (ampacity: 517 A; ampacity error: 27 A). When the ambient temperature is 5 ºC, the solar radiation 100 W/m^2 and the wind speed is 4 m/s the ampacity error is 4.31 % (ampacity: 1016 A; ampacity error: 44 A).

Figure 6 represents the ampacity error as a function of temperature error for different temperature difference values. These curves correspond to fixed weather conditions (25 ºC, 1000 W/m^2, 0.6 m/s). For a given temperature difference the ampacity error is proportional to the temperature error, with a quasi-linear relation.

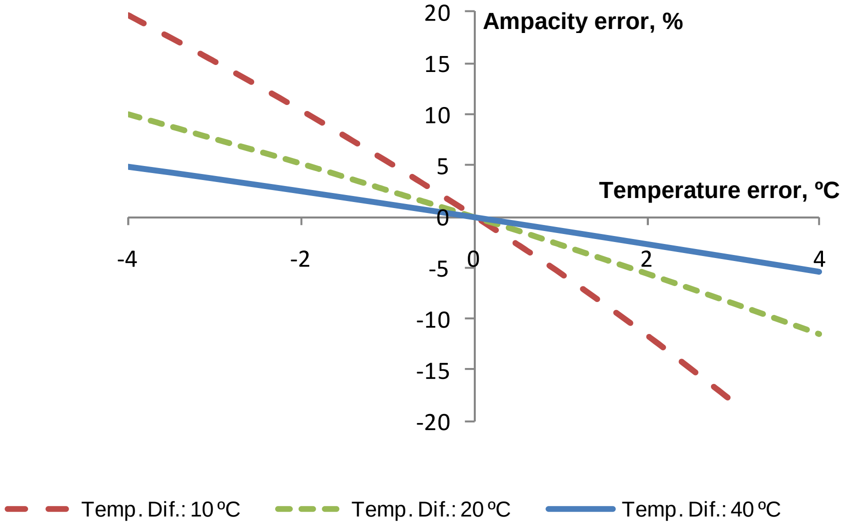


Fig. 6. Ampacity error as a function of the temperature error and the temperature difference

3.2. Temperature difference and current intensity

There is a relation between the line current intensity and the ampacity error. When the current intensity is low the conductor temperature is low and the ampacity error is high. As long as the current intensity increases, the ampacity error decreases (Fig. 7). Hence, a minimum current intensity value is needed to guarantee that the error is below a certain value. For example, in the case of Figure 7, the current intensity must be above the 60 % of the ampacity value in order to guarantee an ampacity error below 5 %.

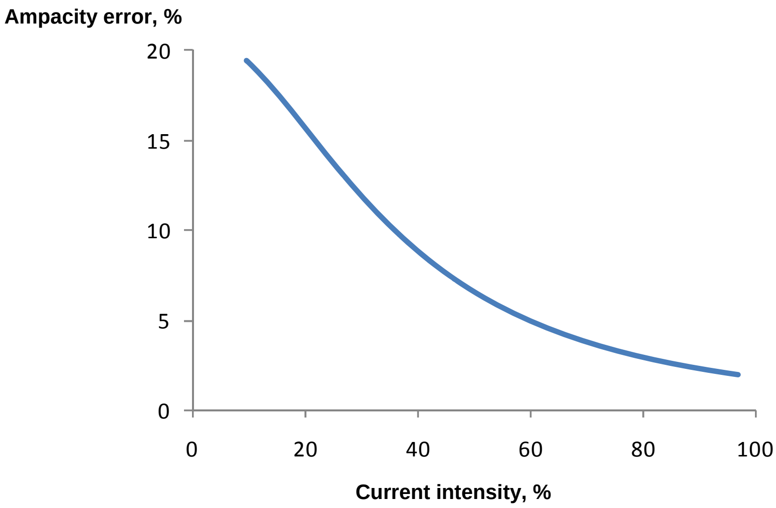


Fig. 7. Ampacity error as a function of the current intensity (cond. temp. error: -2 ºC)

Figure 8 shows the current intensity needed to guarantee certain ampacity error values as a function of the temperature error. The lower the required ampacity error is the higher the current intensity is. Lower temperature errors require lower current intensity values to guarantee the same ampacity error values.

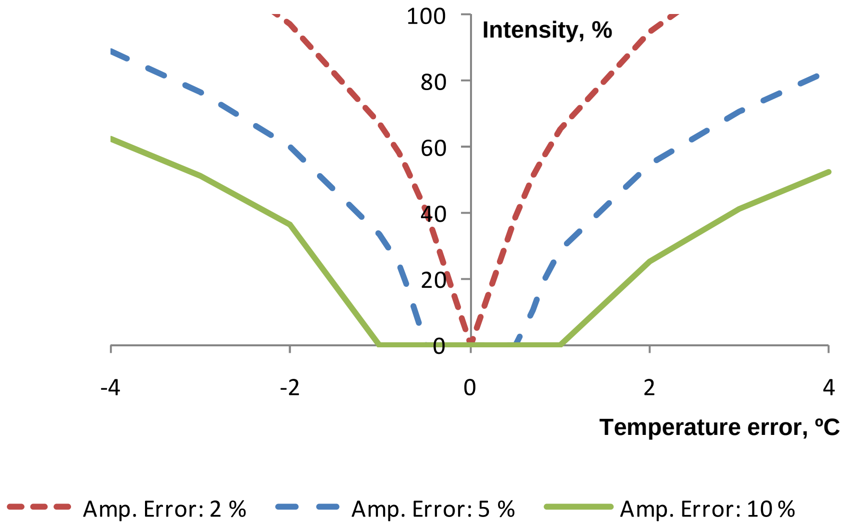


Fig. 8. Current intensity needed to guarantee a certain ampacity error as a function of the temperature error

4. APPLICATION IN THE AMPACITY MONITORING SYSTEMS

The analysis methodology can be adapted for the ampacity monitoring systems in order to provide additional information. The ampacity uncertainty can be calculated if the conductor temperature uncertainty is known. The ampacity monitoring systems based on the conductor temperature value (measured or estimated) should be able to quantify the conductor temperature uncertainty. The monitoring system output values can be modified so that the ampacity error is given and the ampacity value is corrected.

The proposed analysis methodology is also a useful tool for the design of the ampacity monitoring systems. The system requirements for the conductor temperature uncertainty can be defined as a function of the required ampacity calculation uncertainty.

4.1. Ampacity error calculation

Figure 9 shows the diagram of the ampacity error calculation. A process that calculates the ampacity error in parallel with the ampacity calculation process described above (Fig. 1) is added. This parallel process is represented with broken lines in Figure 9.

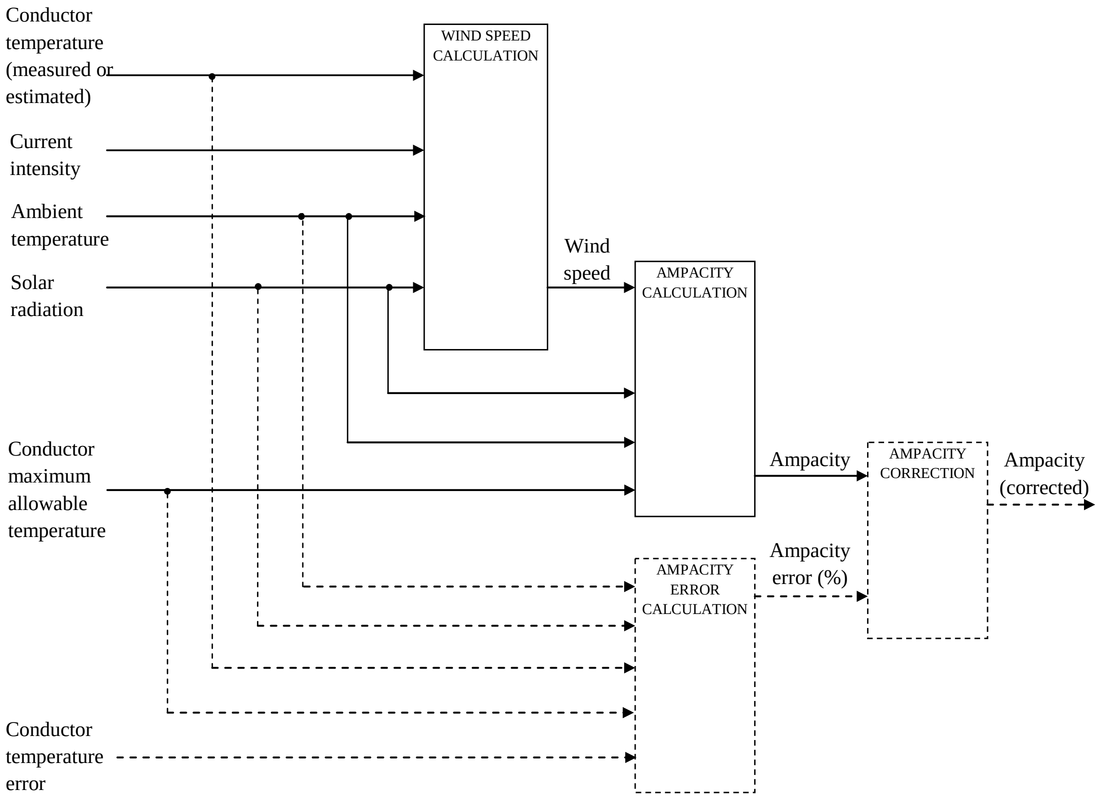


Fig. 9. Ampacity error calculation

The ampacity error calculation is based on the analysis process described in Figure 2. In this process, two ampacity values, with and without error, are obtained. From these values the ampacity error is calculated. To make the calculation given in the diagram of Figure 2, the values of the wind speed and current intensity are not given in the diagram of Figure 9. The error in the calculated wind speed is unknown and for this reason another wind speed value is taken for the calculation. A low wind speed (e.g. 0.6 m/s) is assumed and it is calculated the current intensity that with the measured ambient temperature and solar radiation values, and taking into account the conductor temperature error, gives a conductor temperature (with error) equal to the conductor temperature (measured or estimated). The wind speed value assumed for the calculation probably differs from the actual wind speed. However, the choice of this value is justified because as it has been shown in the subsection 3.1, the ampacity error is almost constant for different weather conditions for a given conductor temperature error and a given temperature difference. Anyway, the choice of a low wind speed is conservative because the ampacity error is higher with low wind speed values as it has been shown above.

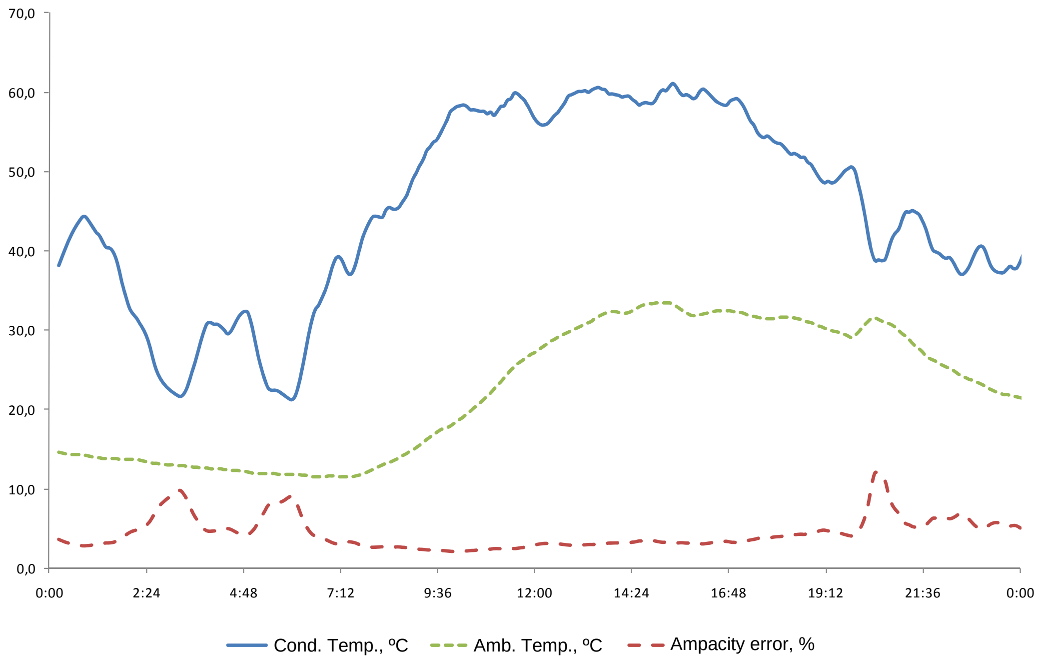
Obviously, the parameter with the highest influence in the ampacity error is the conductor temperature error. From a conservative point of view, the assumed error must be negative (calculated or measured temperature lower than actual temperature) so that the ampacity is corrected decreasing its value.

The calculation is simplified if only the corrected ampacity is given without the value of the ampacity error. In this case, the parallel process described above and represented in the Figure 9 is not needed. A similar result of the corrected ampacity value is obtained if the ampacity process represented in Figure 1 is carried out with a corrected conductor temperature value. This corrected conductor temperature value is obtained subtracting the conductor temperature error from the conductor temperature (measured or estimated). For example, if the conductor temperature (measured or estimated) is 56.4 ºC and the conductor temperature error is -2 ºC, the calculation is carried out using the value 58.4 ºC.

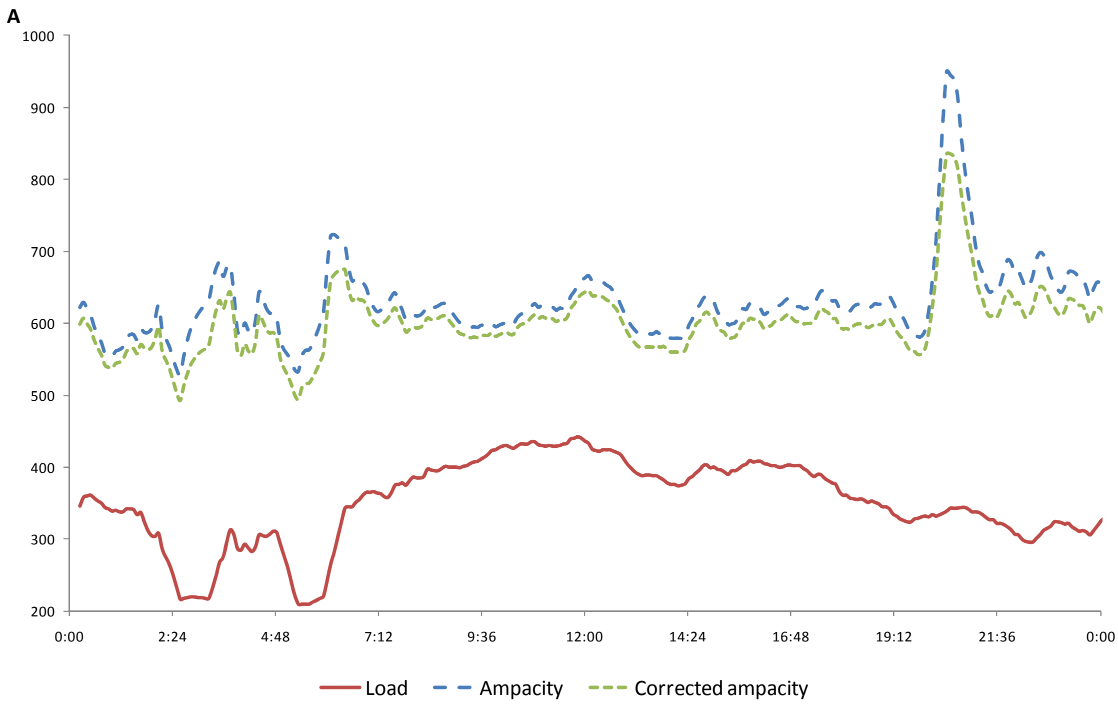
4.2. Application example

The ampacity correction has been applied to the TAM System [13]. This system obtains the conductor temperature from the measured conductor tension. The calculation requires a tension-temperature reference provided by a calibration process. There is an uncertainty in the obtained conductor temperature due to the uncertainty of the tension monitoring system and the uncertainty in the calibrated tension-temperature curve. The conductor temperature uncertainty of the TAM System can be around 2 ºC. Hence, a negative error of -2 ºC has been assumed for the ampacity correction.

Figure 10.a shows the measured ambient temperature and the calculated conductor temperature during a whole day. From these values the ampacity error is calculated as it has been described above. The obtained results have been plotted in Figure 10.a. The results show the correspondence between the temperature difference and the ampacity error. Figure 10.b shows the ampacity correction.



a)



b)

Fig. 10. Ampacity correction in the TAM System
a) Conductor temperature, ambient temperature and ampacity error
b) Load, ampacity and corrected ampacity

5. CONCLUSIONS

The influence of the conductor temperature error on the ampacity calculation has been analyzed. The analysis has quantified the ampacity error as a function of the difference between the conductor temperature and the ambient temperature. When the temperature difference is low the ampacity error is high and vice versa.

The influence of the temperature error has been quantified too. The results show the importance of the temperature error in the accuracy of the calculated ampacity value. Considerable temperature errors give high ampacity errors when the temperature difference is low. In other words, the temperature difference must be high in order to have low ampacity errors.

The relation between the current intensity value and the ampacity error is another aspect that has been analyzed. The closer the current intensity is from the ampacity value, the lower the ampacity error is. When the temperature error is low it is possible to have low ampacity error values for low intensity values. However, for higher conductor temperature errors the current intensity must be high to have a low ampacity error.

The analysis methodology is a useful tool for the design of the ampacity monitoring systems because the requirements for the conductor temperature uncertainty can be calculated as a function of the required ampacity uncertainty. Furthermore, it can be used to provide additional information. The ampacity uncertainty is calculated from the conductor temperature uncertainty value and the ampacity value given by the monitoring system is corrected.

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