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The Effect of Aging of Surface Non-Metallic Coatings on the Ampacity of Medium Voltage Rectangular Bus Bars

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Abstract—**There are two major types of non-metallic coatings for bus bars: oil- and epoxy-based coatings. The oil-based coatings have a limited lifespan of a few years, while the epoxy-based ones have a lifespan of over ten years. In contrast to the lifespans of indoor substations and components in them, the lifespans of coatings on bus bars are significantly shorter. Accordingly, it is obvious that the surface coating aging can affect the ampacity of rectangular or other shaped bus bars. The extent to which this effect can reduce the ampacity is analysed in this paper. An indoor substation, in which medium voltage (MV) rectangular bus bars of the same type can be found inside and outside the substation building, is considered as a case study. In order to simulate the aging process of the surface coating, it is assumed that the surface radiation properties (thermal emissivity and solar absorptivity) gradually change in the following manner: a new paint/coating layer, a layer of dirt over oxidised paint/coating, and a layer consisting of heavily-oxidised paint/coating, heavily-oxidised metal and dirt under both indoor and outdoor conditions. The results obtained for indoor and outdoor conditions are compared against one another in order to quantify the effect of solar irradiation. In addition, each non-metallic layer over the bus bars is considered as additional thermal insulation. The aging process is analysed analytically, and then validated numerically by finite element method (FEM) in COMSOL. Finally, the discussion yielded some important conclusions relevant for practice.**

Keywords – aging process, ampacity, rectangular bus bar, non-metallic coating, thermal analysis

I. Introduction

It is well-known that bus bars can be coated to increase ampacity, provide electrical insulation, inhibit corrosion, identify the phase and neutral conductors (i.e. for cosmetic reasons), and improve joint performance [1]. Metal and non-metallic coatings are used for this purpose. Metal coatings do not affect significantly the ampacity of the bus bars, while non-metallic coatings (such as oil-based coatings and epoxy-based coatings) behave as additional thermal insulation that can reduce the ampacity. In addition to this, aging of any non-metallic coating can contribute to a further reduction in the ampacity. Accordingly, the aging process will also affect the operating temperature of the bus bars [1, 2].

Bus bars coated black are considered in [3], while bus bars coated with various oil paints are analysed or mentioned in [1, 4-6]. There also are studies such as [7] where only bare bus bars are considered. According to [2, 3], when bus bars are installed indoor the thermal emissivity has a low value, and the solar absorptivity equals zero. This provides the most conservative ampacity for indoor conditions. In contrast, when bus bars are installed outdoor a high value of thermal emissivity essentially equal to solar absorptivity can give the most conservative ampacity for

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outdoor conditions [3]. In connection with this, it should be highlighted that solar heating of any bus bar always reduces its ampacity and can result in outdoor ampacities which are lower than that corresponding to indoor conditions [3]. This is less likely on bus bars with smaller cross-sectional areas for which the coefficients due to forced convection are relatively high. However, for bus bars having large cross-sectional areas and high solar absorptivities, the contribution from solar irradiance can exceed the improvement in heat transfer due to forced convection and the ampacities are decreased accordingly [3]. In addition, as a rule, comparisons of the ampacities of bare and coated bus bars are performed in [2, 5-7]. Furthermore, there are many other studies on bus bars, but they do not need to be reviewed for the purposes of this paper.

Lifespan of non-metallic coatings and its potential effect on the ampacity of bus bars is mentioned in [1]. According to [7], the surface radiation properties of a bus bar are functions of the age, as well as a contamination level of the surface of the bus bar. As a coated bus bar ages, the presence of a layer of dirt over oxidised paint/coating, or a layer consisting of heavily-oxidised paint/coating, heavily-oxidised metal and dirt over its conductor changes both the thermal emissivity and thermal absorptivity. There are a number of papers considering aging of bare bus bars, but there is no paper dealing with aging of coated bus bars. Accordingly, the effect of aging of oil- and epoxy-based coatings on the ampacity of MV rectangular bus bars is analysed in this paper.

The aging process of non-metallic coatings on bus bars is modelled as follows. Firstly, it is assumed that the non-metallic layer consists of two sublayers in different thicknesses, a thicker layer over the conductors of 0.2 mm and a finer layer over the coatings of 0.1 mm. Secondly, it is assumed that the aging process takes place in the following three stages: (i) a 0.3 mm thick new paint/coating layer – the two sublayers have the same values of thermal conductivity, (ii) a 0.1 mm thick dirt layer over a 0.2 mm thick oxidised paint/coating layer – the two sublayers have different values of thermal conductivity, and (iii) a 0.3 mm thick layer consisting of a mixture of heavily-oxidised paint/coating, heavily-oxidised metal and dirt – the two sublayers have the same values of thermal conductivity. In order to identify the effect of solar irradiance, the aging of oil- and epoxy-based coatings is considered for both indoor and outdoor conditions.

Thirdly, it is taken into account that the thermal conductivity of oil-based coatings, epoxy-based coating and dirt is 0.2 W/(m·K) [8], 0.3 W/(m·K) [9] and 0.98 W/(m·K) [10], respectively. In addition to this, the thermal conductivities of the dirt and the mixture of heavily-oxidised paint/coating, heavily-oxidised metal and dirt are assumed to be the same. These assumptions allow each non-metallic layer over the bus bars to be considered as thermal insulation. Fourthly, it is assumed that the thermal emissivity and solar absorptivity of the considered layers gradually change in an appropriate manner [9, 11-16].

Heating of the MV rectangular bus bars installed in and outside the building of an indoor substation is considered as a case study. The aging is analysed using a MATLAB programme entitled BUSBAR.m [2], while the validation is performed by means of FEM in COMSOL. The discussion of the analytical and numerical results yielded a number of important conclusions.

II. GOVERNING EQUATIONS

The steady-state heat conduction equation can be derived from the law of conservation of energy in the volume of a 1-meter length of the coated bus bar. One such volume element having the dimensions W_b, H_b and L_b=1 m is shown in Fig. 1. It is assumed that the materials of the bus bar and two sublayers are homogenous and isotropic, as well as that there is no longitudinal heat conduction in them. In addition, it is assumed that the heat Q_{tg} (in W) is generated within the given volume element and that the values of thermal conductivity k for the materials of the bus bar and two sublayers are constant.

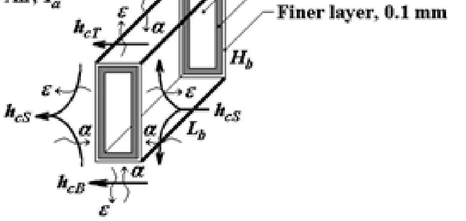

Figure 1. Heat transfer in the volume of a 1-meter length of the coated bus bar for typical outdoor conditions.

Accordingly, for the analytical analysis of heat transfer in a steady-state, the governing Eq. is [2]:

$$\alpha \cdot S_{pM} \cdot Q_{tsun,s} + Q_{tg}(T_{cpT}) = [2 \cdot h_{cS} \cdot S_S + \\ + h_{cT} \cdot S_T + h_{cB} \cdot S_B + h_r(T_{cpT}) \cdot S_{o1}] \cdot (T_{cpT} - T_a) \quad (1)$$

where $\alpha \cdot S_{pM} \cdot Q_{tsun,s}$ is a maximum amount of solar heat that can be absorbed by the outer surface of a 1-meter length of the bus bar in W, α is the solar absorptivity of the outer surface of the bus bar, S_{pM} is the maximum projected area of a 1-meter length of the bus bar in m^2, T_{cpT} is the tabulated continuously permissible temperature of the bus bar in °C (65 or 70°C), h_{cS} is the heat transfer coefficient due to the natural/forced convection between side surfaces of the bus bar and ambient air in W/(m^2·K), S_S is the surface area of one lateral side of the bus bar in m^2, h_{cT} is the heat transfer coefficient due to the natural/forced convection between the top surface of the bus bar and ambient air in W/(m^2·K), S_T is the surface area of the top side of the bus bar in m^2, h_{cB} is the heat transfer coefficient due to the natural/forced convection between the bottom surface of the bus bar and ambient air in W/(m^2·K), S_B is the surface area of the bottom side of the bus bar in m^2, h_r is the heat transfer coefficient due to the radiation heat exchange between the outer surface of the bus bar and ambient air in W/(m^2·K), S_{o1} is the outer surface area of a 1-meter length of the bus bar in m^2, and T_a is the temperature of the surrounding air in °C.

A situation corresponding to typical indoor conditions can be obtained by setting the solar absorptivity to α=0 and the wind velocity to v_w=0 m/s. This means that Fig. 1 and (1) will be simplified accordingly. For instance, the forced convection will be reduced to the natural one, solar radiation will be ignored, and so on. Further details on the analytical modelling of heat transfer in a steady-state can be found in [2].

The ampacities corresponding to central European indoor conditions are determined under the following assumptions [2,5,7]: (i) that the ambient air is still, i.e. v_w=0 m/s; (ii) that the surfaces of conductors are painted/coated giving an emission coefficient of ε=0.94 – for oil-based paint/coating and ε=0.88 – for epoxy-based paint/coating; (iii) that the surfaces of conductors are covered with an oxidised paint/coating layer together with a dirt layer over it giving an emission coefficient of ε=0.5; or (iv) that the surfaces of conductors are covered with a mixture of heavily-oxidised paint/coating, heavily-oxidised metal and dirt giving an emission coefficient of ε=0.7.

The ampacities corresponding to central European outdoor conditions are determined under the following assumptions [2,5,7]: (i) that the ambient air moves slightly, i.e. v_w=0.6 m/s; (ii) that the solar irradiance is $Q_{tsun,s}$=1000 W/m^2; (iii) that the surfaces of conductors are painted/coated giving an emission coefficient of ε=0.94 – for oil-based paint/coating and ε=0.88 – for epoxy-based paint/coating, as well as an absorption coefficient of α=0.7 – for oil-based paint/coating and α=0.94 – for epoxy-based paint/coating; (iv) that the surfaces of conductors are covered with an oxidised paint/coating layer together with a dirt layer over it giving an emission coefficient of ε=0.5 and an absorption coefficient of α=0.9; or (v) that the surfaces of conductors are covered with a mixture of heavily-oxidised paint/coating, heavily-oxidised metal and dirt giving an emission coefficient of ε=0.7 and an absorption coefficient of α=0.9.

In addition to the indoor and outdoor conditions, the scenarios tested in the analytical modelling ignore the effects of thermal conductivities of the two sublayers on the heat transfer processes. This is done for the reason that the potential effects can be identified after performing numerical simulations.

FEM calculations of steady-state temperature distributions over the two-dimensional (2D) domain in Fig. 1 are performed using the following Eq. [17]:

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + Q_v = 0 \ , \quad (2)$$

where x, y are Cartesian spatial coordinates in m; k is the thermal conductivity in W/(m·K); T is the temperature in K; and Q_v is the volume power of heat sources in W/m^3.

The volume power of heat sources in the bus bars with a geometric cross-sectional area of approximately $W_b \cdot H_b$ in m^2 is

$$Q_v = \frac{R_{ac}(T_{cpT})}{W_b \cdot H_b} \cdot I_{cp}^2 \ , \quad (3)$$

where $R_{ac}(T_{cpT})$ is the a.c. resistance per unit length of one bus bar at temperature T_{cpT} in Ω/m, and I_{cp} is the ampacity in A. In addition, there are no heat sources in the two sublayers over the conductor.

The numerical validation of the analytical model used for the case of natural or forced convection heat transfer is carried out in COMSOL [2], by performing a thermal FEM-based analysis of rectangular bus bars. The COMSOL Heat Transfer Module uses as input data some of the output data generated by the BUSBAR.m programme. For instance, the effect of the bus bar ampacity (the value of which is obtained by the BUSBAR.m programme) is taken via the volume power of heat sources located in the bus bar material. In addition to this, as boundary conditions, COMSOL also uses heat transfer coefficients due to the natural/forced convection and radiation generated by means of the BUSBAR.m programme.

III. Case Study

The case study 35/10 kV substation considered in this paper is located in the northern part of Bosnia and Herzegovina, in the Brčko District. This case study is presented in Figs. 2 and 3. Fig. 2 provides an actual image of the 35/10 kV substation, while Fig. 3 provides a simplified graphical representation of the outdoor and indoor bus bars used in this substation. In connection with this, the accent on controlling heat transfer along the outdoor and indoor bus bars using the surface radiation properties (i.e. solar absorptivity and thermal emissivity) is very important. For these purposes the oil-based and epoxy-based paints and coating are usually applied to the surfaces of bus bars.

As can be seen from Figs. 2 and 3, after installation the bus bars are usually coated with appropriate paints or coatings. Depending on the phase, the MV bus bars can be coated as follows: phase R – yellow, phase S – green, and phase T – purple. In addition, at the low voltage, neutral conductor N may be white, gray or black. Moreover, a neutral conductor that is not grounded can be coated with black and white stripes, and a neutral conductor that is grounded can be coated with black and purple stripes. Furthermore, plus and minus pole conductors in a dc circuit can be red and gray, respectively. All these paints and coatings are

Figure 2. A 35/10 kV substation in the Brčko District of Bosnia and Herzegovina *(sourcee: https://radiobrcko.ba/vijesti-brcko/u-toku-redovan-godisnji-remont-cvornih-trafo-stanica-u-distriktu/).*

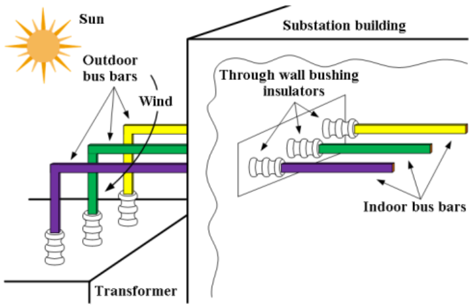

Figure 3. A simplified graphical representation of the outdoor and indoor bus bars used in the 35/10 kV substation from Fig. 2.

standard colors for metal which can withstand temperatures up to 100°C.

IV. Results and Discussion

The results of analytical and numerical simulations carried out for the case of indoor conditions are given in Table I, whilst Table II shows results of analytical and numerical simulations carried out for the case of outdoor conditions. Width W_b, height H_b, assumed current I_{ass}, and skin effect coefficient k_s for the considered bus bars are also given in Tables I and II. In addition, for purposes of comparisons, the ampacities of single bare bus bars with rectangular cross-sections from [2] were utilised. These ampacities are obtained for the same central European indoor and outdoor conditions and are provided in Tables I and II.

According to [2], the dc resistivity of the aluminium alloy 6101-T61 at 20 °C and its temperature coefficient are $2.998 \cdot 10^{-8}$ Ω·m and 0.00383 1/K, respectively. The thermal conductivity of 218.5 W/(m·K) is taken for the aluminium alloy 6101-T61. Initial values for the heat transfer coefficients due to natural and forced convection corresponding to the turbulent flow in the gases are assumed to be equal to 12 W/(m^2·K) and 300 W/(m^2·K) [2], respectively.

For the indoor installation of single rectangular bus bars, the analytical (using BUSBAR.m) and numerical (using COMSOL) simulations were carried out in accordance with [2], that is, for the following on-site conditions: installations with the vertical and horizontal major axes, T_{cpT}=70 °C, T_a=40 °C, v_w=0 m/s (natural convection), different values for thermal emissivity ε, solar absorptivity α=0, and frequency f=60 Hz. For the outdoor installation of single rectangular bus bars, the analytical and numerical simulations were carried out for the following on-site conditions: installations with the vertical and horizontal major axes, T_{cpT}=70 °C, T_a=40 °C, v_w=0.6 m/s (forced convection), different values for thermal emissivity ε, different values for solar absorptivity α, $Q_{tsun,s}$=1000 W/m^2, and frequency f=60 Hz.

TABLE I. AMPACITIES OF SINGLE BARE AND COATED BUS BARS WITH RECTANGULAR CROSS-SECTIONS OBTAINED FOR CENTRAL EUROPEAN INDOOR CONDITIONS. *

W_b	H_b	k_s at 70 °C / I_{ass} from [2] **	I_{cp} and T_{cp} ***							
			For ε=0.94 and α=0		For ε=0.88 and α=0		For ε=0.5 and α=0		For ε=0.7 and α=0	
			BUSBAR	*COMSOL*	*BUSBAR*	*COMSOL*	*BUSBAR*	*COMSOL*	*BUSBAR*	*COMSOL*
m / in	**m** / in	**-** / A	**A** / °C	**A** / °C	**A** / °C	**A** / °C	**A** / °C	**A** / °C	**A** / °C	**A** / °C
Bus bars installed with a vertical major axis										
0.00635 / 0.25	**0.0508** / 2	**1.014** / 545	**665** / 69.97	**664.4** / 70.00	**653** / 69.90	**656** / 70.00	**578** / 69.94	**581** / 70.00	**619** / 69.95	**624.8** / 70.00
0.009525 / 0.375	**0.1016** / 4	**1.100** / 1186	**1475** / 69.93	**1468.4** / 70.00	**1448** / 69.93	**1447.1** / 70.00	**1263** / 69.90	**1264.6** / 70.00	**1363** / 69.90	**1370** / 70.00
0.0127 / 0.5	**0.2032** / 8	**1.259** /2376	**3019** / 69.91	**3000** / 70.00	**2959** / 69.90	**2951.2** / 70.00	**2549** / 69.91	**2545.6** / 70.00	**2772** / 69.90	**2778.2** / 70.00
Bus bars installed with a horizontal major axis										
0.0508 / 2	**0.00635** / 0.25	**1.014** / 519	**643** / 69.98	**643.7** / 70.00	**631** / 69.93	**634.9** / 70.00	**553** / 69.98	**556.9** / 70.00	**595** / 69.93	**602.2** / 70.00
0.1016 / 4	**0.009525** / 0.375	**1.100** /1125	**1426** / 69.91	**1421.7** / 70.00	**1398** / 69.91	**1399.2** / 70.00	**1206** / 69.90	**1209.2** / 70.00	**1311** / 69.93	**1318.6** / 70.00
0.2032 / 8	**0.0127** / 0.5	**1.259** /2279	**2950** / 69.90	**2933.1** / 70.00	**2889** / 69.90	**2882.7** / 70.00	**2467** / 69.90	**2465.5** / 70.00	**2697** / 69.90	**2704.4** / 70.00

* For aluminium alloy 6101-T61 horizontally installed bus bars, T_a=40 °C, T_{cpT}=70 °C, v_w=0 m/s and f=60 Hz.
** For bare bus bars, ε=0.35 and α=0.
*** For coated bus bars.

TABLE II. AMPACITIES OF SINGLE BARE AND COATED BUS BARS WITH RECTANGULAR CROSS-SECTIONS OBTAINED FOR CENTRAL EUROPEAN OUTDOOR CONDITIONS. *

W_b	H_b	k_s at 70 °C / I_{ass} from [2] **	I_{cp} and T_{cp} ***							
			For ε=0.94 and α=0.7		For ε=0.88 and α=0.94		For ε=0.5 and α=0.9		For ε=0.7 and α=0.9	
			BUSBAR	*COMSOL*	*BUSBAR*	*COMSOL*	*BUSBAR*	*COMSOL*	*BUSBAR*	*COMSOL*
m / in	**m** / in	**-** / A	**A** / °C	**A** / °C	**A** / °C	**A** / °C	**A** / °C	**A** / °C	**A** / °C	**A** / °C
Bus bars installed with a vertical major axis										
0.00635 / 0.25	**0.0508** / 2	**1.014** / 675	**638** / 70.09	**632.5** / 70.00	**532** / 70.09	**531.7** / 70.00	**455** / 70.06	**456.4** / 70.00	**506** / 70.05	**512.8** / 70.00
0.009525 / 0.375	**0.1016** / 4	**1.100** /1278	**1163** / 70.09	**1148** / 70.00	**819** / 70.09	**812** / 70.00	**517** / 70.08	**512.4** / 70.00	**730** / 70.09	**732** / 70.00
0.0127 / 0.5	**0.2032** / 8	**1.259** /2190	**1829** / 70.09	**1796** / 70.00	**427** / 70.09	**355.8** / 70.00	**0** / >70.00	**0** / >70.00	**0** / >70.00	**0** / >70.00
Bus bars installed with a horizontal major axis										
0.0508 / 2	**0.00635** / 0.25	**1.014** / 675	**638** / 70.09	**632.5** / 70.00	**532** / 70.09	**531.7** / 70.00	**455** / 70.06	**456.4** / 70.00	**506** / 70.05	**512.8** / 70.00
0.1016 / 4	**0.009525** / 0.375	**1.100** / 1278	**1163** / 70.09	**1148** / 70.00	**819** / 70.09	**812** / 70.00	**517** / 70.08	**512.4** / 70.00	**730** / 70.09	**732** / 70.00
0.2032 / 8	**0.0127** / 0.5	**1.259** /2177	**1829** / 70.09	**1796** / 70.00	**427** / 70.09	**355.8** / 70.00	**0** / >70.00	**0** / >70.00	**0** / >70.00	**0** / >70.00

* For aluminium alloy 6101-T61 horizontally installed bus bars, T_a=40 °C, T_{cpT}=70 °C, v_w=0.6 m/s, wind direction parallel to bus bar axis, $Q_{tsun,s}$=1000 W/m^2 and f=60 Hz.
** For bare bus bars, ε=0.5 and α=0.35.
*** For coated bus bars.

Values of continuously permissible temperature of bus bars obtained in cases of indoor and outdoor conditions using BUSBAR.m and COMSOL differ from the temperature T_{cpT}=70°C by approximately ±0.1°C. Accordingly, the differences are negligible and represent a consequence of the specified accuracies.

According to Table I, it is evident that the coated bus bars, when there is no solar irradiance, have higher ampacities compared to the ampacities of bare bus bars of the same cross-sectional areas. The higher the thermal emissivity, the higher the bus bar ampacity. In addition, and also as expected, the larger the cross-sectional area, the higher the bus bar ampacity. Moreover, the larger the cross-sectional area, the higher the percentage difference between the ampacity of coated bus bars and the ampacity of bare bus bars. Furthermore, the percentage difference between the ampacities of coated and bare bus bars decreases with decreasing the thermal emissivity.

All the previous observations are valid for the results obtained using both BUSBAR.m and COMSOL. Any difference between the results obtained using BUSBAR.m and COMSOL is lower than 1%. This difference is the consequence of not taking thermal conductivity of the materials into account in the BUSBAR.m programme. Accordingly, with physical aging of the paint/coating layer and an increase in the level of contamination on the bus bar surface, it first leads to a decrease in the bus bar ampacity, and then to its increase. Therefore, it can be considered that a 0.3 mm thick layer, consisting of a mixture of heavily-oxidised paint/coating, heavily-oxidised metal and dirt, has a favourable effect on heat dissipation conditions from the surface of any bus bar to the environment.

Based on Table II, when there is solar heating, the coated bus bars have lower ampacities compared to the ampacities of bare bus bars of the same cross-sectional areas. As in the case of indoor conditions, the higher the thermal emissivity, the higher the bus bar ampacity. The bus bar ampacity increases with increasing the cross-sectional area of bus bars in the case only when the thermal emissivity (ε=0.94) is higher than the solar absorptivity (α=0.7). Moreover, the percentage difference between the ampacity of coated bus bars and the ampacity of bare bus bars increases with increasing the cross-sectional area of bus bars. When there is solar radiation, this difference increases with decreasing the thermal emissivity. In this particular case, all the differences between the results obtained using BUSBAR.m and COMSOL are lower than 3.3%. This is due to the fact that thermal conductivity of the materials is not taken into account by the BUSBAR.m programme.

According to Table II, the ampacity is zero for the bus bars having the largest cross-sectional areas and the solar absorptivity α=0.9. This means that the contribution from solar heating exceeds the improvement in heat dissipation due to wind from the surface of the bus bars to the environment. In connection with this, it is found that there is a contribution from solar heating that can heat up the bus bars up to T_{cpT}=70 °C and decrease the ampacity to zero. In the case where ε=0.5 and α=0.9, this would occur for $\alpha \cdot S_{pM} \cdot Q_{tsun,s}$=358.3 W/m^2. In addition, for ε=0.7 and α=0.9, the same would occur for $\alpha \cdot S_{pM} \cdot Q_{tsun,s}$=405.5 W/m^2.

The effect of physical aging of the paint/coating layer covering the bus bar surface on the ampacity has the same trend as in the case of indoor conditions. However, the bus bar ampacities from Table II (outdoor ampacities) are significantly lower than those from Table I (indoor ampacities). Therefore, in the case of outdoor installation, physical aging of the paint/coating layer does not have any favourable effect on heat dissipation from the considered bus bars to the environment.

V. CONCLUSIONS

The main conclusions that can be drawn from the presented results and discussion are as follows:

- It was successfully demonstrated that the physical aging of coated bus bars can be modelled analytically and numerically by the surface radiation properties and thermal conductivity of the layers/materials covering the bus bar conductors. The effectiveness of the proposed model is also ensured.
- The coating of bus burs with oil- and epoxy-based paints/coatings gives the possibility to increase the ampacity of the considered bus bars up to 29.44% for the central European indoor conditions. This applies only for new bus bars.

- The physical aging of coated bus bars, under the central European indoor conditions, can reduce the difference between the ampacities of the coated bus bars and the ampacities of the corresponding bare bus bars to 6.06-8.25%.

- It is found that, during the aging process under the central European outdoor conditions, the contribution from solar heating can exceed the improvement in heat dissipation due to wind from the considered bus bars to the environment.

- The physical aging of the paint/coating layer has a favourable effect on heat dissipation from the considered bus bars to the environment in the case of indoor installation rather than in the case of outdoor installation.

- It is also found that the thermal conductivities of the materials covering the considered bus bars have a negligible effect on the bus bar ampacity.

A priority for future work will be a more in-depth focus on: (i) thermal analysis of bare bus bars together with bus bars coated with oil- or epoxy-based coating, wrapped in mylar insulation, and surrounded by polyolefin shrink tubes, (ii) determination of cooling rate as a function of oil- or epoxy-based coating thickness, and (iii) generalisation of the proposed model for the aging of non-metallic coatings on bus bars.

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