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EXACT LOSS DETERMINING OF POWER STATION BUS DUCT SHELL WITH ISOLATED SHELLS AND PHASES BY CALCULATING OF INDUCED CURRENT IN COMSOL SOFTWARE ENVIRONMENT

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Abstract- Loss in the power station bus duct is one of the technical features of these equipment's, and one of their designing parameters. The high rate of loss in the bus duct shell causes the heat in the shell and reduction of the bus duct current capacity. Various analytic methods have been suggested to calculate this parameter. Whereas, the exact calculation of the shell loss is crucial with methods that are more effective and considering the triple-phases mutual effects, proximity effect, cortical effect, and bus duct exact modeling. In this paper, the impact rate of bus duct was identified and the induced current of every phase shell was calculated separately with different bus duct designing state by the actual modeling of every three-bus duct phase in the COMSOL software environment considering the time change and phases' current and also cortical effect. In the following, the overall electric loss rate was determined by simulation results. Eventually, the shell loss change curve was extracted based on the shell thickness, and the results were analyzed.

Keywords: Power Station, Bus Duct, Shell Loss, Phase and Isolated Shell, Induced Current, Simulation.

I. INTRODUCTION

In the electricity power stations, because of the high generator output current and constrains of cable use, from the current constrains perspective and economical constrains, bus duct is used to transfer the power toward the other equipment's. Bus ducts are usually designed under three methods, common metal shell with uncut phases, common metal shell with isolated phases, and phase-type bus duct with separate shell. A sample of bus duct separated phase is presented in Figure 1.

Designing, optimizing, and making bas ducts (especially the power station high current) are the exclusive technologies in electricity production. Making the bus ducts more economic and compact was among the scientists' ends in this field. Studies in the field of bus ducts are very vast and ongoing. For instance, there have been a large number of studies in the field of gas bus ducts. Furthermore, the discussion of Gas Insulated Lines (GIL) lies on this category.

Engineering and normative design of bus ducts is paid less attention, and only resembling of the foreign examples is being done. Meanwhile, determining the exact loss in the power station bus ducts is among the designing stages and is considered as one of the technical characteristics of the bus ducts. Determining the shells loss of the bus ducts, because of the behavioral complexities of induced current in the shell and because of mutual effects of triple-phases, should be done through appropriate and accurate methods, and approximate analytic methods do not suffice. In the following, after a brief explanation of the loss in bus ducts, simulation of the problem will be elaborated.

Figure 1. The bus ducts of IPB Pars Generator

II. ISOLATED PHASE BUS DUCTS (IPB)

Due to the high current rate of the power station generators, the produced heat in the main phase and in the bus duct shell is considerable. This is that important that in specific states (high currents and other necessities like installation space), artificial cooling systems are used in bus ducts. Power station bus ducts design has experienced various alterations during past years. Nowadays IPB bus ducts structures are such that non-magnetic materials like aluminum are used in the main phase and the shell. Consequently, heating in the main phase is only due to the current flow, and heating in the shell is only due to the induced currents and the sun radiation (in the outdoor installation state).

If the shell is made out of the magnetic materials, the losses due to flow and Eddy (Foucault) current should be considered. The amount of current loss in each continuous enclosure IPB system phase is calculated as follow:

$$W_{tot} = W_1 + W_2 + W_s \quad (1)$$

where, W_1 is the loss in the phase conductor influenced by the current I_r, W_2 is the loss in the crust influenced by I_e, and finally, W_s is the loss due to sun radiation in the outdoor installation state. Considering the indoor bus duct installation to be studied here, W_s is ignored. The amounts of W_1 and W_2 are calculated as follow:

$$W_1 = R_c \times I_r^2 \quad (2)$$

$$W_2 = R_e \times I_e^2 \quad (3)$$

where, I_r is the phase effective rated current (effective Ampere), R_c is the ac resistor of the phase conductor in the rated temperature of Ω, I_e is the induced current in the shell (effective Ampere), and R_e is the ac resistor of the shell in the rated temperature of Ω.

The amount of DC resistor, shell, and phase conductor length is calculated as follow:

$$R_{dc,20} = \frac{\rho}{\pi . d_m . t} \quad (4)$$

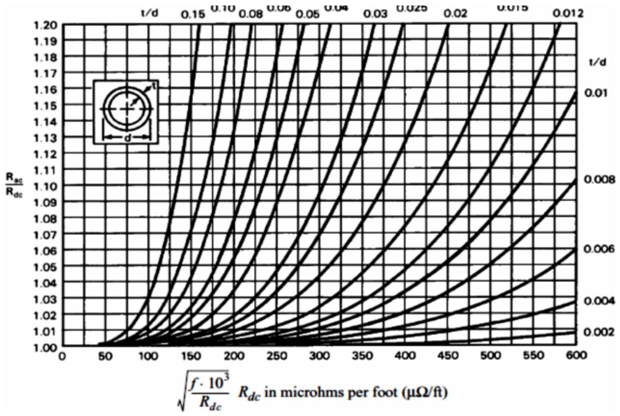

Figure 2. Determination of R_{ac}/R_{dc}

where, ρ is the specific conductor resistance on Ω/m in 20 centigrade degree, d_m is the medium tube thickness (m), and t is the tube thickness (m). According to Figure 2 and having the ratio of tube conductor t/d, it is possible to calculate R_{ac}/R_{dc} ratio.

Tube conductor is the best choice for the high current flow. In this type of the conductor, the density of the current is maximized on the conductor surface, and it gradually minimizes toward the center. In a certain profundity, the current density will be $1/e$ (0.368) of the surface current density, which is called profundity influence (δ_p). It is possible to prove that around 80 percent of the conductor losses occur up to this profundity. Profundity influence is calculated as follow:

$$\delta_p = \frac{1}{2\pi}\sqrt{\frac{\rho}{\mu . f}} \quad (5)$$

It is obvious that profundity influence relies on the material, frequency, and the temperature.

The final consequent of this problem is that since most of the current flows to the profundity influence, making the conductor thicker is just a raise in the cost. For aluminum tube conductor and frequency of 50 Hz, profundity influence in 20 centigrade degree is approximately 12 mm, and in the 85 centigrade degree is 14 mm.

III. CALCULATION OF INDUCED CURRENT IN BUS DUCT SHELL

Calculation of induced current in bus duct shell is a fundamental problem in determining the exact bus duct losses, and it needs an accurate analysis of the plan, and to determine it, it is possible to use approximate analytical methods. Analytical methods could be used for general problems though they are simple. Meanwhile, for an accurate design of a practical plan, which uses more complicated methods, it is crucial to calculate the induced current in all three phases accurately.

The amount of induced currents in all the three phases induced currents bus duct shells depends on bus duct density distribution of magnetic flow. For which more exact methods like magnetic field simulation must be applied considering the mutual triple-phases effects due to proximity effect (distribution alteration of the current and the neighboring floating current carrier conductors), and also magnetic coupling between the phase conductor and the shell. Furthermore, conductors shell effect should be considered for more determination that is accurate.

In the present paper, COMSOL software is used to determine the exact induced current in the bus duct shell. The bus duct studied here is the bus duct design of Ardebil post, and it is shown in the Tables 1 and 2. Considering the bus duct triple-phases mutual effects, all the three phases should be simulated. Furthermore, sinusoidal current must be calculated based on the time in all the three phases in order that the induced currents are calculated correctly. The shell effect of the conductors is also considered. The program used in the AC/DC module is like Magnetic, Vector, and Potential Perpendicular Induced Current. The solver is also selected transient so that it is possible to check the time domain.

Under the mentioned program, the currents flow vertically on the model's surface, and magnetic domains are calculable in both conductive and non-conductive materials. The formations of the phases on each other's sides on a line are considered (from left to right, Phase A, Phase B and Phase C). The surface current density is also considered like a three symmetric phases. The simulation time is selected equal to a cycle of 50 Hz and 20 ms. Time steps are also considered as 1 ms. The bus duct rated current equals to 800 effective Ampere (Figure 4 shows 1131 Ampere Peak).

The peak of the phases' currents is 1131 Ampere. The study of these results shows that the time changing of the magnetic density flow and the induced currents in the bus duct shell are sinusoidal. Phase difference between the phase current and the induced current in the shell is almost 90 degree. Peaks of the induced current in the triple-phases are respectively 126, 94, and 114 Ampere, which are 11.1, 8.3, and 10.1 percent of the peaks of the phases' currents.

Practically, due to the direction of the rotation of the current (and also the magnetic domain) in different spots, the magnetic domains neutralize the effects and cause a different behavior in the induced currents of phases' shell.

Table 1. The general characteristics of Ardebil power station bus duct

Formation	Isolated Phases
Voltage	17.5 kV
rated current (50 Hertz)	800 Ampere
the distance between the phases	640 mm
Momentary peak of circuit	500 kA
Short-time rated current (1 second)	200 kA
The designed environment temperature	44 centigrade degree
The maximum conductor temperature	105 centigrade degree
The maximum shell temperature	85 centigrade degree

Table 2. The studied bus duct parts characteristics

The main conductor	Material	Aluminum 99.5%	
	External Diagonal	100 mm	
	Thickness	10 mm	
	Segment Area	2827 square millimeters	
	Weight	7.65 kilograms per meter	
Shell		Material	Aluminum 99.5%
		External Diagonal	480 mm
		Thickness	3 mm
		Segment Area	4496
		Weight	12.65 kilograms per meter
Insulator		Material	Porcelain

The point to be discussed in the amount of the bus duct shell induced current is the impact rate and considering the reinsurance insulator model in the results (μ = 1). The scrutiny of the results show that when ignoring the insulator model, the peak of the induced current of the triple-phases reaches to 140, 100, and 120 Ampere which differs slightly from the basis state (Figure 5). In the designing of the power station bus duct, the main conductors and shells' radiuses, and conductors and shells' thickness are of utmost importance.

The thickness and the radius of the conductor is determined based on the mechanical constrains and the flow capacity (permanent and short circuit state). There are four case studies here. In the first case, the internal radius of the phase conductor remains the same and the external radius increases (the increase of the thickness twice as big as the basis state toward the shell). In the second case, the external radius of the main phase remains the same and the internal radius decreases (the thickness increases twice as big as the basis state toward the center).

In the first state, with the increase of the main conductor thickness (twice as big as the basis state), the amount of the induced currents reduces 50, 53, and 53 percent respectively. This expresses that with the increase in the segment area of the main conductor, the current is distributed in a wider area, and the density of the main conductor decreases. This even compensated the decreased distance between the phase main conductor and the shell (which principally causes the increase in the induced current in the shell).

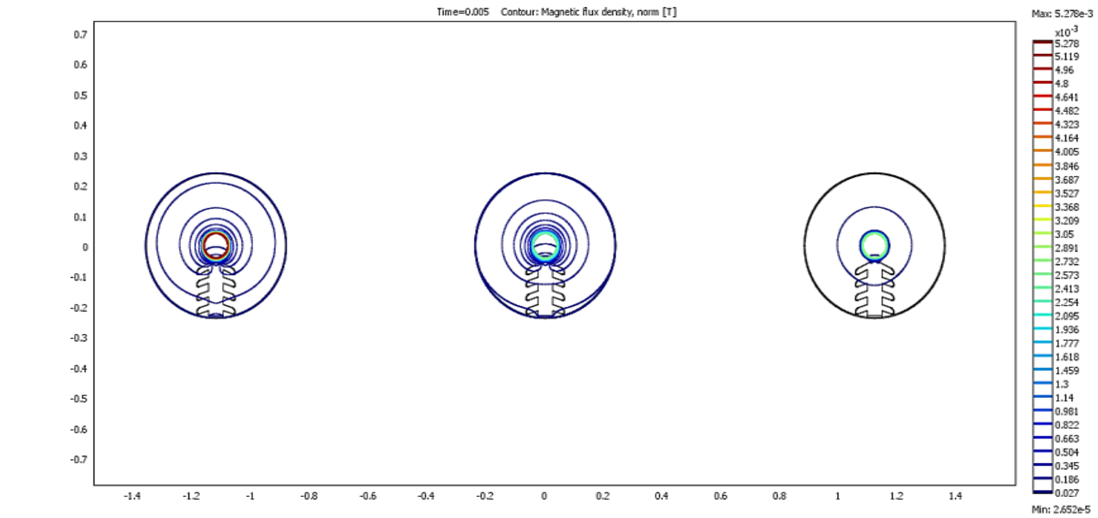

Figure 3. Basic position of t = 5 ms

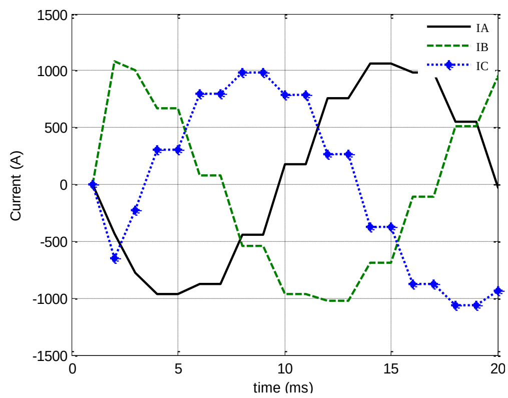

Figure 4. The real bus duct in basic position

In the second state, the segment area is increased and the distance between the main conductor and the shell has remained the same. The decrease has also grown in the induced currents up to 60, 61, and 61 percent. In the third state, with the increase of the thickness of the shell toward the center of bus duct (in which the distance between the main conductor and the shell has decreased), the amount of the induced currents increase 21, 12, and 17 percent which is a considerable increase compared to basis state.

Now the fourth state will be scrutinized. In this state, keeping the phase shell thickness fixed, the internal radius is increased. Figure 6 shows the result in this state.

It shows that in the beginning of the shell thickness increase, the increase of the induced current is perceptible. Then the gradient flow decreases and after a certain thickness, the induced current will stay fixed. The final point out of the scrutiny of the induced currents in the shells shows that based on the final goal of decreasing the induced currents in the shells, it is necessary to increase the main conductor's thickness and decrease the shell's thickness.

Table 3. The comparison between the induced currents in the phases shells in different sates

	I_{eC}	I_{eB}	I_{eB}
Basis state	114	94	126
First state	53.5	44	61.5
Second state	44.5	36.5	51
Third state	133.5	105	151.5

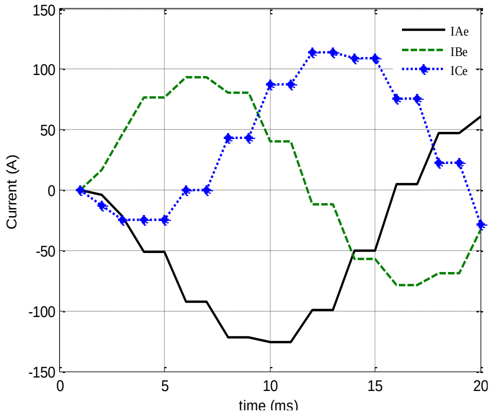

Figure 5. The real Bus duct with reinsurance insulator model in results (μ=1)

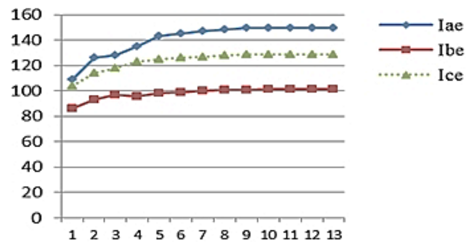

Figure 6. The variation of shell thickness to induced current (Ampere) The horizontal axis is shell thickness and the vertical axis is to induced current (Ampere)

The direction of these changes is important because it changes the effectiveness of the so-called change. For this, the increase of the main conductor thickness must be toward the bus duct center (the external radius of the main conductor remains fixed) and decrease of the shell thickness toward the outside of the bus duct (the external radius of the shell remains fixed) so that the effectiveness of these changes increase. However, the increase of the cost must be considered when increasing the thickness.

IV. DETERMINING THE LOSSES IN BUS DUCT SHELL CONSIDERING INDUCED CURRENT IN TRIPLE PHASE SHELL

One of the bus duct designing necessities is that the bus duct losses must be minimized. This is why the losses rate should be determined accurately. Calculation of the losses of main conductor is rather simple, however, calculation of the losses in the shell is more difficult due to the complex calculation of the induced currents. To calculate the exact rate of losses, we the following could be performed. Based on the Equations (1) to (3), the following equation for overall loss in the shell is obtained:

$$W_{tot} = k_e \times \frac{\rho}{\pi . d_{me} . t_e} \times I_{eA}^2 + k_e \times \frac{\rho}{\pi . d_{me} . t_e} \times I_{eB}^2 + k_e \times \frac{\rho}{\pi . d_{me} . t_e} \times I_{eC}^2 \qquad (6)$$

where, k_e is the ratio of R_{ac}/R_{dc} in the shell conductor which is identifiable from Figure 2. I_{eA}, I_{eB} and I_{eC} are also the (effective) induced currents for phases A, B, and C. To determine the equation between the overall losses, we perform as follow. First, the amount of R_{dc} should be determined. Then the amount of K_e is determined, and according the last equation the overall loss graph will be drawn. In this state, the shell internal radius is kept fixed.

Figure 7 shows the final result of the loss determination in the bus duct shell based on the shell thickness. At first, a dramatic fall is observed; however, the fall intensity reduces gradually and finally it starts growing in the thickness of 14 millimeters.

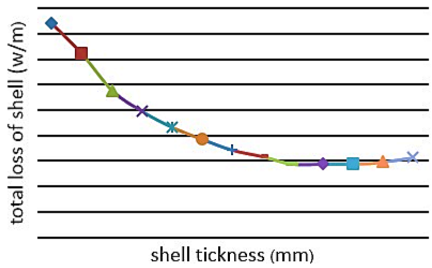

Figure 7. Variation of shell thickness to total loss of shell

The losses rate in each bus duct phase shell is proportionate to the square of the effective induced current in that phase, and is also proportionate to its ac resistor. On the other hand, when shell thickness increases, the t/d ratio also increases. This causes the increase in the shell effect coefficient. Besides, according to Figure 6, induced current equation in shells and their thickness is in way that after certain thickness, gradient induced current is reduced.

Eventually, it could be claimed that in low thicknesses, the decreasing effect is dominant (in comparison with the increase of the induced current and also the increase of the shell effect coefficient) and causes a perceptible decrease in the losses. In the higher thicknesses, when the shell effect coefficient reduces, the intensity of the decrease also reduces and even there would be a relative increase of the losses in the higher thicknesses.

V. CONCLUSIONS

The present paper has intended to go through an accurate determination of the bus duct losses in Ardebil power station considering the shell effects, triple-phase modeling, and time changes in the phases' currents. The results show that the phase difference between the phase current and the induced current in the shell is about 90 degrees. The peak of the induced current in basis state of the triple-phases is approximately 11.1, 8.3, and 10.1 percent of the phases' current peak. Practically due to the proximity effect, the magnetic domains neutralize or improve each other's effects and cause a different behavior of the induced currents in the triple-phases shells. Reviews have shown that considering the insulator model has a low influence on the simulation results.

Furthermore, it is crucial to increase main conductor thickness and decrease the shells thickness considering the goal to decrease the induced currents in the shells. To do this, the main conductor thickness must be toward the bus duct center (keeping the main conductor's external radius fixed) and the shell thickness decrease must be toward the outside of the bus duct (keeping the shell's external radius fixed) so that the impact of these changes grows more.

Eventually, the overall loss of the shells based on the shells thickness is deduced from the simulation results of the shells. Results show that with the increase of the shells thickness, the amount of the losses show a considerable decrease at first, then the density of decrease will reduce, and finally it starts a gradual increase in a certain thickness.

The results of this paper could be an effective method to calculate the induced currents in the bus duct shells and to scrutinize the parametric designing effect on its amount, and also to determine the shells loss accurately, and even minimizing the loss in these equipment's.

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BIOGRAPHIES

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