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On the Electromagnetic Stress Impact on the Synchronous Generator Structural Dimensions and Efficiency

Structural dimensions as well as the ability to safely operate in often transient processes or short emergency situations are usual customer requirements. These requirements can be fulfilled already in the design phase by careful selection of electromagnetic stress values (current layer, air gap magnetic displacement).This work contributes to finding optimal values for the above mentioned stresses such that customer requirements are fulfilled

Keywords: *criterion, main variable, current layer*

1. Introduction

To design synchronous generators an engineer starts from its nominal data and follows certain steps well established in the professional literature. Often enough the designer has to choose among various charts or to set certain constraints on electromagnetic stresses or other coefficients. The choice of a particular value results in a particular generator which, in the end, may not fulfill the objective function.

Employing computers in this design activity, by using special optimal design programs, facilitates the parameter value choice such that an optimal synchronous generator is realized [1].

2. Theoretical considerations in optimal designs of synchronous generators

The optimal design program that we employ follows the exhaustive search method [6] and uses mathematical models described in the professional literature. The exhaustive search method is shortly presented in [4].

The main variables used in the optimal design algorithm are: $D, A, B_\delta, \delta, t_1, J_1, \beta_{c1}, B_{j1}, B_{j2}, J_a, J_e, h_{02}, b_{02}$.

The analyzed criteria C_{it} in this work are defined as [5]:

$$C_{it} = f\left(A, B_\delta\right) \quad (1)$$

with minimum restrictions of the kind:

$$C_{it\min} = C_{ito} \leq C_{itc} \quad (2)$$

or maximum restrictions of the kind:

$$C_{it\max} = C_{ito} \geq C_{itc} \quad (3)$$

where C_{ito} is the value of the chosen criterion obtained with the optimal design, and C_{itc} is the value of the chosen criterion obtained with the classical design.

In this work we present the results obtained by an optimal design with the current layer and air gap magnetic displacement as main optimization variables. The hereby shown optimization uses the structural and the safety criteria.

3. An example of exhaustive search design optimization for a synchronous generator

The nominal data used with this optimization method are: apparent output S_n = 350 kVA, rated speed n = 300 rot/min., rated voltage U_n = 400 V, and the power factor $cos\varphi$ =0.85. During the design we have taken that the generator is operating non-interruptedly, S1, its operating life being 15 years, and that it operates autonomously. This fact increases the interest on how flask currents behave.

The employed resources costs as well as the electricity costs employed in computing the total generator's costs are: c_{Fe} = 15 € – cost of a 1 Kg iron, c_{Cu} = 45 € – cost for 1 Kg copper, c_{ela} = 0.1 € – cost for 1 kWh energy, and c_{elr} = 0.03 € – cost for 1 kVARh quadergy.

The classic design has led to the following optimization main variables values: current layer A = 324.311 A/cm, air gap magnetic displacement B_δ = 0.763 T. In the literature the current layer range for external poles generators is (200÷500) A/cm, while the air gap magnetic displacement range is (0.6÷0.9) T [3]. The main optimization variables range between -30% and 15% in comparison with the classical design variable values [5]. Thus, the current layer A range is (230÷370) A/cm and the air gap magnetic displacement range is (0.53÷0.89) T. The design optimization algorithm has given us the following optimal values of the main variables: A_o = 369.66 A/cm, $B_{\delta o}$ = 0.759 T. This shows a 14% increase in the current layer and a 0.524% decrease in the air gap magnetic displacement.

The charts below are realized using MathCad [1]. On these charts we have marked with a yellow dot the classic design variable values, with a red dot the optimal value, and with a green or blue dot the worst variable values.

The structural criterion we have chosen to do optimizations on may aim at optimizing the generator's structural dimensions and mass. When we choose the outer length L_e to be the optimization criterion (may well be a customer request) and, at the same time, fulfill all the main variable constraints, we obtain the response surface shown in Figure 1.

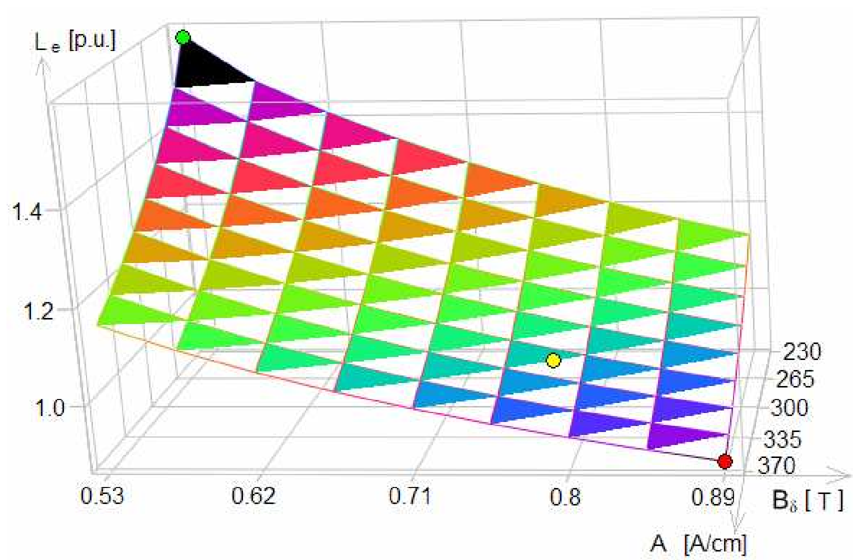

Figure 1. Outer length response surface

For this generator design the minimum outer length is obtained when the current layer A and the air gap magnetic displacement B_δ are maximum in the specified ranges. The minimum outer length is only 80% of the outer length in a classic design. Taking the minimal range values for the analyzed requirements we see a 58% increase in the generator's outer length.

Requiring the generator's outer diameter D_e to be minimum (may be a customer requirement) we can answer to this request by taking the minimal range values for the current layer A and air gap magnetic displacement B_δ.

Figure 2 shows that the outer diameter decreases by 3% compared to those in the optimal computations. This value is obtained by choosing minimal electromagnetic stresses. Choosing maximal values for the main variables gives an only 0.8% increase in the outer diameter.

Another technical optimization criterion is the generator's whole mass m_t whose respond surface is shown in Figure 3.

A minimal generator total mass is obtained when the current layer takes the maximum value in the accepted range (A=370 A/cm) and the air gap magnetic displacement (B_δ =0.53 T). These value give a 10% decrease in the generator's total mass.

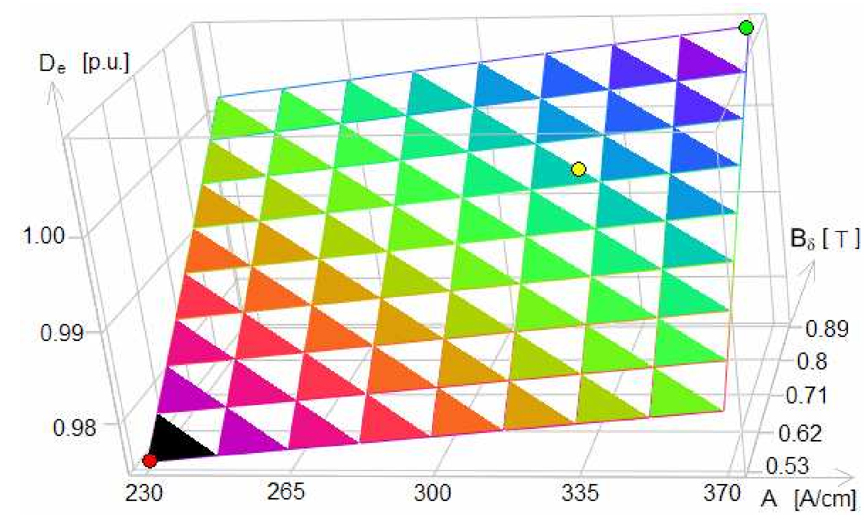

Figure 2. Outer diameter response surface

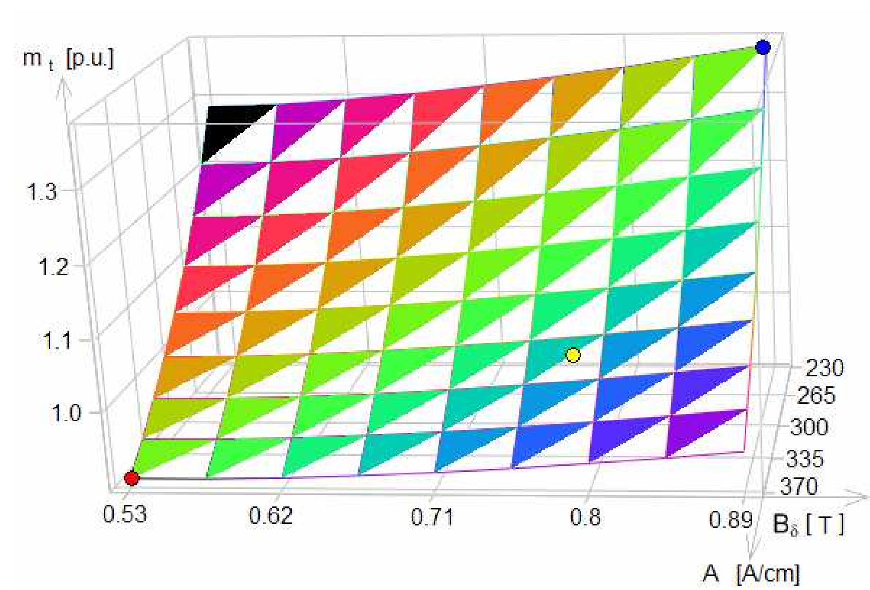

Figure 3. Total mass response surface

The highest total generator mass (30% greater than the classically designed generator) is obtained when the current layer takes the minimum value in the range (A=230 A/cm) and the air gap magnetic displacement takes the maximum value in the range (B_δ=0.89 T).

When the technical criterion is defined depending on the generator's efficiency, the response surface is shown in Figure 4.

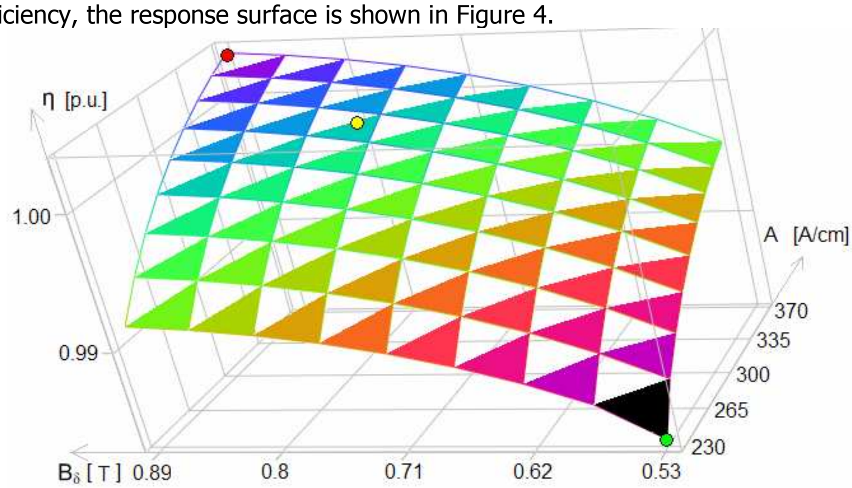

Figure 4. Efficiency response surface

A 0.3% efficiency increase is possible when the two main variables take maximal values in the accepted ranges. Minimum variable values lead to a 1.6% efficiency decrease when compared with the classically designed generator.

Safety criterion is very important in a correct operation of the synchronous generator in transient regimes or during short time emergencies.

Figure 5 shows the surge current $I_{şoc}$ response surface, also named maximum current, which we used to define the safety criterion. The values in Figure 5 are to be read in relation to the nominal current I_n.

In a classic design, the surge current is about $14.4 \cdot I_n$. We can obtain a value below 10% of the nominal surge current when the current layer takes the minimal value and the air gap magnetic displacement is minimal.

A minimal current layer value, corroborated with a high air gap magnetic displacement can lead to a $22 \cdot I_n$ surge current value, which exceeds the maximum value allowed (max. $21 \cdot I_n$).

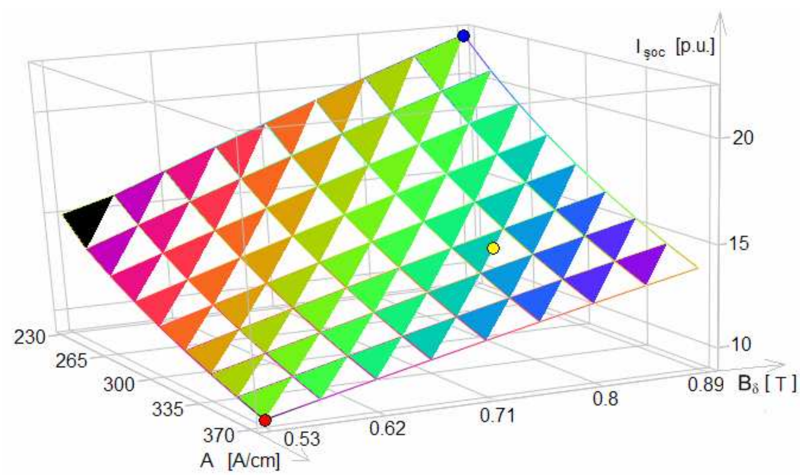

Figure 5. Surge current response surface

Another safety parameter which can be used in the optimization process is the one-line-to-earth flask overtransient current which, in this situation, has a higher value than other schort-circuits.

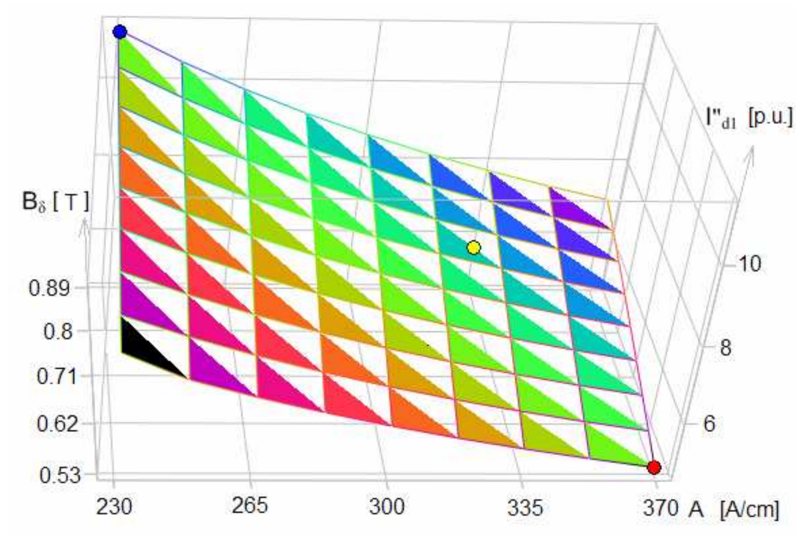

Figure 6. Response surface for the one-line-to-earth flask overtransient current

Figure 6 shows the one-line-to-earth flask overtransient current response surface the values being reported to the nominal current. In the classical design, the value of this current is $7.35 \cdot I_n$.We see in this plot that the minimal value for this current is when the current layer is high (370A/cm) and the air gap magnetic displacement is small (0.53T).

4. Conclusion

Examining the plots in Figures 1 and 2 we can conclude that the current layer A the air gap magnetic displacement B_δ values have a small impact on the generator's outer diameter, but a strong impact on its length.

Besides determining lower generator costs, the current layer and air gap magnetic displacement also lead to a higher efficiency [4].

Satisfying the objective function in the situations presented in this work can be done when the current layer is maximum and the magnetic displacement is minimum. These conclusions can significantly aid the synchronous generators designer to obtain a generator with respect to a certain objective function.

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