RESEARCH ON DECREASING THE COST PRICE FOR THE SYNCHRONOUS HYDROGENERATOR

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REZUMAT. Preţul de cost al unui hidrogenerator este sensibil influenţat de parametrii constructivi adoptaţi sau calculaţi. Cele mai importante variabile care intervin in proiectarea generatorului sincron destinat microhidrocentralelor, sunt pătura de curent, densitatea de curent din înfăşurarea statorică şi mărimea întrefierului. În lucrare s-a analizat, influenţa variabilelor menţionate asupra costului generatorului sincron, pentru hidrogeneratoare având aceeaşi putere dar cu turaţii diferite. Concluziile rezultate oferă informaţii esenţiale pentru etapa de proiectare a hidrogeneratoarelordestinate MHC.

Cuvinte cheie: generator sincron, turaţie, proiectare optimală, cost total, parametri optimi. (Maximum 1 rând)

ABSTRACT. A hydrogenerator's cost price is considerably influenced by the used and computed design values. The most important parameters in the design of micro hydro power plants synchronous generators are the power blanket, the current density in the statoric winding and the air gap size. In this work we analyze the impact of these parameters on the cost price for a family of hydro power plant synchronous generator where the power is the same but the rotations vary. The conclusions we take offer information essential to the design phase of these micro hydro power plant hydrogenerators.

Keywords: synchronous generato, rotation, optimal design, total cost, optimal parameters

1. INTRODUCTION

Taking into account the European requirements regarding the material and energy restrictions [1] optimal design becomes an essential part in fulfilling this desideratum.

When designing hydrogenerators the values chosen for its various parameters define its operating performances. In the optimal design we chose the objective function that minimizes the total cost, C_t. This cost is computed as the sum of the manufacturing cost, C_f, and the exploitation costs, C_f [2].

After a detailed analysis we found that for a hydrogenerator equiping a micro hydro power plant of 353 kVA the most impact on the objective function is made by the following parameter combinations: the power blanket A and the air gap size δ, (a cost decrease of 20%); and the current density in the statoric winding J_1 and the air gap size δ (a cost decrease of 20.04%) [3].

Starting with various parameter combinations, we analyze in this work the impact the rotation has on the total cost when the hydrogenerator's power is maintained constant and the initial variables are revised. For this we implemented the Complex optimal design algorithm. We chose the $(0,7\cdot\overline{x}\div1,2\cdot\overline{x})$ variation range for the values of the initial parameters of the existing hydrogenerators [3].

We compared the variable values and the afferent costs for seven classic synchronous hydrogenerators to the variable values and costs obtained using the optimal design. The seven studied micro hydro power plants hydrogenerators have a power of 300 kVA and 400 V voltage, a 50 Hz frequency, a 0.85 power factor and differ in their operating rotations: 250, 300, 375, 500, 600, 750, and 1000 rot/min.

2. OPTIMIZING ON THE POWER BLANKET AND THE AIR GAP SIZE

While desigining a hydrogenerator, its parameter values are chosen according to the design specific literature chosen, to the design algorithm and to the designer's expertise. The design manuals recommend that the power blanket ranges between 180 and 640 A/cm, for a polar pitch variation between 150 and 700 mm.

The polar pitch size depends on the hydrogenerator inner diameter [4,5]:

$$\tau=\frac{\pi\cdot D}{2\cdot p} \tag{1}$$

while the diameter's value depends on the number of pole pairs, p, and the rotation:

$$D = 100 \cdot \sqrt[3]{\frac{2 \cdot p}{\pi \cdot \lambda} \cdot \frac{60 \cdot S_{iN}}{n \cdot C}} \quad (2)$$

We know that the number of pole pairs depends on the turation:

$$f = p \cdot n \quad (3)$$

The specific design literature presents two methods to compute the size of the air gap:

- Expressing the ratio δ/τ depending on the power blanket and the air gap magnetic induction B_δ, which, for the external poles synchronous machines with variable air gap below the polar step, the air gap is defined by [6]:

$$\frac{\delta}{\tau} = 0,3 \cdot \frac{A}{B_\delta} \cdot 10^{-4} \quad (4)$$

- Imposing that the longitudinal synchonous reactance, x_d, takes values between 1 and 1.6 p.u., that the dispersion reactance, $x_{\sigma 1}$, takes values between 0.08 and 1.13 p.u. and for the air gap coefficient, k', takes values between 1.05 and 1.1 for the steel rotoric sider [7,8]:

$$\delta = \frac{0,36 \cdot 10^{-4} \cdot A \cdot \tau}{k' \cdot (x_d - x_{\sigma 1}) \cdot B_\delta} \quad (5)$$

The air gap value given by relations (4) or (5) is rounded up every 0.25 mm, these values being those to be used in the subsequent design computations [4].

Recalling that both the current blanket and the air gap magnetic induction values are first estimated based on the pole pitch and number of pole pairs, we immediately see that the rotation influences the air gap size.

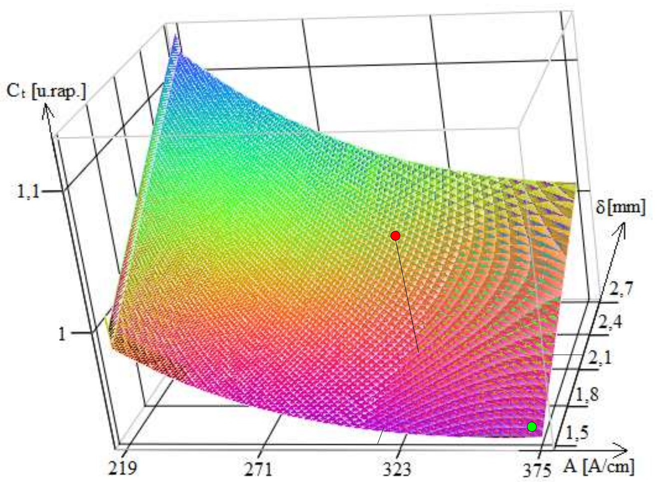

Fig. 1. Total cost variation depending on the current blanket and the air gap size for the 250 rot/min hydrogenerator.

For the 300 kVA hydrogenerator designed to operate at 250 rot/min, the optimal current blanket value is 15.183% higher than the reference values, and – at the same time – the optimal value for the air gap size is with 30% smaller than the reference value. These lead to a manufacturing cost decrease of 13.71%, exploitation cost decrease of 7.253%, and a total cost decrease of 8.063% compared to the reference hydrogenerator's costs. Values of the total cost as determined by the analyzed parameters are shown in Fig. 1; all numerical values are computed 'per unit'.

All figures in this work show a red dot for the reference hydrogenerator's initial cost value, and a green dot for the optimal design values.

Optimally designing the 300 rot/min hydrogenerator shows the same 30% decrease in the air gap size. This decrease obtained for all other hydrogenerators studied in this work, and will not be mentioned explicitly anymore.

The power current blanket increases with 11.923%. Choosing these optimal values lead to a decrease of 16.973% in the manufacturing costs, a decrease of 7.942% of the exploitation costs, and a 9.15% decrease of the total costs, compared to the reference hydrogenerator (Fig. 2).

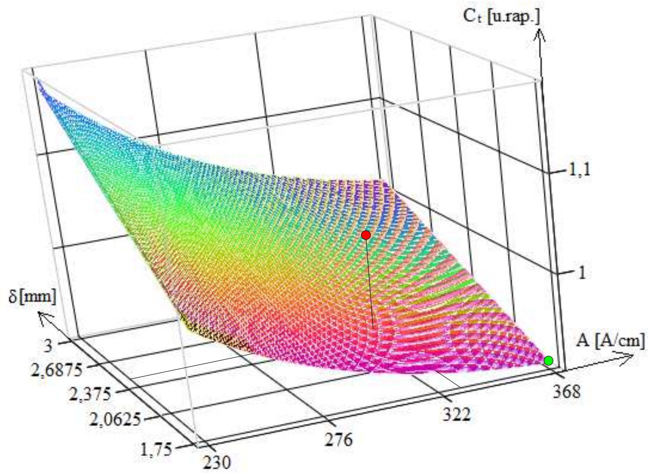

Fig. 2. Total cost variation depending on the current blanket and the air gap size for the 300 rot/min hydrogenerator.

Looking at the 375 rot/min hydrogenerator we observe an increase of the current blanket optimal value of 12.41% compared to the same parameter measured in the reference generator. The analyzed optimal values lead to a 15.923% manufacturing cost decrease, a 6.555% exploitation cost decrease, and a 7.697% total cost decrease compared to the same costs for the same nominal data reference hydrogenerator (Fig. 3).

Optimally desgining the 500 rot/min hydrogenerator shows a current blanket value increase of 19.833% compared to the reference value, and leads to the manufacturing cost decrease of 20.394%, the exploitation cost decrease of 8.288%, and the total cost decrease of 10.02% (Fig. 4).

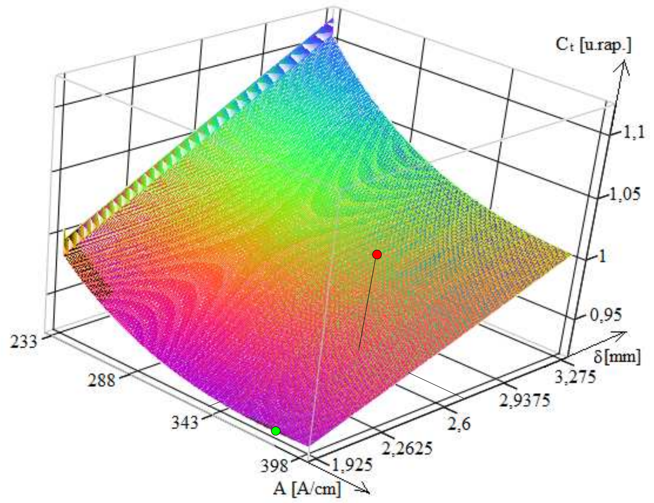

Fig. 3. Total cost variation depending on the current blanket and the air gap size for the 375 rot/min hydrogenerator.

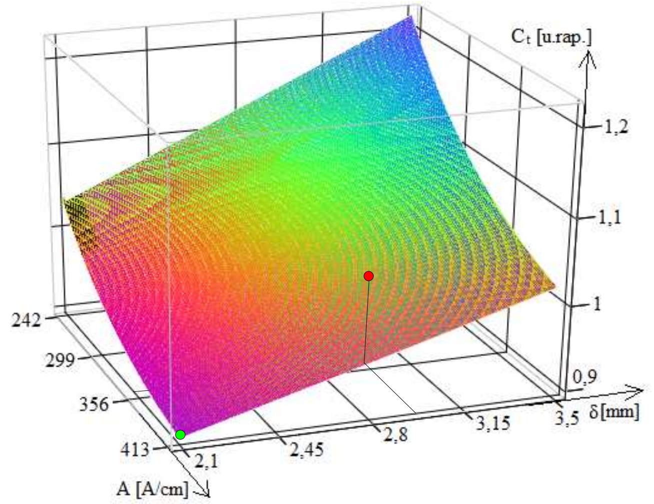

Fig. 4. Total cost variation depending on the current blanket and the air gap size for the 500 rot/min hydrogenerator.

The current blanket optimal value for the 600 rot/min hydrogenerator is with 19.896% higher than the reference value and leads to a 17.384% manufacturing cost decrease, a 9.188% exploitation cost decrease and a 10.241% total cost decrease (Fig. 5).

The optimal current blanket value increase for the 750 rot/min hydrogenerator is similar to the optimla value increase observed in the 600 rot/min hydrogenerator (19.862%). This value leads to the following decreases in the manufacturing, exploitation, and total costs: 19.756%, 7.922%, and 9.756% (Fig. 6).

The hydrogenerator designed to operate at 1000 rot/min has an optimal current blanket increase of 19.834% leading to a 19.861% manufacturing cost decrease, a 7.7% exploitation cost decrease, and a 9.255% total cost decrease (Fig. 7).

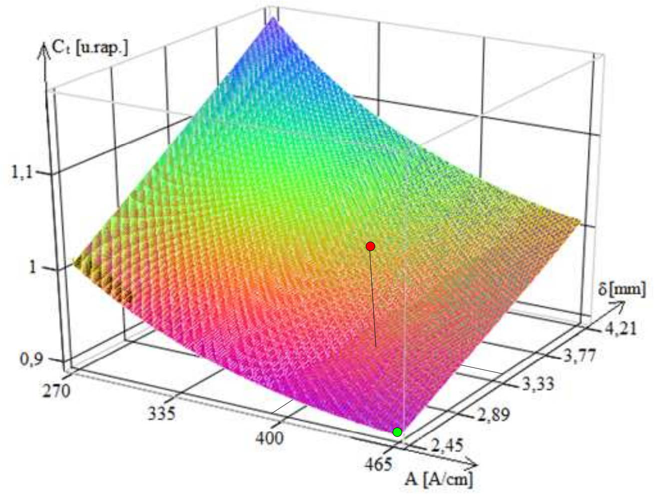

Fig. 5. Total cost variation depending on the current blanket and the air gap size for the 600 rot/min hydrogenerator.

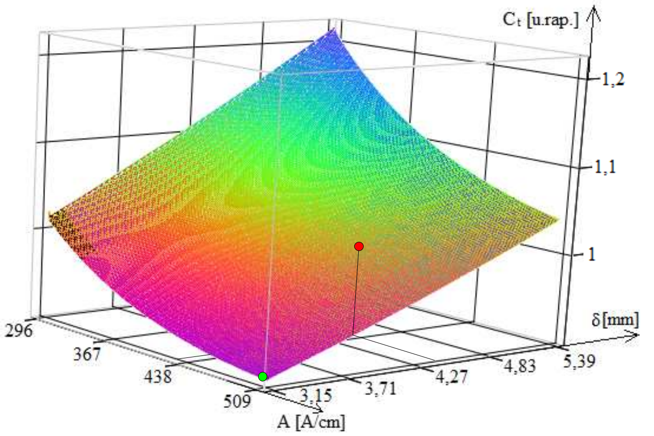

Fig. 6. Total cost variation depending on the current blanket and the air gap size for the 750 rot/min hydrogenerator.

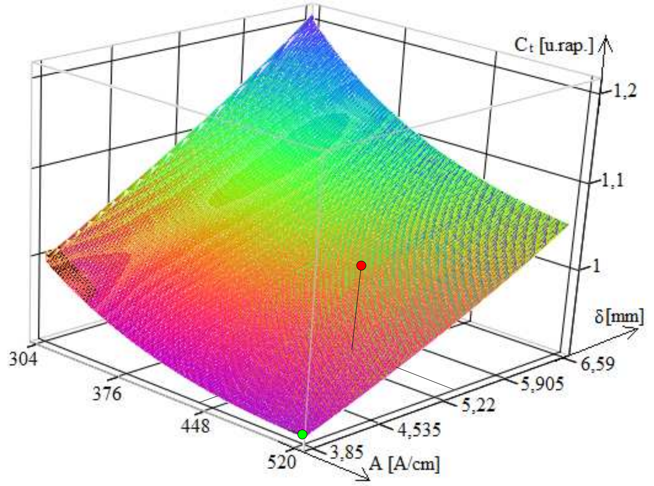

Fig. 7. Total cost variation depending on the current blanket and the air gap size for the 1000 rot/min hydrogenerator.

3. OPTIMIZING ON THE STATORIC WINDING CURRENT DENSITY AND THE AIR GAP SIZE

To study how the density in the statoric winding and the air gap size impact the design of a hydrogenerator we used the same optimization program and algorithm as the one mentioned above, and chose the same variation range, (0.7 ÷ 1.2), to vary the initial design parameters.

The specific generator design literature recommends that, for low voltage machines, that is U_n<1000 V, the current density in the statoric winding, J_1, must be in the (5.5 ÷ 7.5) A/mm^2 range [2,4,5].

Compared to the initial values of the 300 kVA, 250 rot/min hydrogenerator, the air gap size optimal value decreases by 30%. The current density in the statoric winding decreases by approximately 30%.

These two optimal values cause a slight increase of 0.535% in the manufacturing cost, and decreases in the exploitation costs (20.057%) and total costs (17.473%), see Fig. 8.

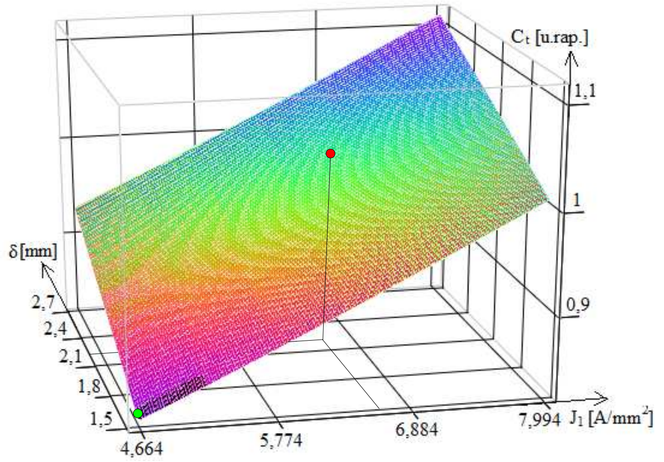

Fig. 8. Total cost variation depending on the statoric winding current density and the air gap size for the 250 rot/min hydrogenerator.

We observe the same 30% decrease of the two parameters of interes for all optimally designed generators studied in this work.

For the 300 rot/min hydrogenerator, the optimal parameter values lead to 0.434% decreases in the manufacturing costs, 18.66% decrease in the exploitation costs, and 16.227% total costs decrease compared to the initial values (Fig. 9).

The 375 rot/min hydrogenerator optimal design leads to a manufacturing cost decrease of 1.388%, of the exploitation costs of 18.365%, and of the total cost of 16.294% (Fig. 10).

The optimal design parameter values for the 500 rot/min hydrogenerator lead to the manufacturing cost decrease of 4.559%, the operating cost decrease of 18.509%, and the total cost decrease of 16.294% (Fig. 11).

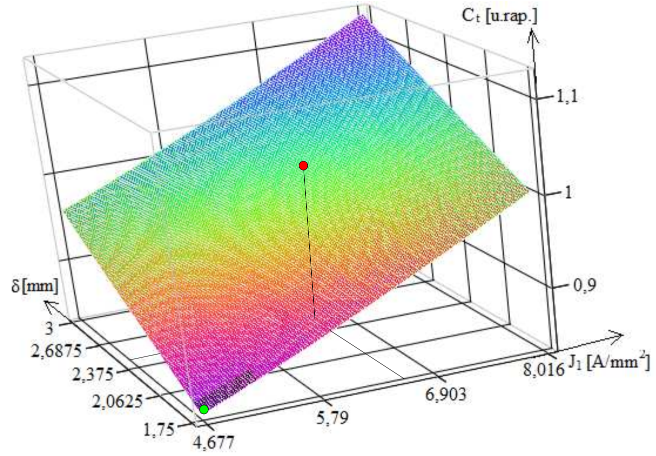

Fig. 9. Total cost variation depending on the statoric winding current density and the air gap size for the 300 rot/min hydrogenerator.

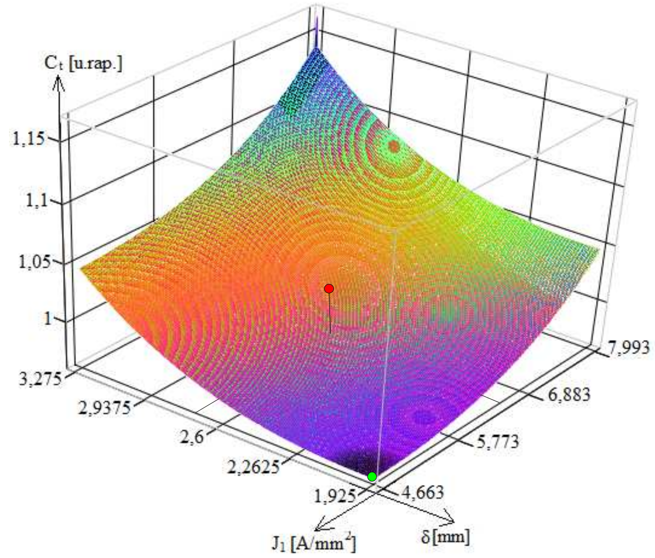

Fig. 10. Total cost variation depending on the statoric winding current density and the air gap size: the 375 rot/min hydrogenerator.

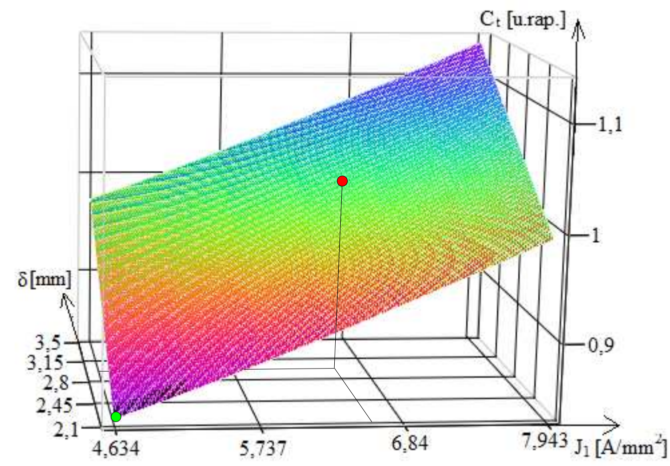

Fig. 11. Total cost variation depending on the statoric winding current density and the air gap size: the 500 rot/min hydrogenerator.

The optimal design of the 600 rot/min hydrogenerator leads to a manufacturing cost decrease of 1.47%, of the operating cost decrease of 21.839%, and the total cost decrease of 19.224% (Fig. 12).

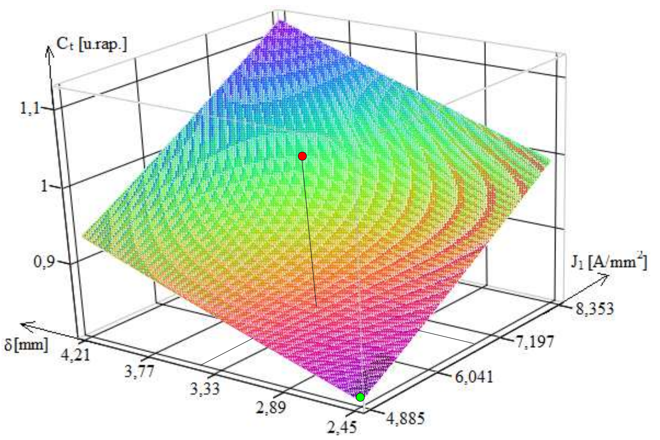

Fig. 12. Total cost variation depending on the statoric winding current density and the air gap size: the 600 rot/min hydrogenerator.

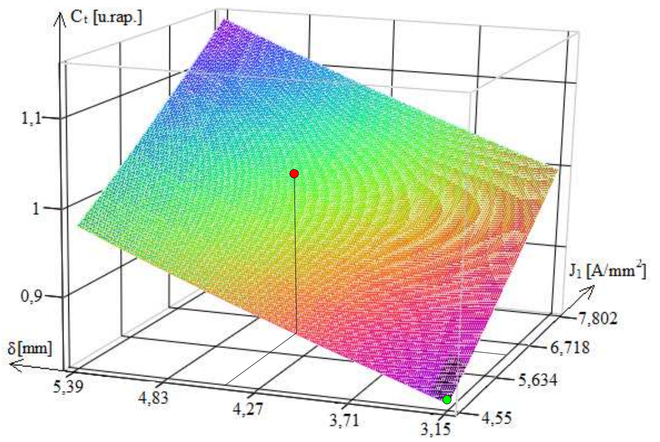

Fig. 13. Total cost variation depending on the statoric winding current density and the air gap size: the 750 rot/min hydrogenerator.

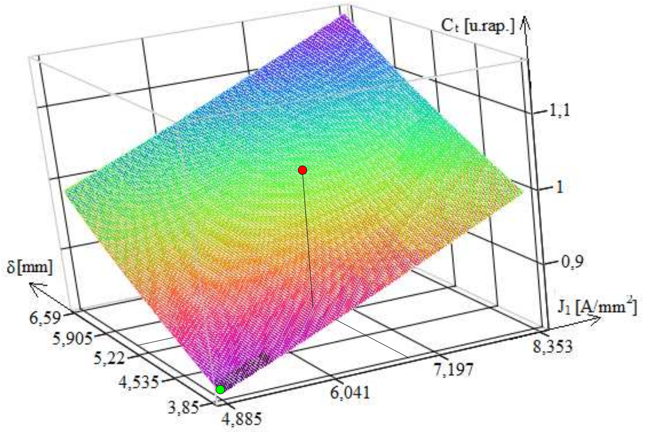

Fig. 14. Total cost variation depending on the statoric winding current density and the air gap size: the 1000 rot/min hydrogenerator

For the hydrogenerator designed to operate at 750 rot/min the optimal parameter values lead to a manufacturing cost decrease of 4.477%, an operating cost decrease of 19.7%, and a total cost decrease of 17.573% (Fig. 13).

Choosing optimal parameter values for the 1000 rot/min hydrogenerator determine a 5.006% decrease of the manufacturing costs, a 19.959% decrease of the exploitation costs, and a 18.047% total cost decrease (Fig. 14).

Table 1 shows the actual values for the current blanket, the statoric winding current density, and the air gap size for the classic design (subscript ‘c’) and for the optimal design (subscript ‘o’) for each of the synchronous generator rotations analyzed in this work.

Table 1

Current blanket, statoric winding current density, and air gap size values for the optimal and classical design

n	A [A/cm]		δ [mm]		J_1 [A/mm^2]	
[rot/min]	A_c	A_o	δ_c	δ_o	J_{1c}	J_{1o}
250	312.564	360.020	2.25	1.575	6.662	4.664
300	328.797	368.000	2.50	1.750	6.682	4.688
375	332	373.203	2.75	1.925	6.662	4.663
500	344.581	412.925	3.00	2.100	6.620	4.645
600	387	463.997	3.50	2.450	6.962	4.885
750	424	508.214	4.50	3.150	6.502	4.562
1000	433.569	519.563	5.50	3.850	6.962	4.885

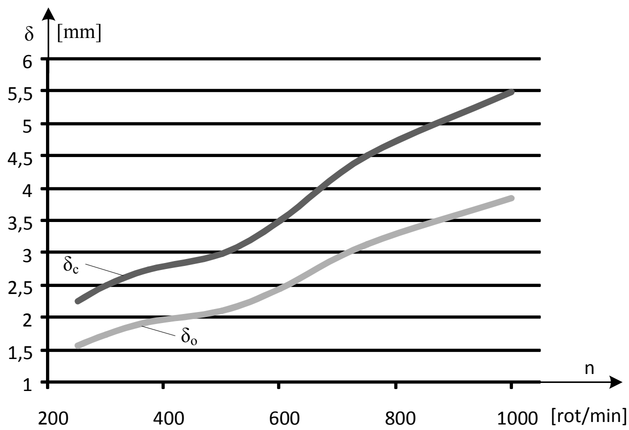

Fig. 15. Air gap size variations depending on the generator’s rotation

If we graphically represent the air gap size for each of the generator turations considered we obtain the plot in Fig. 15.

4. CONCLUSIONS

✓ When the power of the synchronous generator is kept constant, the current blanket value, A, increases with the generator’s rotation.

✓ When the power of the synchronous generator is kept constant, the air gap size, δ, increases with the generator’s rotation.

✓ Achieving the objective function chosen for the optimal design is determined by choosing current blanket values in the upper limit of the variation range, and air gap size values and statoric winding current density values in the lower limit of the variation range.

✓ We could not establish a correlation between the hydrogenerator's rotation and the statoric winding current density optimal values.

BIBLIOGRAPHY

[1] European Parlament and Council Directive 2012/27/UE, October 25, 2012.

[2] **Vlad, I., Câmpeanu, A., Enache, S.,** *Assisted Design of Electrical Machines*, Editura Universitaria, Craiova, 2011 (in Romanian)

[3] **Spunei, E.,** *Optimizing the Design of a Micro Hydro Power Station Synchronous Generator* – PhD Thesis, Craiova, 2012 (in Romanian)

[4] **Cioc, I., Cristea, N., Bichir, N.,** Electrical Machines – Design Guide. Vol. III, Scrisul Românesc, Craiova, 1985 (in Romanian)

[5] **Spunei, E., Piroi, I.**, Electrical Machines – Synchronous Generator Design. Editura „Eftimie Murgu", Reşiţa, 2011 (in Romanian).

[6] **Dordea, T.,** *Electrical Machines Design and Construction.* Parts I and II, „Traian Vuia" Polytechnic Institute Timişoara, Electrotechnic Faculty, 1979 (in Romanian)

[7] **Răduleţ, R., Opaschi, M.,** *Hydrogenerator and Sychdronous Engine Design.* Vol I, Editura Tehnică, Bucureşti, 1980 (in Romanian)

[8] **Nicolaide, A,** *Electrical Machines – Theory and Design,* Vol II, Editura Scrisul Românesc, Craiova, 1975 (in Romanian)

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