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A Case Study of Getting Performance Characteristics of a Salient Pole Synchronous Hydrogenerators

İ. Topaloğlu
Çankırı Business and Technical College, Karatekin University,
18100, Çankırı, Turkey, phone: +90536 746 0944, e-mail: itopaloglu@karatekin.edu.tr

C. Ocak
Department of Electrical Education, Gazi University,
06500, Ankara, Turkey, phone: +90536 746 0944, +90505 639 9076, e-mail: cemilocak@gazi.edu.tr

İ. Tarımer
Department of Electronics and Computer Education, Muğla University,
Kötekli Kampüsü, 48170, Muğla, Turkey, phone: +90 252 211 1722, e-mail: itarimer@mu.edu.tr

Introduction

The position of hydro plants become more and more important in today's global renewable technologies. Hydro electric energy is worldwide responsible for some 2750 *TWh* of electricity output per year, which means about 22% of the world's entire electricity demand being one of the most reliable and cost effective renewable energy source.

Efficiency is directly influenced on hydrogenerator's performance and it is a result of the losses occurred in a hydrogenerator [1]. These losses are called as winding, iron, mechanical, brush & ring losses. The supplemental losses occur on winding surface and iron core surface, and causes electromagnetic harmonics [4–5]. In this study, HG's heat, excited voltage, efficiency and losses have been researched in order to see influence on a hydrogenerator.

Efficiency is calculated under overload conditions of 25%, 50%, 75%, 100% and 125% loads in industry. This process is very effective method to determine performance characteristics of a hydrogenerator [6–7].

To get performance characteristics of a salient pole synchronous hydrogenerators, various characteristic of a machine must be defined to get optimum running parameters in different running temperatures and the excited values. Efficiency of a hydrogenerator can be written as seen in (1) [1]

$$\eta_{HG} = \frac{(P_2)_{electric}}{(P_1)_{mechanic}} = \frac{(P_2)_{electric}}{(P_2)_{electric} + \sum \text{Losses}}. \qquad (1)$$

where η_{HG}– efficiency, P_1 and P_2– input and output powers correspondingly.

When HG's speed and voltage are kept as constant, the exciter, supplemental, mechanical and iron losses must be taken account. If the terms represent: K_{load} – stator current divided by steady state stator current, S_n – apparent power , $cos\varphi$– power factor, P_{feo}– iron losses , P_{mech} – mechanical losses, P_{scn} – short circuit losses, P_{exch} – excitation losses, P_{brush} – brush and ring losses, P_{stray} – stray load losses are orderly ferrite material, mechanical, short circuit, excitation, brush&ring and stray powers. I_f – field current and I_{fn} – rated load excitation current. In this case it is possible to write the efficiency equation related with these as shown in equation 2 [1–3].

In HG design process, the total losses and efficiency at different load levels may be predetermined to assess the design goodness from this crucial point of view [10–17]. The investigated HG's insulation class is known as F. However exciter current is 35 amperes DC at steady state conditions and it has direct cooling system with air and water. Performance characteristics of the investigated HG have been carried out according to the thermal conditions listed above. In direct–cooling HGs, the winding losses tend to dominate the losses inside the machine, on the other hand, for indirect cooling; the non-winding losses tend to become predominant. It follows that the efficiency tends to become maximum for above the rated load at indirect cooling, and for below the rated load at direct cooling [18–22].

$$\eta_{HG} = \frac{K_{load} \cdot S_n \cdot \cos\varphi}{K_{load} \cdot S_n \cdot \cos\varphi + P_{feo} + P_{mec} + P_{scn} \cdot K_{load}^2 + P_{exch} \cdot \left(\frac{I_f}{I_{fn}}\right)^2 + P_{brush} \cdot \left(\frac{I_f}{I_{fn}}\right) + P_{stray}}. \qquad (2)$$

Investigated Heat, Efficiency and Rated Voltage Capacity in a Hydrogenerator

To define real running performance of a hydrogenerator, some specific methods may be used, which of the most preferred one are heat, efficiency and rated voltage capacity in a HG.

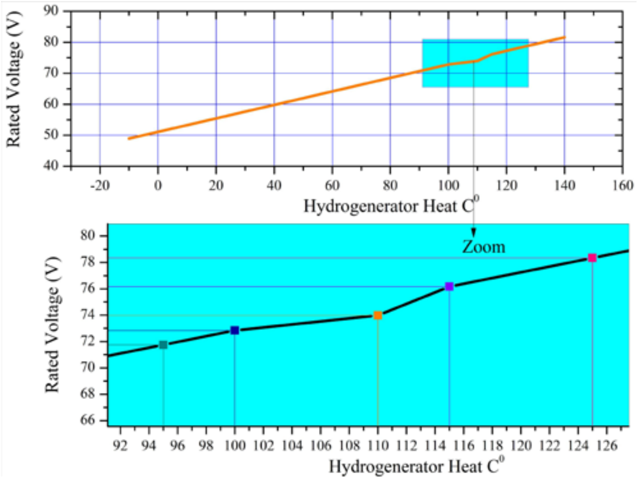


Fig. 1. Exciter voltage variation with hydrogenerator heat

There is a linear relationship between the hydrogenerator's heat and the rated voltage as shown in Fig. 1. When generator's running heat value is at maximum, house-box's of hydrogenerator's cooling capacity does not become enough for that running condition. That's why; upper model of generator house-box must be preferred according to IEC standards. In this study, maximum running heat value has been chosen as 120 C°. This value directly influences the HG's efficiency. HG's heat capacity can be accepted between –20 C° and +140 C°. Exciter losses are directly related with HG's heat and rated voltage. In Fig. 2, exciter losses variation with HG's heat and rated voltage is shown. Exciter loss is about 720Watts at maximum HG running heat value and rated voltage is about 76 volts.

Exciter loss becomes less when HG heat value is decreased. Rated voltage, HG heat value and exciter loss are based on the linear relationship amongst these values. One of them is increased, the rest of them will increase, on the other hand, when one of them is decreased, the other two will be decreased.

HG's efficiency depends on several HG design parameters. But HG's heat and cooling system directly affects HG's running performance. When the rated voltage is setup as about 76 volts DC, efficiency will decrease from 95.8% to 95% increasing together with the heat value of HG. In addition to that, when HG's heat value is about –10 C°, the rated voltage is seen as about 45 volts. As seen in Fig. 3, the optimal running values of HG are seen that the rated voltage is 76 Volts, the heat value is +110 C° and the efficiency is about 95.8 %.

A HG has been designed for this investigation by Ansoft Maxwell and Rmxprt softwares [8]. HG's heat and the rated voltages variations have been obtained by using OriginLab 8 software [9]. This hydrogenerator designed to be used at hydro–electric power plants. As known, cylindrical rotor generators are called as turbogenerator; they are used at the power systems which need to have high speed like thermal, natural gas and nuclear plants. Because of salient pole machines could be easily produced as multi poles, they are being used at hydro–electric power plants which need to have low speed. However, salient pole synchronous hydrogenerators' numbers of speed (*rpm*) can easily be come to stable under load with help of nonlinear control systems.

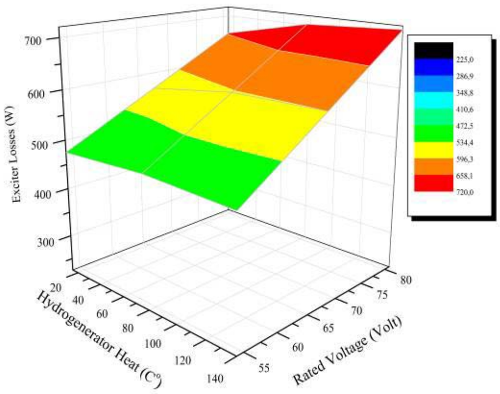


Fig. 2. HG's heat and the rated voltages variation with the exciter loss

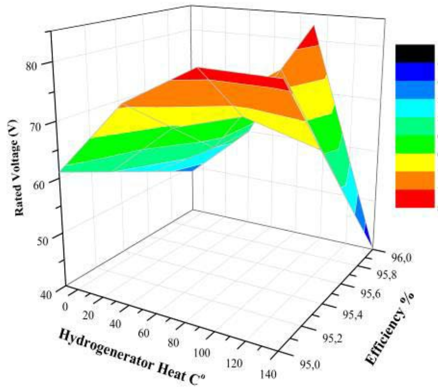
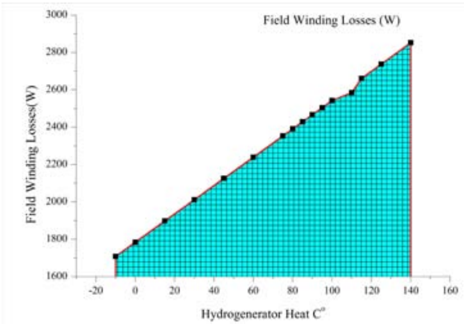


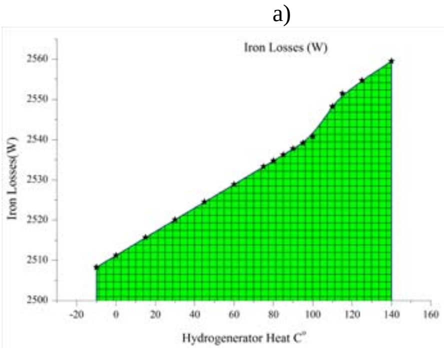
Fig. 3. HG's heat and the rated voltages variation with the efficiency

HG's losses are known as field winding losses, iron losses, and stator winding losses which were described as electrical losses. The total losses of HG are shown in Fig. 4, and these losses are about 26 kilowatts. When this value is obtained, environment heat value is measured as 25 C°. When optimal running conditions are provided for this HG, maximum total losses will be about 26 kilowatts.

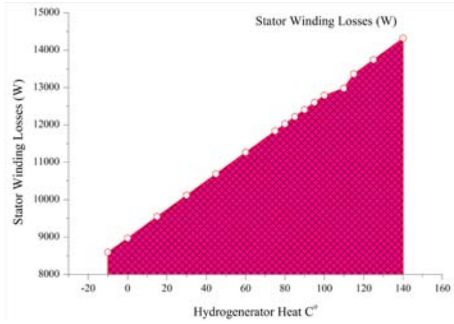
The heat performance characteristic of HG for this study has been obtained as shown in Fig.5. This graphic shows the analyzing results of the electromagnetic and electro mechanic design and analyze software. According to this graph, **V** curves of the studied HG have been obtained at different air gap powers. Thus, the active power of this HG is being seen that it's fitted to use for suitable compensate purpose. The turbogenerators take places at the core of electric power systems. Their prime function is to produce necessary active power. However, they are also required to provide (or absorb) reactive power both, in a refined controlled manner, to maintain frequency and voltage stability in the power system. The Investigated HG can be run likes a turbogenerator to produce active power and can provide capacitive reactive power to be able to compensate main power system.



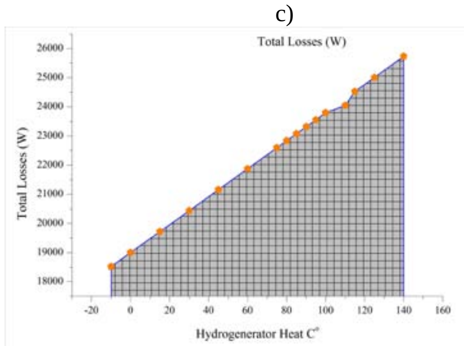
a)



b)



c)



d)

Fig. 4. Power losses variation with HG's heat (Watts versus C^{o}): a – field winding losses; b – iron losses; c – stator winding losses; d – total losses

The Designed Hydrogenerator's Parameters

The pre–requisite values of the investigated HG have been given in Table 1.

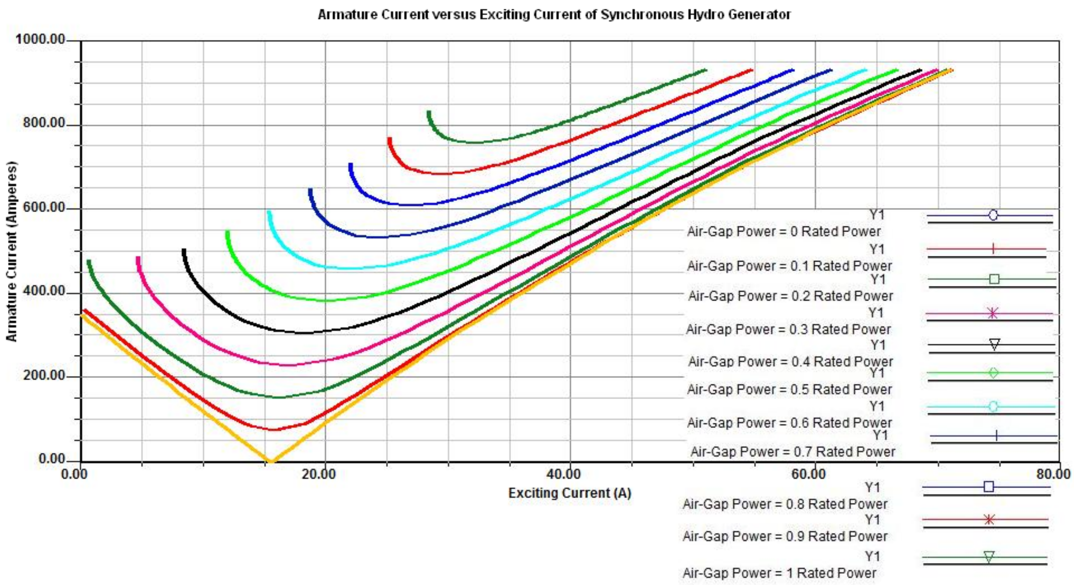


Fig. 5. V Curves of the HG (Armature current versus exciting current)

The running values under full–load can be seen in Table 2. While the machine was running under full–load, the stator current density has been obtained as 6.89133 A/mm^2 as shown in Table 2.

That means that it is a normal value for this air and water–conditioned (cooled) system inside the limits allowed. If the stator current density were being greater than 7.5 A/mm^2, the system would need to have an external cooling system. Because of the exciter current density has been occurred as smaller than 3, there will not need to have any external cooling system. Thus, direct air cooling can be enough for this design.

Table 1. The pre–requisite values of HG

Apparent power (*kVA)*	550
Rated power factor (*cos*φ)	0.8
Stator voltages (*Volts*)	400
Connected type	Star
Number of poles	6
Frequency (*Hz*)	50
Speed (*rpm*)	1000
Insulation class	F
Exciter efficiency (%)	80
Exciter current (*Amperes*)	35

Table 2. HG Full–load data

Stator phase current (*Amperes*)	776.536
Stator thermal loading (A^2/mm^3)	3657.96
Specific electric loading (*A/mm*)	530.807
Stator current density (A/mm^2)	689.133
Exciter current density (A/mm^2)	241.814
Exciter voltages (*Volts*)	761.636
Core iron loss (*Watts*)	2551.49
Friction and wind losses (*Watts*)	2600
Stray losses (*Watts*)	2690
Stator winding losses (*Watts*)	13362.8
Field winding losses (*Watts*)	2661.43
Exciter losses (*Watts*)	665.357
Total losses (*Watts*)	24531.1
Input power (*kW*)	529.953
Output power (*kW*)	505.422

Conclusions

In this study, the relationship between HG's heat, efficiency and the rated voltage has been researched. In order to do this, a 560 *kilowatts*, 50 *Hertz*, 400 *Volts*, 1000 *rpm*, 6 Pole, salient pole synchronous hydrogenerator has been investigated. It has been seen that HG's heat value depended on the used cooling system, its environmental factors and the running heat values in the designing of HG. As a result, the heat and the optimal running performance characteristics of the studied HG have been come up with the numbered values. These values and the **V** curves of this HG have been represented in the figures above. All these figures show the required field current of HG's for different kinds of load level. According to the dominated V–curve which is being seen at the right–hand side, HG's active power capability is obtained as higher than reactive power. If the left side of V–curve were dominant, HG's reactive power capability would become higher than active power. Thus, it has been inferred that the reactive power capacity of this HG was obtained as lower than the active power. As an advantage, this HG can provide more capacitive reactive power to be able to compensate main power system.

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Today, continuously increasing electrical energy demand makes every one to investigate how to benefit maximum efficiency from hydro–electric power plants' generators. In this study, 560 *kW*, 400 *V*, 1000 *rpm*, 6 pole salient pole synchronous machine's heat, excited voltage, efficiency and losses have been researched to see the influence on hydrogenerators and to design a suitable model for natural running environment. In addition to these, the field current versus stator current under various load conditions has been determined and the reactive capability of a hydrogenerator has been calculated. It has been seen that the performance characteristics of the designed hydrogenerator was directly related with the running environment and the load conditions. Ill. 5, bibl. 22, tabl. 2 (in English; abstracts in English, Russian and Lithuanian).

И. Топалоглу, Ц. Осак, И. Таример. Исследование технических характеристик водородного синхронного генератора // Электроника и электротехника. – Каунас: Технология, 2010. – № 1(97). – С. 57–61.

Описывается водородный шестипольный генератор, обеспечивающий 560 kW мощность при обороте 1000 об/мин. Исследована теплота, напряжение возбуждений генератора, эффективность работы, а также потери энергии в нормальных условиях работы. Теоретически и экспериментально технические характеристики зависимы от нагрузки генератора и параметров окружающей среды. Ил. 5, библ. 22, табл. 2 (на английском языке; рефераты на английском, русском и литовском яз.).

İ. Topaloğlu, C. Ocak, İ. Tarımer. Sinchroninio vandenilio generatoriaus pagrindinio poliaus techninių charakteristikų galimybių studija // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 1(97). – P. 57–61.

Nuolatos augantis elektros energijos poreikis verčia ieškoti alternatyvių energijos šaltinių, juos maksimaliai ištirti ir išnaudoti. Išanalizuotas 6 polių 560 kW, 400 V, 1000 aps./min., vandenilio generatorius. Siekiant įvertinti poveikį vandenilio generatoriams ir suprojektuoti tinkamą modelį, ištirta vandenilio generatoriaus skleidžiama šiluma, žadinimo įtampa, efektyvumas ir nuostoliai veikiant natūraliai aplinkai. Įvairiomis sąlygomis palygintos statorių srovės ir apskaičiuotas reaktyvusis pajėgumas. Nustatyta, kad suprojektuoto vandenilio generatoriaus techninės charakteristikos tiesiogiai priklauso nuo apkrovos ir aplinkos parametrų. Il. 5, bibl. 22, lent. 2 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).