A NEW HIGH POWER DENSITY GENERATION SYSTEM

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Keywords: amorphous alloys, magnetic amplifier, PM-generator

Abstract

A trend of increased Electric Power in Aircraft stresses the need of robust, low weight systems with low losses. New hard and soft magnetic materials have made it feasible to work with high speed and high frequency. Applications of new soft magnetic materials and hard magnetic materials like NeFeB magnets have enabled high density power generation systems. A new concept comprising a high speed PM-generator system and a magnetic amplifier control is presented.

Magnetic amplifiers are used in the power supply of the Electronic Flight Control System in the Swedish "Gripen" fighter-aircraft. This technology is attractive in More Electric Aircraft (MEA) systems due to the possibility to achieve a compact, robust and a highly reliable system with low losses. Applications of new soft magnetic materials, such as amorphous magnetic alloys, have enabled the use of magnetic amplifier (magamp) technology in the design of competitive electric power converters.

This paper presents a studied design on a 20-40 kW generator system including a +/- 270V controlled output, performed by magnetic amplifier technology. This work addresses the power generator, and the power converter. High speed PM-generators are offering high power density.

The impact of operating a generation system with higher frequency and an increasing number of poles as well as the advantages with new soft magnetic materials is studied.

The iron losses and the copper losses are analyzed for the generator, and the power converter.

1 Introduction

In the process of designing an electric power supply system for an aircraft, parameters like low weight and low losses are important [1]. The proposed system is an electric power generation system supplying a vehicle with +/- 270 VDC at a power of 20 kW. This work is a conceptual study.

An autonomous Unmanned Aerial Vehicle (UAV) is a feasible platform for a new high power density generator system in the studied power range.

The objectives of this paper are to demonstrate that the weight and the efficiency of the proposed system will be competitive.

2 Power Generation System

The main components in the studied electric power generation system include an electric power generator and a converter regulator as shown in figure 1. A conceptual electric power supply system is sketched and analyzed together with the required components.

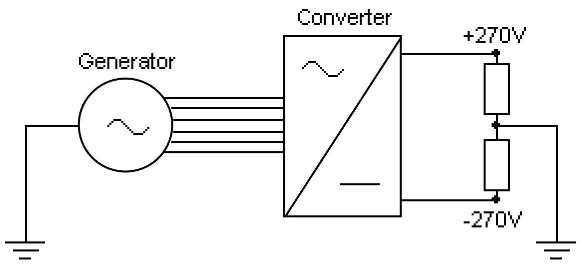


Fig. 1. System +/- 270 VDC

Draft specification data is given in table 1. The equivalent circuit of a permanent magnet generator (PMG) with variable frequency and voltage is shown in figure 2.

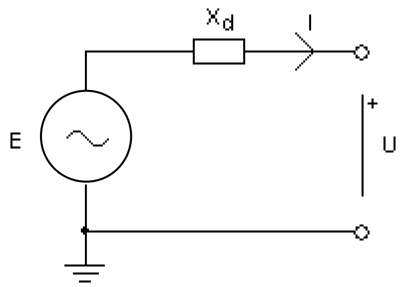


Fig 2. Generator equivalent circuit

The generator no load voltage E, is in direct proportion to the generator input speed. The generator output voltage, U, depends on the output current and the generator impedance X_d as shown in figure 3.

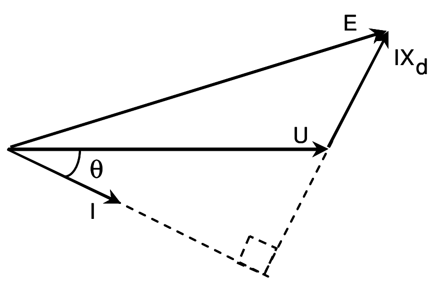


Fig. 3. The generator vector diagram

Table 1.

Generator System	
Generator	20-40 kW
Generator voltage output (phase)	460 VAC
Frequency at full speed 100%	5330 Hz
Frequency at Ground Idle 50%	2665
Weight (max) generator	7 kg
Power Converter power	20 kW
Voltage output Converter	+/-270 VDC
Electric efficiency converter	97 %
Weight (max) Converter	7 kg

3 Power Generator

The proposed power source is a PM-generator with variable frequency and variable voltage. In an aircraft application it can be foreseen that the input speed varies within approximately a factor of two. With the proposed concept the generator output frequency is allowed to vary between 2665 Hz to 5330 Hz when the engine varies from 50 % to 100 %. Normally the speed does not go below 60 %, which gives a design margin in this study. The output voltage from the unregulated generator will vary in proportion to speed, see figure 4. Thus the output voltage will vary between 230/400 VAC and 460/800 VAC.

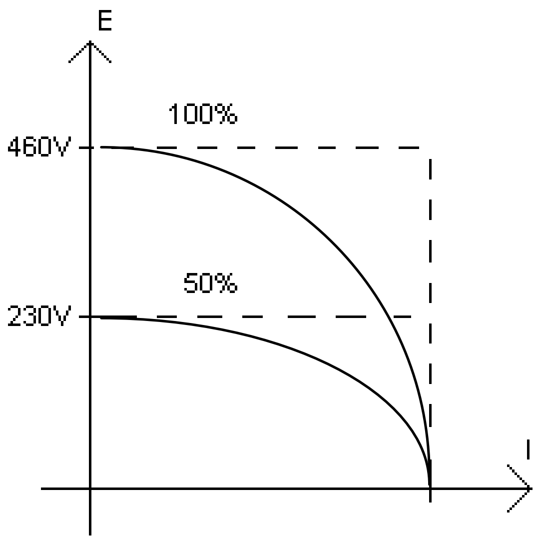


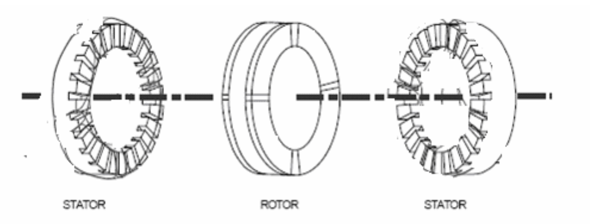
Fig. 4. The Generator Characteristics

In an UAV, the primary energy source is one generator or possibly one of two generators attached to the engine pad. A feasible electric power output can be 20-40 kW in a medium size UAV.

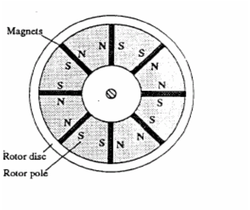
The generator output shall be adapted to the power converter and be able to supply different phases. The generator studied here is a novel 3-phase axial flux machine [2] with a concentrated winding arrangement. The continuous output power is minimum 20 kW with a power capability of 40 kW at a phase to phase voltage level of 230 VAC varying up to 460 VAC.

A multi phase output winding arrangement from the generator with a 12 terminal connection is proposed to enable a 24 pulse arrangement in the following power converter. The multi phase winding arrangement enables a multi pulse converter unit.
The proposed generator concept offers the feasibility of a multi phase output partly enabled by a dual stator design. The output shall enable 12 outputs giving an electrical angle of 15° between the pulses.

An example of a feasible axial flux PM-machine concept is shown in figure 5.



(a)



(b)
Fig. 5. (a) An example of an axial flux machine with a single rotor-double stator assembly, (b) Cross sectional view of the rotor

The stator offset shown in figure 7 will decrease the higher order harmonic components in the air gap flux density but also cause an unbalanced axial force due to this asymmetry [3]. The outer radius of the studied machine is 125 mm, the inner radius 84 mm, and the length of the machine 48 mm. The mechanical speed is 20000 rpm, which with 32-poles gives an electrical frequency of 5330 Hz. The weight of the generator is estimated to 7 kg. The estimated efficiency of the generator is 95 %.

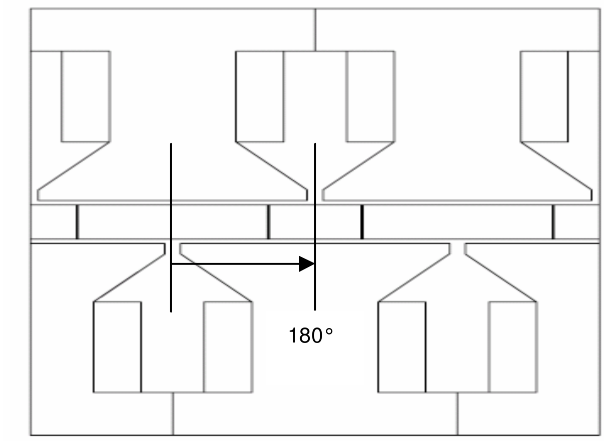


Fig. 6. An unfolded cross sectional view of the rotor-double stator assembly, and the rotor with permanent magnets, here shown with 180° stator offset

The equi-potential lines of the magnetic vector potential of the proposed generator are shown in figure 7.

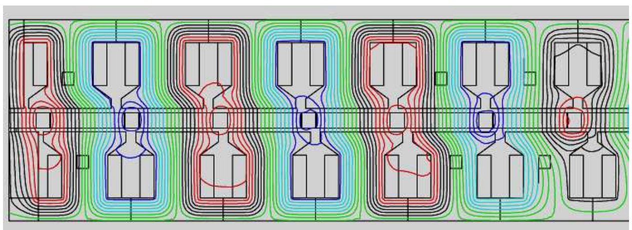


Fig. 7. The equi-potential lines, magnetic vector potential

4 Power Converter

The power converter is supplied with electric power from a permanent magnet generator with variable frequency and voltage.
Due to a non regulated output voltage from the generator a voltage control is needed. This can

be achieved by use of magnetic amplifiers [5]. The advantages with magnetic amplifiers are high reliable and rugged design [7]. The power converter includes rectifiers, power control and output filters.

Due to the multi phase winding arrangement and the adapted voltage of the generator, transformers will not be required in design of the proposed power converter. The rationales for a multi-pulse design power converter unit are reduced distortion on the aircraft generator output voltage as well as a clean DC power supply.

The magnetic amplifiers can be designed by use of toriods based on amorphous alloys offering the possibility to work at high frequency and low losses.

A 24 -pulse rectifier design can be built by adding the contribution from four six-pulse bridges, in parallel, resulting in +/- 270 VDC output. An example of one of the six pulse bridges are shown in figure 8.

The maximum output then is 540 VDC, where the regulated +/- 270 VDC output complies with the Mil-Std-704 requirements.

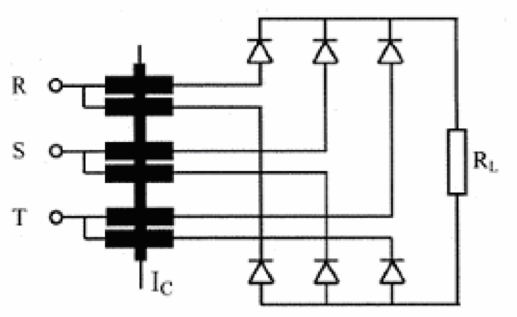


Fig 8 Block diagram for one of four parallel bridges

A feasible material in the toroids is an amorphous alloy. The studied material in the Metglas 2605-family [4] is the preferable alloy in audio frequencies, due to low its losses and relative high flux density resulting in a low core weight.

The high reliability and robustness also represents a significant value adding to the attraction of magnetic amplifiers in aircraft applications. The sizes of the cores are based on (1) the required magnetic flux. The induced voltage E, is given by

$$E = 4.44 \cdot \hat{B} \cdot A \cdot N \cdot f \qquad \text{[V]} \qquad (1)$$

where B is the flux density, A the core area, N the number of turns, and f the frequency. Iron area, number of turns and frequency and consequently then gives the core weight.

The amorphous alloys 2605TCA data is extracted [13] to give the equation (2) expressing the core losses as a function of frequency and magnetic flux.

$$P = 88 \cdot 10^{-6} \cdot f^{1.57} \cdot B^{1.7} \qquad \text{[W/kg]} \qquad (2)$$

Efforts are put on analyzing the magnetic circuits, calculating weight, copper losses and losses in the cores as function of number of turns as shown in Figure 9.

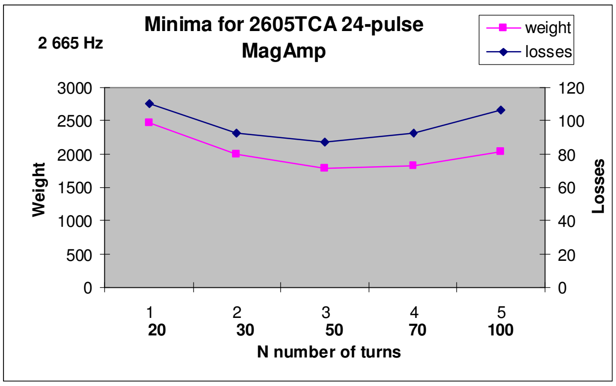


Fig. 9. Optimization of weight and losses for the magnetic cores including windings in the 20 kW magamp

The analyses of the magnetic amplifier give a weight of approximately 2.0 kg and losses of 90 W. In this study a current density of 5 A/mm^2 is used.

A total estimated weight of 7.0 kg of the power converter includes magnetic amplifiers, wiring, insulation, rectifier diodes, power control, internal power supply, housing, filters, protective circuits and connectors.
With that weight of the power converter and a power output of 20 kW, a power density of 2.85 kW/kg is expected.
A conventional transformer rectifier unit (TRU) with a rating of 3.5 kW at 400 Hz and a 28 VDC output weights 6.8 kg. This yields a power density of 0.51 kW/kg. However the comparison with a TRU might be unfavorable to the conventional 28 VDC system due to the required transformers in the TRU.

The total estimated losses of the power converter including the losses from the magnetic amplifiers, control circuits, internal power supply, rectifier diodes and filtering is 600 W.

These losses enable an efficiency of the power converter at rated load to be 97 %.

5 Future work

Housing and mechanical support need further analysis and optimization. Detailed design and analysis of the magamps [6], control circuits and the required filtering remains.

6 Conclusions

The proposed electric power generation system delivers an output power of 20 kW and a voltage rectified and regulated to +/- 270 VDC. One of the big advantages with proposed system is the rugged design and the potential of a low weight and a high reliability. Improved cooling could give further decrease of weight.

This work was financed by the Swedish Defence Material Administration (FMV).

7 References

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