OPTIMAL DESIGN OF SYNCHRONOUS ENGINE USED IN A SYSTEM OF PHOTOVOLTAIC PUMPING WITH CONSIDERATION THE AGEING

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ABSTRACT

The photovoltaic pumping systems are an interesting solution for water supply to isolated sites of power systems, such as rural areas in developing countries. Indeed, these sites generally have a favorable sunshine which allows to consider the use of the only source of energy (renewable) for pumping water. Unfortunately, such devices often suffer from failures that, for lack of maintenance render the device inoperable. In this context, this paper proposes optimal design multicriteria of the synchronous pumping system taking into account the aging of the motor. The objective is to dimension the engine as accurately about the service life of the panels.This optimal design requires as a first step the electrical, thermal and geometric modeling of the motor. For more accurate, live parts are taken into account in the geometrical and thermal modeling. Based on the thermal aging of the motor windings, we estimate the lifetime of the synchronous motor. These two models are the basis of multicriteria optimization which is then conducted with the NSGA II algorithm. A compromise between the mass and the heating is then proposed in order to control the cost of installation while choosing a more robust system. Finally we compare a solution using single motor over the entire life of panels with a solution using a replacement of motor to half life of the panels. The second solution could be an interesting solution economically, despite the investment related to renewal, because the reduction of the duration of the motor allows a significant reduction in the weight of the machine.

KEYWORDS: *Photovoltaic pumping system, Synchronous motor, Multicriteria optimization, Ageing, Electrical, thermal and geometrical models.*

I. INTRODUCTION

The purpose of the work is to design a system of photovoltaic pumping with weak maintenance dedicated to the rural populations, where the maintenance is a difficult task and relatively expensive. So, we can remove batteries [1], [2] and optimize the ageing of the various components of the system. The idea is to fit the life expectancy of components to that of the photovoltaic panels. In this context, we present in this paper the optimal design of the synchronous engine by taking into account its ageing.

To make the optimal design with the ageing consideration, we start by presenting in section 2, the description of the system of pumping. In section 3, we present the model of ageing to estimate the life expectancy of motor according to the rise of temperature of the winding and their insulation; which temperature is determined by solving of thermal model presented in section 4. We also present in section 5, some results of the optimal design by holding in account the ageing due to the heating of the winding. Finally, the section 6 concludes the paper.

II. DESCRIPTION OF THE SYSTEM OF PUMPING

2.1. Overview of the complete system

In this paper we consider a photovoltaic pumping system, which is used to provide a water rate flow of about 7.20m^3/h, which is the necessary volume to satisfy the daily needs in water of 500 households (houseworks) if we consider 100 liters by household. The total manometric height in the considered zones is about 73 m. So, the hydraulic power is determined by the following formula [3]:

$$P_h = \rho g H Q \quad (1)$$

with Q the flow of water, H the total manometric height and ρ the volume density of water.
With a fixe means accurate, we can estimate the motor's power to about 2.2kW. The complete system is presented to the figure 1.

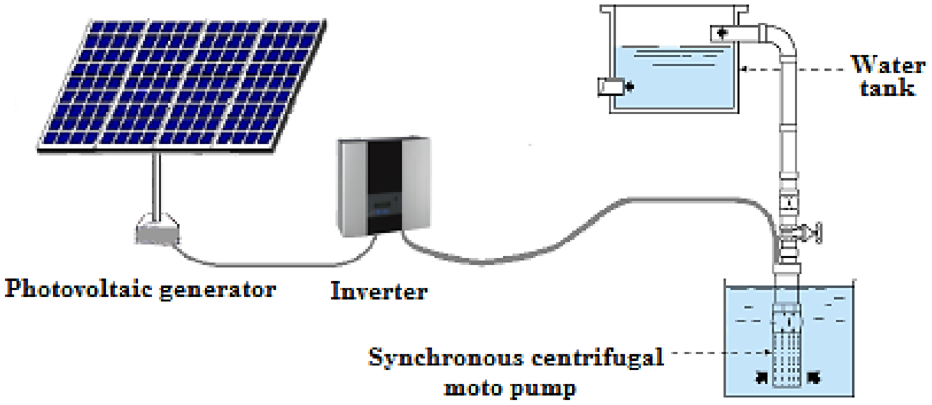

Figure 1: Description of the complete photovoltaic pumping system

It includes:

- the photovoltaic panels which supply to the system the necessary power,
- the inverter of tension which is used to convert the continuous tension coming from the photovoltaic generator in necessary alternating voltage to feed the synchronous machine,
- the synchronous engine which is used to make turn an immersed centrifugal pump.

2.2. Structure of the machine

The geometry of the synchronous machine, which is considered here, is presented to Figures 2 and 3.

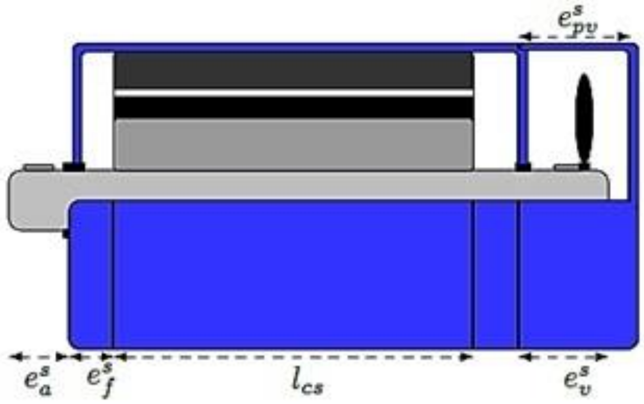

Figure 2: Longitudinal cuts view

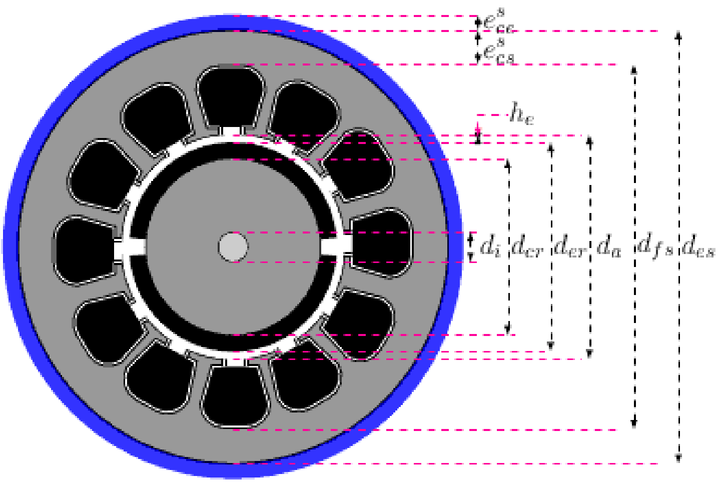

Figure 3: Transversal cuts view

The masses of the different parts are easily calculated by the knowledge of its geometric form.
Once all these masses determined, we also looked for the relation between the diameter of the motor shaft and the mass of the motor bearings. Indeed, for the determination of the mass of the motor bearing, we use the data of the designer Koyo [4] and by an exponential extrapolation we find the link between the internal diameter of the bearing and its mass.
Finally, the total mass of the synchronous engine is the sum of the masses of all its various parts.

III. AGEING OF THE DRIVE

3.1. Origins of the ageing

The main origins of the ageing of the drive are the following ones:

- ageing of the windings: due to the heating of the windings, the properties of the insulation deteriorate and the lifetime decreases. So the temperature of the copper must be adjusted well to avoid the early ageing of the engine,
- ageing of the bearings: due to the high temperature of functioning, the loss of lubrication,...
- ageing of the VSI semiconductors: the warm up of semiconductors leads to a reduction of the life expectancy, So that the currents of VSI and the frequency of cutting must be carefully chosen.

In this paper, we focus rather on the drive design methodology and in particular on the way to take into account the ageing. So, to simplify, we consider only one of the factors: the warm-up of the windings.

3.2. Model of the ageing of the winding

The model of ageing of the windings is based on the temperature of the copper. We assume that the temperature is constant during all the operating life and that the engine starts when the necessary lighting for its own work is available.
Generally, the reference life expectancy of the windings is $\tau_{ref} = 100000\ \text{h}$ for the reference temperature of 40°C. This life expectancy decreases in half for a rise of 10°C over the reference temperature [5]. We suppose that for the considered windings, the life expectancy is equal at 1000 hours when the temperature of functioning increases 150°C over the reference temperature. So, the corresponding model is given by the following formula:

$$\tau = \tau_{ref} \times 2^{\Delta\theta^s_{bo}\left(a \times \Delta\theta^s_{bo} + b\right)} \qquad (12)$$

where *a* and *b* are constants to be determined and $\Delta\theta^s_{bo}$ the temperature averages of the winding of the stator.

IV. ELECTROMAGNETIC AND THERMAL MODELS OF THE MACHINE

4.1. Electromagnetic model

The equivalent electric scheme of the used motor is presented to the Figure 4.

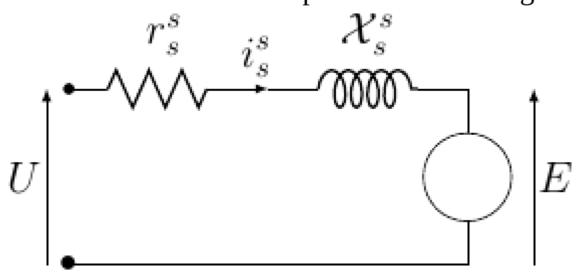

Figure 4: Equivalent electric scheme of the synchronous motor

Where:

- E is the electromotive force,
- r_s^s is the electric resistance of one of the phases of the engine,
- X_s^s is the leakage inductance estimated from an expression approached on the basis of the geometrical parameters [6].

4.2. Thermal model

For the calculation of the temperature of the winding, we finalized a model of thermal analysis of the engine according to the geometry of the machine and the thermal properties of the used material. The thermal equivalent circuit of the machine is presented to the Figure 5.

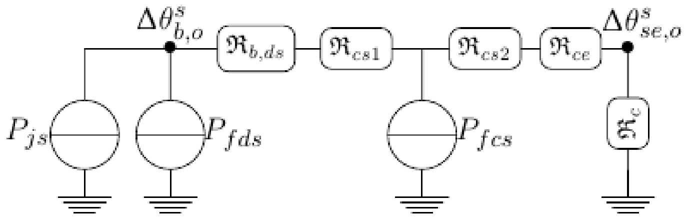

Figure 5: Thermal simplified equivalent plan of the synchronous engine

Where:

- P_{fds} and P_{fcs} are respectively the irons losses in in the teeth of the stator and in the breech of stator [7],
- P_{Js}^{s} is the losses Joule,
- $R_{b,ds}$ is the thermal resistance between winding and stator teeth,
- R_{cs1} and R_{cs2} are respectively by the thermal resistances of the internal and outside parts of the breech of stator [8],
- R_{ce} is the thermal resistance between the external carcass and of the air,
- $R_{c,o}$ is the thermal resistance due to the convection.

V. OPTIMAL DESIGN OF THE MACHINE

5.1. Methodology

To realize the design, we suggest using the optimization. Indeed, the increase of the life expectancy leads to a decrease of the temperature of the rolling-up, then a decrease of the losses or an increase of the weight. To make the good compromise between the cost and the life expectancy, an optimization multi-objective is used. To achieve that, we have used a Non dominating Sorted Genetic Algorithm II [9], [10] whose structure is presented to the Figure 6.

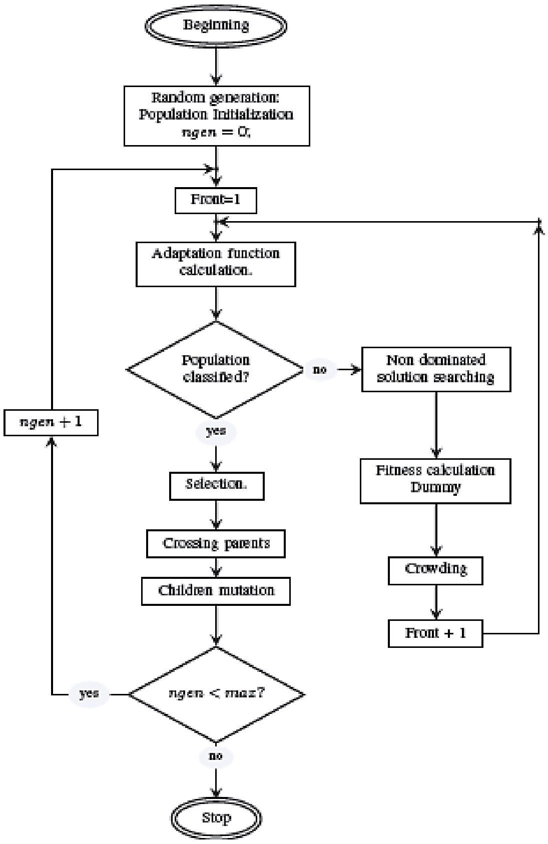

Figure 6: NSGA II structure

5.2. Results and comments

For the calculation of the optimizations, we used a Matlab program proposed by Song [11] that we adapted to our model. We also used the geometric, electric and thermal parameters as optimization variables.

Consequently, the results are obtained for 200 values per variables after 500 iterations.

The following figures present the evolutions of the average temperature of the windings and its life expectancy when the total mass of the engine increases with two approaches of the optimal design, which will be described farther.

The curves of the figure 7 show the evolutions of the life expectancy of windings when the total mass of the engine increases for two approaches. When the mass increases, the temperature of the winding decreases. So, the losses in the copper decrease, and the efficiency on the engine increases. The first approach presented in this figure consists in choosing the life expectancy of the synchronous machine as equal to that of the photovoltaic panels, which is considered as approximately 30 years [13][14] (76650 hours for 7 working hours a day). For this approach, the mass (i.e. the cost) of the corresponding engine is about 14.85 kg. Then, we proposed the second approach which consists in changing the engine (or the windings) once during the life expectancy of panels.

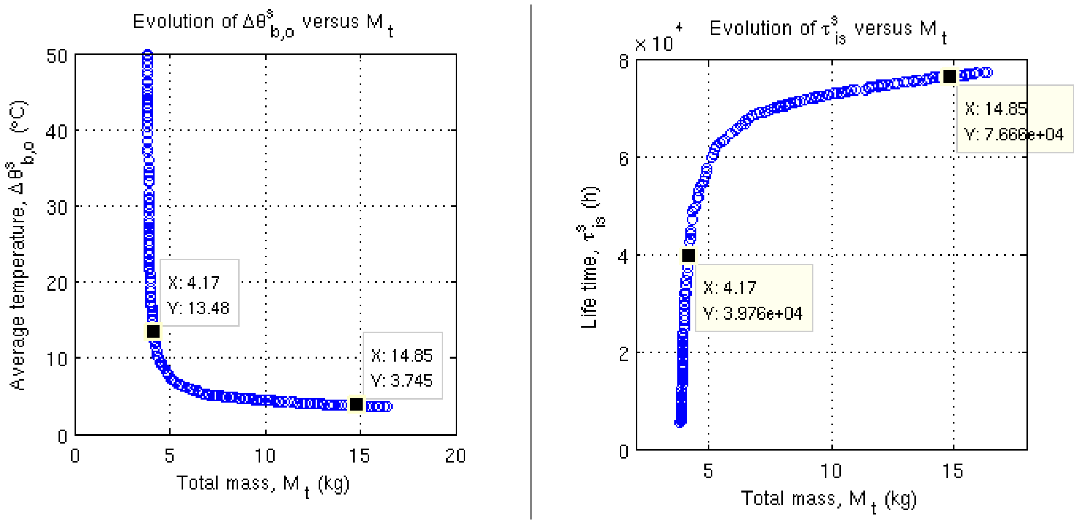

Figure 7: Winding average temperature and ageing evolution with different range of mass for the two approaches

The increase of the mass means that the cost of the system of pumping increases far too much. For us, the best economic solution would be to choose the life expectancy of the windings of engine equal in the middle of the life expectancy of the photovoltaic panels. For this approach, we can note that the total mass is very weak (approximately 4.17kg) with regard to the first approach. It is also important to note that the double of the total mass of the second approach is lower than the total mass of the first approach. With this study, a predictive maintenance of the engine can be made to maintain operational the system until its complete ageing.

VI. Conclusion

To achieve the aim of this study we developed the geometrical, electric and thermal models of the synchronous engine. By basing itself on the thermal ageing of the windings of the engine, we estimated its life expectancy. These models are the base of the optimization multicriterion which is then realized with the algorithm of NSGA II. A compromise between the mass and the warm-up is then proposed with the aim of controlling the costs of installation while choosing the most strong engine. This engine will be used in the system of pumping which will be installed on isolated sites of our countries where the temperature is often raised. Finally, we compared a solution using a unique engine on all the life expectancy of panels with a solution of replacement of the engine at the half-life of panels. The second solution can be an interesting solution on the economic plan, in spite of the investment bound to the renewal, because the reduction of the life expectancy of the engine allows a significant reduction of the weight of the machine.

It is important to note that, in the system of photovoltaic pumping, the ageing of the inverter is also important and that is the object of a future study.

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