Design Optimization of a Round-Rotor Synchronous Generator for Enhancing Short-Circuit Ratio (SCR)

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Abstract — This paper presents an optimization of a 17.5kVA turbo generator using genetic algorithm, in order to meet the maximum short circuit ratio (SCR) maintaining the main external dimensions and minimum compromising of performance requirements of an existent machine. The choice of SCR as an objective function is motivated by a present need of a specific segment of Brazilian energy market which has been growth significantly for the last decade. This variable defines the generator capacity to fast recovering facing grid fluctuations, becoming highly desirable when the generator is connected to the grid. In counterpart the SCR also means large air gaps, losses and inevitably higher costs once, in general, the volume of rotor needs to be increased.

I. Introduction

In the last decade, the Brazilian energy market has witnessed a rise of independent energy producers entering into the national electrical grid, coming mainly from sugarcane segment [1]. In these plants the bagasse, a sugarcane by-product, is used as fuel for steam turbines in a cogeneration system, providing economical and environmental benefits.

In past years this system was exclusively used to provide energy for self-consumption. Seasonality and lack of regulation discouraged the small producers to sell exceeding energy due the below market prices [1]. With a new electricity sector regulation approved in 2004, turning energy sales a profitable opportunity even for small energy producers, some technical requirements for turbogenerators from this segment becomes more regular.

The requirement of larger short circuit ratio (SCR) for generators from sugarcane generation plants is correlated to static stability limits. However, in general, it is not considered the gain or the impact of this improvement. Nowadays, for instance, modern excitation systems and digital regulators would allow the turbogenerators operate safely with SCR values between 0.4 and 0.5. Besides that, the enhancement of SCR tends to lose its advantage as long the grid connection where the plant is settled becomes stronger [5]. As a direct consequence, the generator cost will increase for the same installed capacity, once larger SCR often means larger air-gaps, rotor volume [5] and consequently generator size.

The goal of this work is to take an existing standard generator (Table 1) and, keeping their main external dimensions (diameter and iron stack length), to optimize its parameters to obtain a larger SCR. This way, both technical and commercial objectives could be attend and generator manufacturer will meet their objective.

II. Problem Definition

This work consists to optimize the geometry (Figure 1) of an existing standardized turbogenerator to achieve the maximum short circuit ratio (SCR) with no alteration on external dimensions, taking in account the electromagnetic and thermal constraints which define a proper generator operation.

Mathematically, a set of parameters [3] $\vec{y} = \left(f(\vec{x}) \right)$ (1) will be evaluated by a simplified analytical calculation, starting by an existent generator. For the first optimization, it is settled a single objective-function and applied the optimization method MOGAII, a variation of Multi-Objective Genetic Algorithm MOGA with a directional crossover operator and multisearch elitism [4].

The constraints and limits are defined according Table III.

TABLE I
GENERATOR CHARACTERISTICS

Characteristics	Value	Unity
Power	17.5	MVA
Voltage	13.8	kV
Frequency	60	Hz
Power Factor	0.8	
Number of Poles	4	
Rotor Type	Laminated Cylindrical	
Armature Current	732.1	A

A. *Generator Topology*

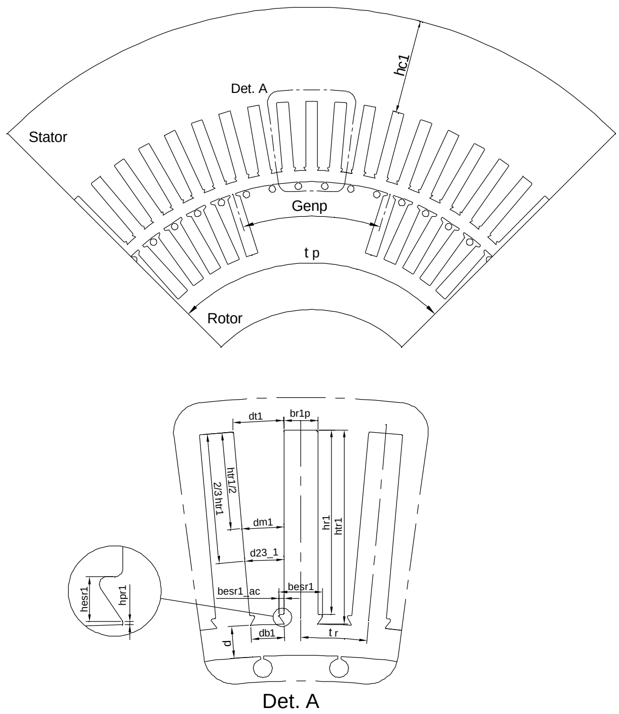

Figure1

B. Objective Function

The short circuit ratio is defined [2] as the ratio between the necessary field current to obtain the rated voltage on no-load (i_{e0}) and the field current necessary to achieve the rated current on short-circuited (i_{esc}):

$$SCR = \frac{i_{e0}}{i_{esc}} \quad (2)$$

This parameter can also be defined as the inverse of the saturated synchronous reactance (x_{ds}) at the direct axis:

$$SCR = \frac{1}{x_{ds}} \quad (3)$$

In this paper the SCR will be the objective function, which will be maximized:

$$Objective\_Function = Max(SCR) \quad (4)$$

C. Constraints and Parameters

The evaluated parameters dealt in this paper are summarized in table II. Basically the generator geometry, winding and strands are modified in order to reach an optimal value for SCR.

TABLE II
EVALUATED PARAMETERS

Parameters	Ab.	Unity
External Stator Diameter	De1	mm
Internal Stator Diameter	Di1	mm
Number of Stator Slots	N1	
Stator Slot Dimensions - Width	br1p	mm
Stator Slot Dimensions - Height	htr1	mm
Number of Turns in Stator Winding	Z1	
External Rotor Diameter	De2	mm
Internal Rotor Diameter	Di1	mm
Stator Parallel Conductors in Height	-	mm
Stator Parallel Conductor in Width	-	mm
Air Gap	•	mm
Stack Length with Cooling Ducts	Ltv	mm
Stack Length without Cooling Ducts	L	mm
External Rotor Diameter	De2	mm
Internal Rotor Diameter	Di1	mm

The constraints, table III, go towards thermal and electromagnetic boundaries defined by theoretical induction limits and iron losses which boundaries are stated based on industrial tests from several existent generators.

Some constructive characteristics were limited due to standardized process, such wire and slot dimension, and others considered fixed once the initial proposal was to keep external dimensions.

TABLE III
CONSTRAINTS AND LIMITS

Variables	Ab.		Values	Unity
Tooth Induction	Bd1	Maximum	2.1	T
Yoke Induction	Bc1	Maximum	1.55	T
Stator Joule Losses	Pj1	Maximum	77	kW
Rotor Joule Losses	Pj2	Maximum	100	kW
Stator Slot Width	br1	Maximum	21.7	mm
Stator Tooth Width	bd1	Minimum	11	mm

III. Results

The table IV presents the first results for generator optimization. The result is a rearranged dimension from the existing turbogenerator, emphasizing the short circuit ratio (SCR), with minimum compromising on cost or mechanical interchangeability, keeping, indirectly, the volume and costs. In this first simulation the amount of copper and iron used in optimized generator was not considered, as well the impact of enhanced SCR on generator performance. Both issues are part of a further analysis to be developed in advance, being part of a second optimization, the following part of this work.

For while, it is important to observe that stator and rotor joule losses increased 5.3% and 4.2% respectively, for an enhancement of 14% in SCR short-circuit ratio.

Details of this first optimization are on table V, where it is presented the MOGAII parameters, initial population and details of process time.

TABLE IV
PRELIMINARY RESULTS

Abb.	Original Generator	Optimization	Unity
SCR	0.49	0.56	-
•	21	23	mm
Bd	2.07	2.09	T
Bc	1.49	1.54	T
Pj1	75	79	kW
Pj2	95	99	kW
De1	1610	1610	mm
Di1	1000	1010	mm
De2	958	964	mm
Ltv	1130	1130	mm
L	950	950	mm
N1	72	84	-

TABLE V
MOGAII PARAMETERS

Parameters	
Number of Generations	200
Probability of Direction Cross-Over	0.5
Probability of Selection	0.05
Probability of Mutation	0.1
Elitism	Enabled
Treat Constraints	Penalizing Objectives
Algorithm Type	Generational Evolution
Initial Population	25
Number of Designs	1724
Unfeasible Designs	1720
Error Designs	3
Tempo	01 h : 28 m

IV. References

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