Conversion of single phase induction motor to single-phase induction generator

Stefan Breban[1], Mihai Chirca[2], Florian Maes[3], Franck Boutoille[3]

[1]SC BMEnergy SRL, Cluj-Napoca, Romania, [2]Faculty of Electric Engineering, Technical University of Cluj-Napoca, Romania,
[3]HEI Lille, France

Abstract *– This paper presents some experimental results of a single-phase induction machine working as generator. The results are showing that the configuration of the capacitors, in connection with the windings of the machine, can reduce the electromagnetic toque variations and increase the energy conversion efficiency.*

Keywords – *single phase induction generator; capacitors; high efficiency operation.*

1. INTRODUCTION

The quest for solutions regarding the electric energy generation from renewable sources is still underway. Considering a small, islanded, power network with an installed power capacity of less than 5 kW, a single-phase operation could have some advantages: lower initial cost of power equipment, especially power electronics.

The use of a biogas installation for production of electrical energy implies the need for an electrical generator. Direct current (DC) or alternative current (AC) machines could be considered. DC machines have the inherent disadvantage of brushes. The AC machines considered are synchronous and asynchronous. The synchronous machines have two main constructive possibilities: with excitation coil on the rotor or with permanent magnets on the rotor. First option has the main disadvantage as the DC machines and yields lower power efficiency as an excitation rotor current is needed. The permanent magnet synchronous machines have the best energy efficiency, but are more expensive and usually need power converters. The most cost-effective solution is to use asynchronous machines. The main drawback, of this topology, is the lower efficiency, due to important Joule losses in the rotor bars and the need of capacitors for the auxiliary coil of the single-phase machine. Also, compensation of the power factor is needed. In order to use an asynchronous generator with a biogas motor, it should be noted that the biogas motor should work at a quasi-variable speed.

The use of a single phase induction machine as generator has been presented in many scientific papers or books. In [1] is presented the configuration of self-excited, self-regulated induction generator. The authors of [2] present several configurations for the operation of the single-phase induction generator. In [3] a self-excited induction generator was modelled and simulated.

The aim of this study was to investigate the operation of the single-phase induction generator driven by a thermal engine and feeding a small power grid that includes other energy sources.

In section 2 is presented the single-phase asynchronous machine converted from motor to generator, in section 3 the experimental results and the paper is ended by conclusions part.

2. ASYNCHRONOUS MACHINE

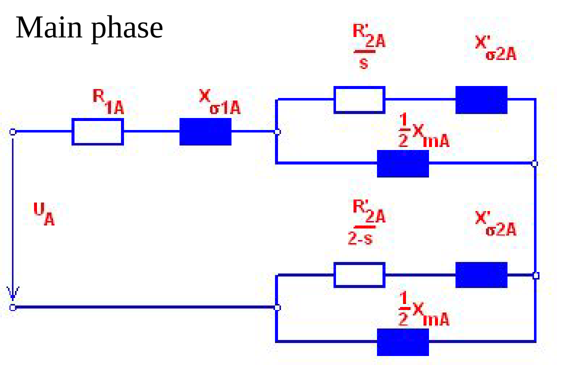
2.1. Characteristics

The operation of the single-phase asynchronous generator (SPAG) implies the use of a two windings machine (main one and the auxiliary one) disposed at 90 electrical degrees in the stator. The voltage phase shift between the two windings is less than 90 degrees, being obtained, usually, by a series connected capacitor with the auxiliary winding.

The machine considered in this study has the following parameters:

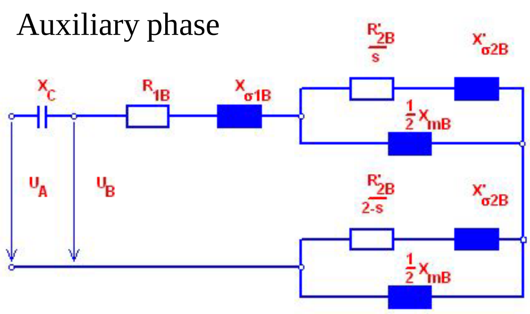
- Power: 1500 W
- Pole pairs number: 2;
- Nominal speed at 50 Hz: 140 rpm;
- Nominal current: 16.8 A;
- Efficiency at rated power: 68%;
- Power factor: cos(φ)=0.91.

The equivalent circuit (received form Electroprecizia Sacele) for the main and auxiliary phases is presented in Fig. 1 a) and b).



R_{1A} [Ω]	$X_{\sigma 1A}$ [Ω]	R'_{2A} [Ω]	$X'_{\sigma 2A}$ [Ω]	X_{mA} [Ω]
0.618	1.529	1.152	1.077	21.280

a)



X_C [Ω]	R_{1B} [Ω]	$X_{\sigma 1B}$ [Ω]	R'_{2B} [Ω]	$X'_{\sigma 2B}$ [Ω]	X_{mB} [Ω]
28.938	0.944	2.029	1.152	1.028	20.315

b)

Fig. 1 – Equivalent circuit for a) principal winding b) auxiliary winding.

In Fig. 1 *R* represents the electrical resistance, X the reactance, *U* the a.c. voltage, *s* represents the slip, the A and B denominators represent the main and auxiliary windings respectively, the 1 and 2 denominators represent the stator and respectively the rotor relative to the stator parameters, the coefficients *m* and *σ* are indicating the magnetizing reactance and leakage reactance respectively. The denominator *C* refers to the capacitor.

2.2. SPAG configurations

The machine presented in section 2.1 is manufactured for use as a motor and the capacitors have a capacity of 110 μF (2x55 μF). In Fig. 2 is presented the single-phase asynchronous machine using the classic configuration of windings and capacitor connection.

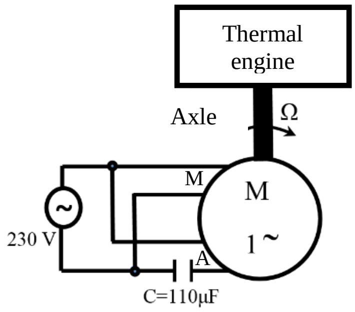


Fig. 2 - Classic connection to the grid of induction machine when used as motor and converted directly to generator.

In Fig. 3 is presented the self-excited SPAG configuration considering a capacity of 55 μF connected to the auxiliary winding.

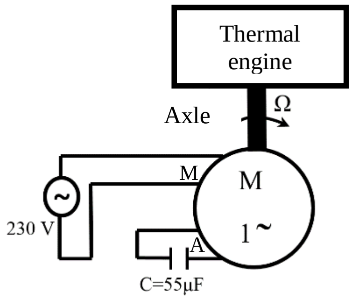


Fig. 3 – Self excited SPAG.

In this configuration only the main phase is connected to the power grid, the auxiliary phase being connected to the capacitor/capacitors [1] – [3].

3. EXPERIMENTAL TESTS AND RESULTS

3.1. Test bench

Both configurations where experimentally tested using a thermal engine emulator and auxiliary measurement devices (Fig. 4). The thermal engine was emulated using a DC machine that drives the SPAG. Between those two machines was intercalated a torque transducer. The speed was measured by using an incremental encoder. The dSPACE board is used for data acquisition. The DC machine is operated in separately excited configuration being fed by two autotransformers and two diode rectifiers.

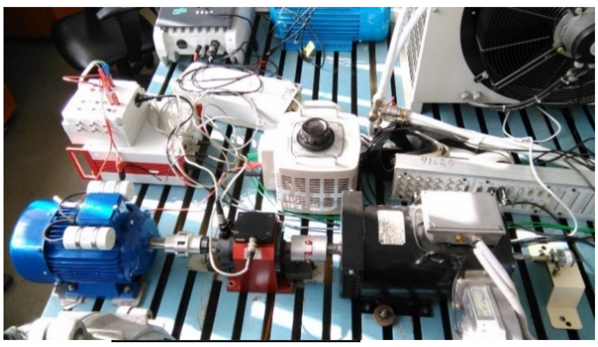


Fig. 4 – Photo of test bench.

3.1. Experimental results

There were made several tests on the classical configuration and self-excited one with the SPAG connected to the power grid. Due to high torque variations the tests were made for an active power of around 500 W.

In Figs. 5 – 9 are presented some results for the test of the SPAG in classic configuration presented in Fig. 2.

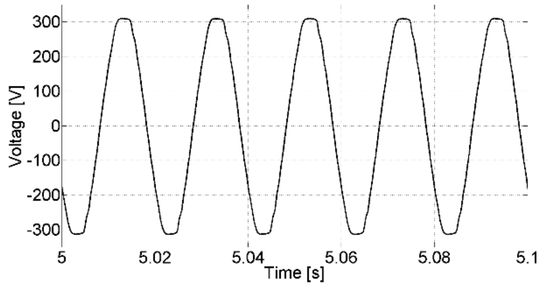


Fig. 5 – Power grid voltage.

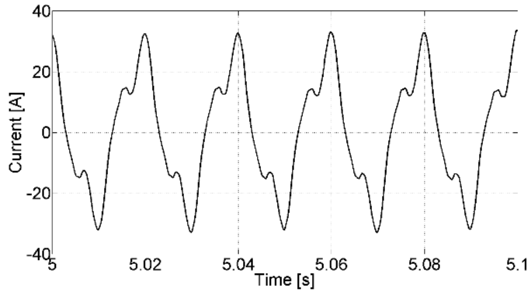


Fig. 6 – Current in the main winding, connected to the power grid.

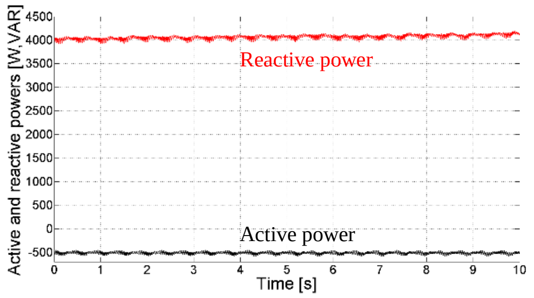


Fig. 7 – Active and reactive powers.

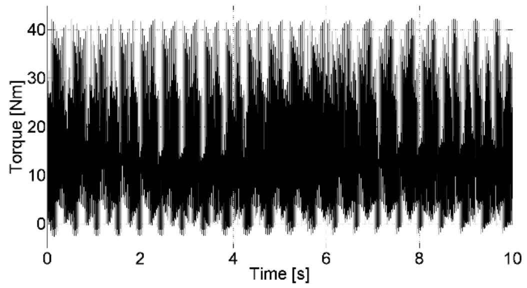


Fig. 8 – Torque of the SPAG.

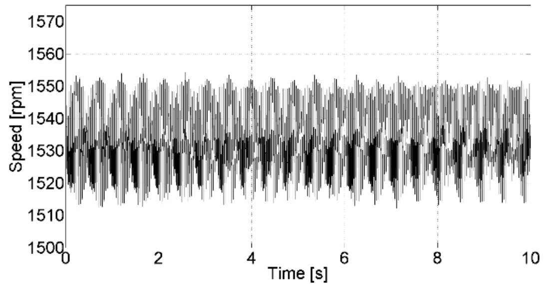


Fig. 9 – Rotor speed of the SPAG.

As can be observed form these results, the torque variations are very high (Fig. 8) and due to this, the rotor speed has also important fluctuations (Fig. 9). The current exchanged with the power grid has important harmonics (Fig. 6). Also, the reactive power absorbed from the power grid is around 4 kVAR (Fig. 7).

In Figs. 10 – 14 are presented some results for the test of the SPAG in classic configuration, presented in Fig. 3, knowing that the second remaining capacitor of 55 μF was connected in parallel with the main winding.

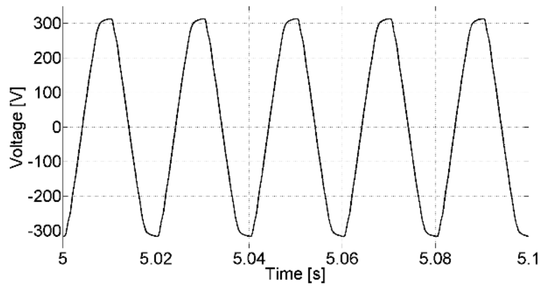


Fig. 10 – Power grid voltage.

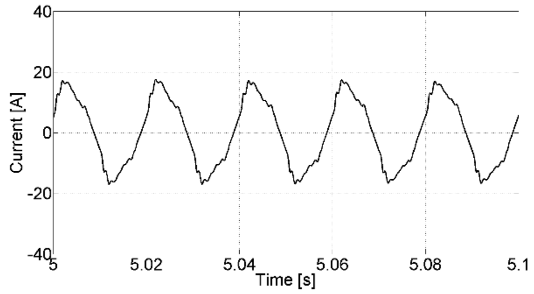


Fig. 11 – Current in the main winding, connected to the power grid.

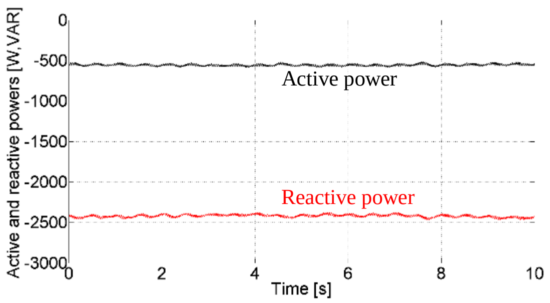


Fig. 12 – Active and reactive powers.

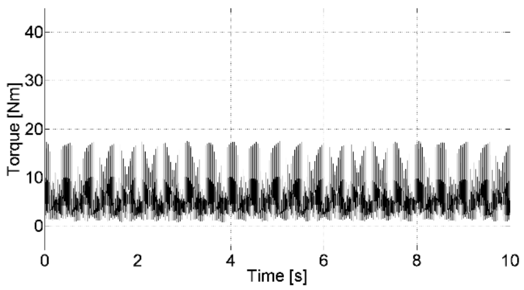


Fig. 13 – Torque of the SPAG.

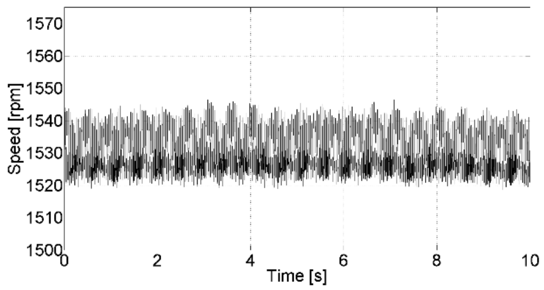


Fig. 14 – Rotor speed of the SPAG.

As can be seen from these results, the torque and speed fluctuations are greatly reduced (Figs. 13 and 14). The current harmonics are also smaller (Fig. 11) and the reactive power is now injected into the power grid (Fig. 12).

It is obvious that the second remaining capacitor of 55 μF can be removed from the main winding. The Figs. 15 – 19 are presenting the test results for this configuration (Fig. 3).

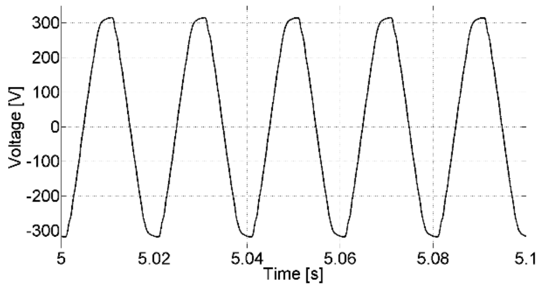


Fig. 15 – Power grid voltage.

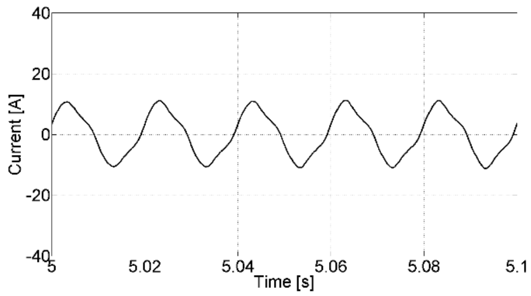


Fig. 16 – Current in the main winding, connected to the power grid.

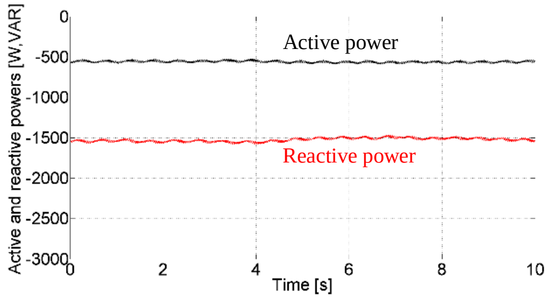


Fig. 17 – Active and reactive powers.

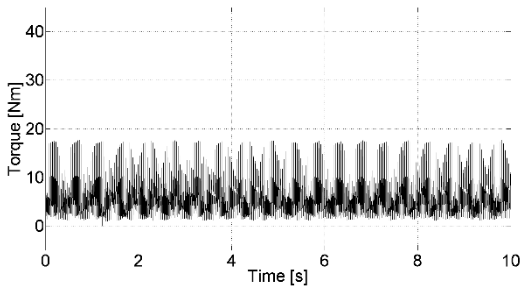


Fig. 18 – Torque of the SPAG.

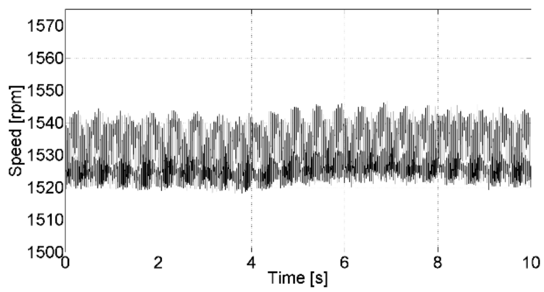


Fig. 19 – Rotor speed of the SPAG.

As expected, compared to the previous results, the reactive power injected into the power grid is reduced (Fig. 17). The torque and speed fluctuations are similar (Figs. 18 and 19). The current injected into the power grid (Fig. 16) has even less harmonics.

Another important aspect is the SPAG efficiency. As can be observed from the current of the SPAG for the three cases (Figs. 6, 11, 16), the efficiency of the machine is increased for the self-excited configurations, the current being smaller for approximatively the same active power injected into the power grid.

4. CONCLUSION

This paper has presented some experimental results for a single-phase induction machine working as generator. The results are showing that the configuration of the capacitors, in connection with the windings of the machine, can reduce the electromagnetic toque variations and increase the energy conversion efficiency.

If this machine would be used as generator in single-phase power systems, a variable capacitor bank could be connected to the main winding, thus the control of the reactive power for the whole power grid can be achieved.

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Stefan Breban
SC BMEnergy SRL, 80, Donath st., Cluj-Napoca, Romania
stefan.breban@bmenergy.ro