INDUCTIVE-CAPACITIVE CURRENT STABILIZER POWERED BY AN ASYNCHRONOUS GENERATOR

GEORGIEV GEORGI[1*], EVSTATIEVA NADEZHDA[1], TZVETKOV ILIAN[1]

[1]Department of Theoretical and Measuring Electrical Engineering, University of Ruse, 8, Studentska str., Ruse, 7017, Bulgaria

Abstract: The simplicity, reliability and low cost of the asynchronous generators make them suitable (compared to the synchronous ones) for use as autonomous generators especially when lower load power is applied. This explains the purpose of the present paper which is to analyze a feasible application of asynchronous generators with practical value as a powering element of an inductive-capacitive current stabilizer. Analytical studies were carried out using a complex method for analysis and research of electromagnetic circuits. The obtained ratios justify the assumption of complementarity of the two systems (parametric current source and autonomous asynchronous generator) in their joint work. Thus, the special capacity for asynchronous generator excitation becomes irrelevant. The experimental checks confirm the analytical results.

Keywords: asynchronous generator, inductive-capacitive current stabilizer, parametric current source

1. INTRODUCTION

The advantages when using low-power asynchronous generators (AG) (about ten kilowatts) compared to synchronous generators are known – significantly lower cost, simplicity and reliability. Only the slightly higher efficiency (with 1-2%) of synchronous generators makes an exception. Its relative impact, however, is explicably diminished when smaller capacities are applied. Therefore, when comparatively low-power generators are needed (for example local or autonomous power supply up to ten kilowatt) exactly asynchronous machines are logically used [1]. Their characteristic feature is the reactive power which is needed for the AG self-excitation. In the conventional cases, it is provided by additional condenser batteries. In spite of their relatively small price, their use causes inconvenience and deteriorates the mass-dimensional indices of the entire generator.

In this paper, the idea for avoiding or strongly diminishing the necessity for such batteries in particular cases is considered. This will simplify the system operation and reduce its cost. The preliminary tests carried out demonstrated that this is very likely when an AG is combined with a specific consumer the input impedance of which has a capacitive nature. In this way, the consumer will provide the needed reactive power for the excitation and generator operation by itself.

The aim of this study is to examine the possibility of asynchronous generator operation without capacitors battery or its operation with small capacities capacitor banks.

[*] Corresponding author, email: grashkov@uni-ruse.bg

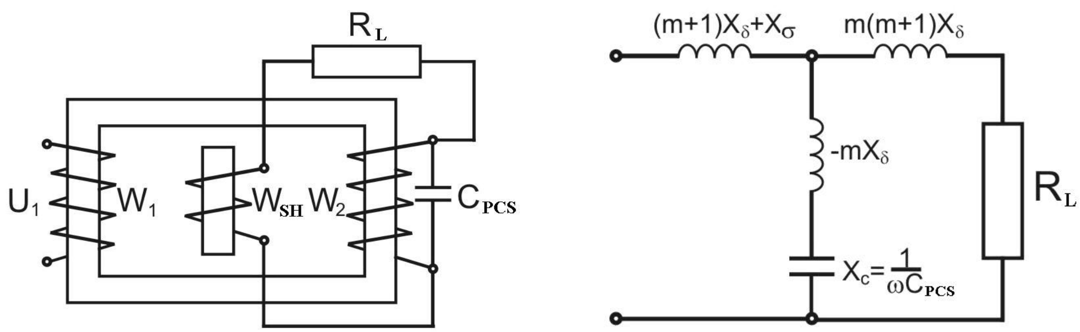
2. ANALYTICAL STUDIES AND RESULTS

2.1. Object of control

The work of inductive - capacitive current stabilizers is analyzed and studied in [2, 3, 4]. The notion "Parametric Current Sources" (PCS) used by authors is identical with the larger notion "inductive-capacitive stabilizers" (ICS) used in some reference sources [5]. A circuit schematic of a basic version of an inductive-capacitive current stabilizer is shown in Figure 1.a. A magnetic shunt transformer with an aerial gap is characteristic for it. Its advantage is due to the fact that a throttle is built in the main matching transformer. A convenient method for analysis and studies of such systems, used by many authors, is the complex one. An equivalent electric circuit [2, 4] is given in Figure 1.b based on which mathematical analysis is made.

The following symbols are used there:

- $m = \frac{W_2}{W_L}$ - coefficient of secondary coils;
- X_δ - inductance from the shunt aerial gap;
- X_σ - inductance from the leakage flux;
- X_C – capacitive resistance;
- R_L - load resistance (in the general case can be full impedance Z_L, but when the power consumer of the unit is the electric welding arc is accepted simplifying assumptions about pure active consumer).



a) b)

Fig. 1. a). Circuit schematic of a basic version of the inductive-capacitive current stabilizer;
b). equivalent electric circuit of an inductive-capacitive current stabilizer based on which mathematical analysis is made.

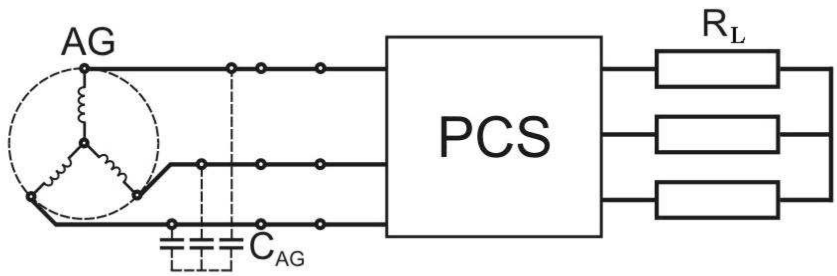
Only one of PCS properties will be subject to special consideration – many authors have unquestionably proven that the input impedance of this type of circuits has a significant capacitive component. It is appropriate to mention that this property favors the power factor ($\cos\varphi$) of the conventional power lines to a great extent. This is why the latter is one of the main advantages when PCS are used.

Systems which stabilize not only current but also voltage have been developed based on electronic elements but this is common for lower power. Since PCS can operate flawlessly under big loads, its major advantages are demonstrated. Electric arc welding is an example for the genuine application of PCS. It was proven [2, 5] that welding power sources based on inductive-capacitive stabilization ensure better technological indices of the welding process and better quality of the weld.

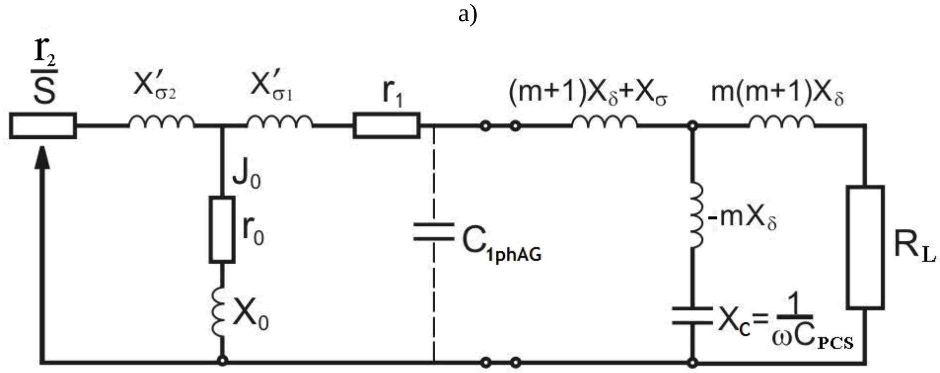
If a relation has to be found out between the asynchronous generators and PCS, a preliminary correspondence of their major properties and the ensuing from it potential to supplement each other are established. On one hand, AG as a power supply needs a capacitive element at its output (for its self-excitation) and on the other hand, PCS as a consumer (or as an agent between the source and the final consumer R_L) provides at its input a significant capacitive impedance component. This means that when both systems operate together, they must be capable of exchanging reactive (capacitive) power. In this case, their size will be changed and under certain conditions the needed condensers for the AG operation will become irrelevant. The set task is to prove and check this potential under real conditions (of electric arc welding).

2.2. Main analytical studies

The circuit schematic solution which combines a three-phase asynchronous generator (as a power supply) and a three-phase parametric current source (as a consumer) is shown in Figure 2. a. Its equivalent electric circuit for one of the three symmetrical phases of the system is shown in Figure 2. b. It is based on the classical theory for asynchronous electrical machines (the symbols of the machine resistors r_1, r_2, r_0, r_1, X_σ, X_0 and shear s are based on it) and reference points [2, 3, 4, 5], according to which the rest of the symbols are used (Figure 1).



a)



b)

Fig. 2. a) Circuit schematic solution which combines a three-phase asynchronous generator (as a power supply) and a three-phase parametric current source (as a consumer); b) equivalent electric circuit for one of the three symmetrical phases of the system.

The condensers which are marked with a punctuated line and index AG are the ones mainly needed for the AG excitation and operation. A PCS will be made in order to prove the potential for their substitution by the capacitive impedance of PCS and respectively for their exclusion.

The electric machines theory states that a condition of the AG operation is the existence of equivalence between the reactive conductivities (B) of one of its phases (inductive) and of the condenser (capacitive):

$$B_{1phAG} = B_{1phC} \tag{1}$$

where: $B_{1phC} = \dfrac{1}{X_{C1ph}} = \omega.C_{1ph}$

For facility's sake and sufficient practical accuracy [6], the needed capacity can be found by making equal the equation of the AG active power (known in advance) and the reactive condenser power instead of solving the circuit from Figure 2. b and equation (1), i.e.:

$$P_{AG} = Q_C$$

On the other hand, the numerous studies carried out of the various circuit solutions of PCS [2, 3, 4] give the following solutions for the total input admittance Y (for one phase) of the circuit solution which is subject to consideration herein:

$$Y_{PCS} = \sqrt{y^2 + g^2}\,, \tag{2}$$

where y is the reactive input conductivity and g is the active one. When the circuit from Figure 1.b is analytically solved, the following expression is obtained:

$$y = \frac{(AB - B^2 - R_L{}^2)^2 + R_L{}^2 A^2}{(AB - B^2 - R_L{}^2)(B^2 + R_L{}^2).A} \tag{3}$$

$$g = \frac{(AB - B^2 - R_L{}^2)^2 + R_L{}^2 A^2}{R_L(B^2 + R_L{}^2).A^2} \tag{4}$$

The following substitution is made: $B = m(m+1)X_\sigma$, $A = X_C + mX_\sigma$.

In order to simplify the mathematical analyses and show the results in a clear manner, it is convenient to assume that $R_L = 0$ (Figure 2. b.). This refers to the real case reviewed here, i.e. when PCS feeds the electric welding arc. This means that the following analyses will refer with the biggest accuracy to a welding current source. There is no major obstacle that those considerations be made for other consumers as well, if needed.

For this purpose, the reactive component of the PCS conductivity is especially important. When $R_L = 0$ the latter is:

$$y = \frac{A - B}{AB} \tag{5}$$

2.3. Results

It is apparent (5) that the input conductivity of the parametric source can have a negative value, i.e. it can be of capacitive nature. This is observed when $B \ge A$ or when $m(m+1)X_\sigma \ge X_C + mX_\sigma$, i.e.:

$$m^2 X_\sigma \ge X_C \tag{6}$$

There are no major obstacles for the practical implementation of this inequality. Indeed, if the purpose is that the capacitive component of the PCS input impedance substituted entirely the needed capacity for the AG operation, the following relation shall be available:

$$BC_{1ph} = y = \omega.C_{1ph} = \frac{X_C - m^2 X_\sigma}{m(m+1)X_\sigma(X_C + mX_\sigma)} \tag{7}$$

The so established condition can be set out as an input condition when designing a PCS powered by an AG. In this case, the matching between them will be maximal. The practice shows that AG operates normally even when there is a certain deviation from condition (1) and therefore when there are deviations from (7) in this case.

A major opportunity which deserves considering is to control the fulfillment of condition (7) as well as the related with the latter automatic control of known capacity (of comparatively small value) in such a way which always ensures its implementation. Such study will be subject to the authors' further efforts.

3. EXPERIMENTAL CHECK

Experiments were carried out in order to check the set out and analytically substantiated above idea for joint operation between AG and PCS. The two main elements of the experimental circuit were selected with similar power and compatibility prerequisites:
1. A standard asynchronous machine of type AD-160-M4 (the used symbols are according to the Bulgarian standard for electric motors) with power 11 kW , set in a generator operation mode (AG).
2.Three-phase welding power source containing PCS (with equivalent circuit for each phase according to Figure 1).

Apparently, they were not designed particularly for such joint operation. Nevertheless, combining them in a common unit according to the circuit solution in Figure 2 was successfully implemented without any special issues.

3.1. Experiments and results

The carried out experiments showed more than satisfactory results. When the PCS is powered by AG, though without including condenser batteries commonly needed for the normal operation of the asynchronous generator, it excited itself to its rated linear voltage (380 V). This is a sufficient proof for the expected and analytically substantiated above ability of the two machines to supplement each other.

At a second stage, experiments were carried out for the unit operation under real conditions of manual electric arc welding. The asynchronous generator powered successfully the welding current source (PCS) when welding with currents from 80 to 160 A. In these operation modes, the fulfillment of condition (7) has a deviation within $\pm$ 20% which is not an obstacle for the operation of the so designed unit. It was expectedly proven that when the welding currents exceed the said values (deviation from the condition with more than 20%), the capacitive component of the PCS input impedance was not sufficient to power the AG with the needed reactive power and the generator used to reduce its output voltage. This impacted the PCS operation and made difficult and even impossible the normal welding modes. When an additional capacity of 10 to 20 μF was added (according to Figure 2) to each of the three phases, the normal joint operation of the system was restored.

4. CONCLUSIONS

As a conclusion it can be stated that the theoretically substantiated and then experimentally checked idea for joint operation of an Asynchronous Generator and PCS without special condensers for AG excitation is true and practically feasible. This suggests a new solution for obtaining an autonomous welding current source to be used under field, breakdown and other conditions when there is no conventional power supply.

The main advantages of this solution are the following:
- improved energy indices of the AG – PCS unit (operation with power factor cosφ very close to 1);
- improved burning of the welding electrical arc and thus improved quality of the welds. This is implemented by powering the welding arc with PCS [2];
- excluding the need for special condenser batteries for self-excitation and asynchronous generator operation;
- better reliability, mass-dimensional and value indices when using AG versus the alternative synchronous generator.

REFERENCES

[1] Georgiev, G.R., Autonomous Asynchronous Generator – Justification, Manufacturing, Purposes. International Scientific Session of Ruse University Angel Kanchev, 2008.
[2] Georgiev, G.R., Single Phase Parametric Current Source. Operation under Conditions of Electric Arc Welding. Ruse, Sofia, 1982, dissertation.
[3] Georgiev, G.R., N.T. Nikolov, Single Phase Parametric Source of Unaltered Current – Author Certificate 28220/25.10.78.

[4] Georgiev, G., Single Phase Parametric Current Source - Operation of a Magnetic Shunt Transformer and Condenser Connected to a Shunt Coil, Summer School and International Conference in Theoretical Electrical Engineering at Sofia Technical University, Sozopol 2005.
[5] Millyah, A.N., Volkov, I.V., Unaltered Current Systems Based on Inductive-Capacitive Transformers, Kiev, 1974.
[6] Voldek, A., Electrical Machines, Technica Publishing House, Sofia 1971.