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APPLICATION OF THE SQUIRREL CAGE ASYNCHRONOUS MACHINE WORKING AS SINGLE PHASE GENERATOR IN MICROHYDRO POWER PLANTS

Sorin Ioan DEACONU, Marcel TOPOR, Gabriel Nicolae POPA, Diana BISTRIAN

"Politechnica" University of Timisoara, Faculty of Engineering of Hunedoara, Department of Electrical Engineering and Industrial Informatics, ROMANIA

Abstract:
Today the hidroenergy potential of Romania is used only in proportion of 60 %. There are in work several project concerning the arrangement of several water flows (Jiu, Strei, Bistrita, Mures). This will increase the overall percent up to 70 % in 2020.
However it remains an important percent of usable potential which can be integrated by technology upgrade or building of new power plants.
The asynchronous generator is a more efficient solution for small installed power and especially where the electric consumers are single phase and the electrical grid is isolated from the main grid.
Keywords:
asynchronous machine, single phase generator, mathematical model

1. INTRODUCTION

Power is the vital input for economic development for any developing country. Technologies being at its zenith, many methods for the generation of power have been developed. Owing to the perpetual increase in energy needs it is difficult to meet the growing demand by exploiting energy from the limited conventional sources such as coal, oil, gas, etc. In consequence a greater emphasis is now being given to the harnessing of energy from non conventional energy sources such as wind, micro and mini hydro and solar [1].

As a result of increasing environmental concern, more and more electricity is generated from renewable energy. The main advantage of electricity generation from renewable sources is the absence of harmful emission and the infinite availability of the prime mover that is converted to electricity [2].

With continuing energy crises, utilities in poor countries are finding it increasingly difficult to establish rural area electrification. The cost of supplying electrical power through grid to such areas is becoming excessively high to the large investments in transmission lines losses. Far these reasons the stand-alone decentralized power generating stations using non-conventional energy sources like wind, micro and mini hydro are being considered for electrifying rural and remote areas [1].

Taking into account its simplicity of use and its modest cost compared to a synchronous machine, the asynchronous machine is as susceptible to function in generating in power stations of production of the electric energy. In this case, the slip is negative and the rotor turns in the direction of the spinning field pattern at a slightly higher speed. The generator provides the active power to the utility, but the reactive power necessary to its supply is provided by the utility. An isolated operation of the induction generator is possible. The convert of renewable energy is mainly equipped by both asynchronous generators and capacitors of self- excitation [3].

In many papers is investigated the ability of some dynamic self- asynchronous generator models to predict the output voltage depending of the variation of turbine speed (figure 1).

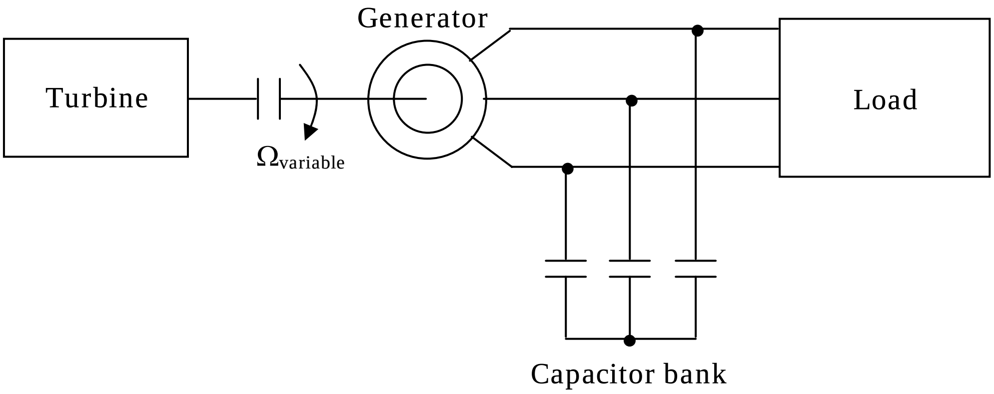


Figure 1 Self-excited asynchronous generator

Low-power generators (say up to 10 kW) invariably feed a single-phase supply system. Since it has been found that a normal single-phase asynchronous motor cannot be effectively used as self-excited generator, a specially designed two-winding single-phase has been proposed in [4]. Since this requires modified manufacturing procedures, and hence is expensive, the alternative of using off the shelf three-phase load asynchronous motor as a self-excited asynchronous generator to feed single-phase load appears attractive. This requires a suitable balancing system to achieve balanced wending currents and to obtain maximum output with minimum losses [5].

Large numbers of exploitable small hydro sites exist in several countries with capacities ranging from 5 to 50 kW, mostly needing to feed single-phase loads. The use of three-phase asynchronous motors as self-excited asynchronous generator to feed such loads makes practical sense. The present paper provides theoretical support to such promising technologies.

2. STATEMENT OF THE PROBLEM

When the rotor speed of asynchronous machine is greater than the synchronous speed of air gap revolving field, then the same asynchronous machine can be act as asynchronous generator.

As a generator asynchronous machine has severe limitation. Because it lacks a separate DC field current, an asynchronous generator needs AC excitation current. The self excitation phenomenon using external capacitors is well known. If an appropriate capacitor is connected across the terminals of an externally driver asynchronous machine as shown in figure 1, an EMF is induced in the machine wending to the excitation provided by the capacitor [1],[6].

Induced voltage and current will continue to rise until the VAR supplied by the capacitors is balanced by the VAR demanded by the machine, a condition that is essentially divided by on saturation of the magnetic circuit.

Let us consider that the machine has an initial residual flux (or same means are provided to inject an initial current into the stator windings), and the rotor is propelled by some external mechanical power source, such as on fuel engine, hydraulic turbine, etc. If external capacitors of adequate values are connected to the stator windings, self excitation occurs. The magnitude of the generated voltage will depend among other things on the capacitance value, the load current, and the load power factor. Considering steady state operation it is possible to observe three regions clearly differentiated: a) a stable zone corresponding to operation in the saturated region of the magnetic core; b) an unstable zone, corresponding to operation on the linear region of the magnetic core; and c) a region of no-generation. In the first case the linear curve of the excitation capacitors intersect the care magnetizing curve at a well defined point. In the second case, the intersection is not well defined, far it occurs at an infinite number of points. In the third case, the only intersection occurs at the origin as is shown in figure 2 [6].

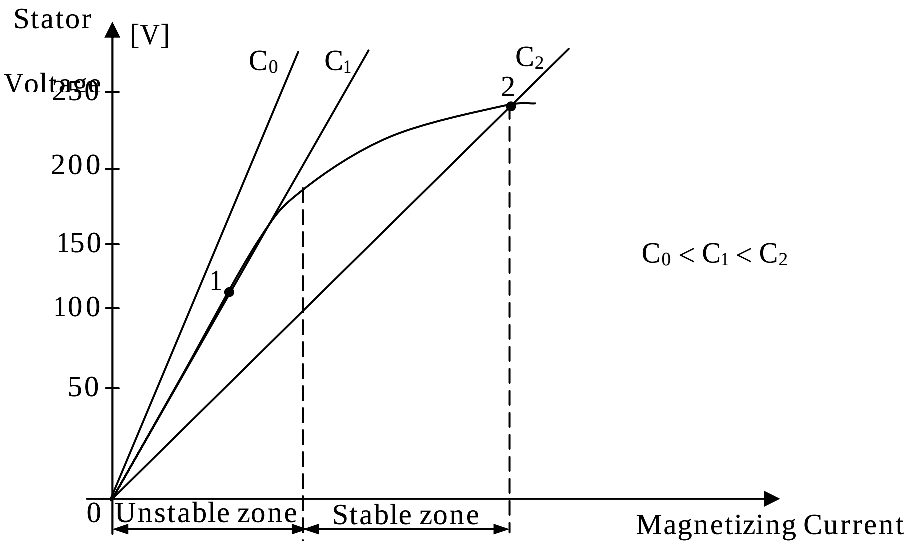


Figure 2 Magnetizing characteristic of a self-excited asynchronous generator

Let us assume that the machine is actually operating at point 1 in figure 2. If a capacitor of value C_2 is connected, the new generated voltage will be determined by the machine characteristic curve, and will evolve from point 1 to point 2 with a definite time constant. Conversely, if the capacitor is reduced from a value C_1 at point 1 to a value C_0, smaller that C_1, the magnetizing current will not be compensated by an identical but leading current component. In this case, the machine will first try to save the situation by dropping some of its magnetizing current in order to reach another stable operating point along its magnetizing curve. This results in a lower air gap voltage and a consequently lower flux; the slip will increase and finally the machine will stop generating (intersection an origin in figure 2). Fortunately, the time constants involved in either situation (voltage increase or decrease) are lower than the generation period, this fact allows corrective commutation actions to be taken to keep the average leading current around its required value [6].

3. EXCITATION REQUIREMENTS OF SELF-EXCITED ASYNCHRONOUS GENERATOR (SEAG)

The minimum capacitance (C_m) for the excitation of asynchronous generator is obtained from no load test. On no load, the capacitor current (I_c) must be equal to the magnetizing current (I_m), under stabile operating:

$$I_m = I_c \qquad (1)$$

$$\frac{U}{X_m} = \frac{U}{X_c} \qquad (2)$$

$$X_c = X_m \qquad (3)$$

where

$$X_c = \frac{1}{2\pi f \cdot C} \qquad (4)$$

From no-load test we calculated the magnetizing reactance X_m by applying the rated voltage of the machine and find out the magnetizing current (I_m). The value of minimum capacitance C for self-excitation is

$$C_m = \frac{1}{2\pi f} \cdot \frac{I_{mphase}}{U_{phase}} \qquad (5)$$

The most serious problem with an asynchronous generator is that its voltage varies widely with changes in load, especially reactive load. In order to maintain constant voltage, reactive current must be controlled from no load to full load. Hence special technologies must be employed to increase the effective capacitance during starting and decrease it during normal operation. [1].

In self-excited mode, output frequency and voltage are affected by speed, the load and terminal capacitor. Changing any of above parameter will change the frequency and magnetizing reactance of asynchronous generators [1].

The schematic diagram of a three phase delta connected self –excited asynchronous generator feeding a three phase unbalanced load is shown in figure 3. The delta connection is deliberately here since a star connected three phase asynchronous motors has be reconnected in delta to feed single phase loads.

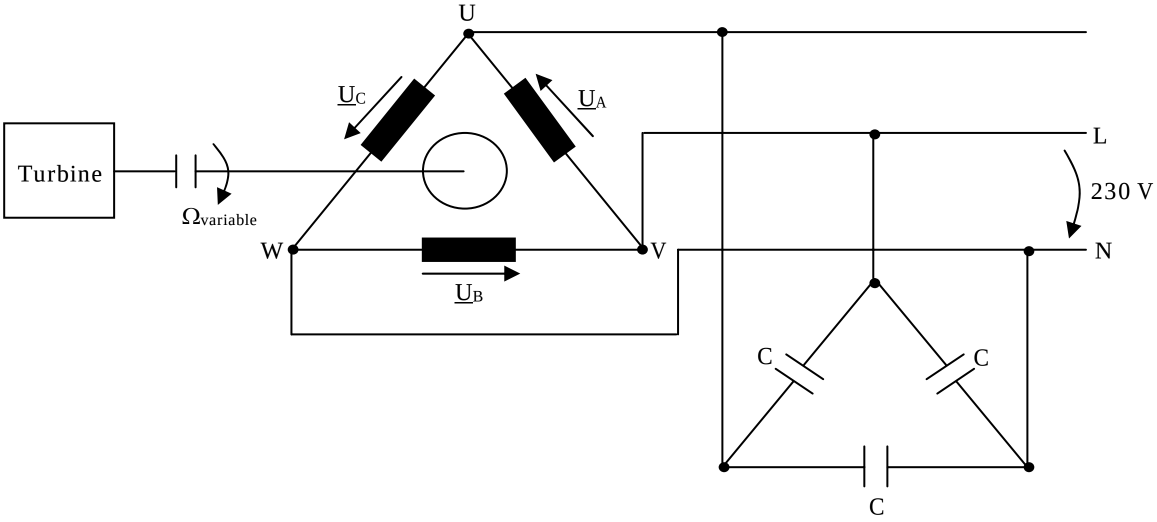


Figure 3 Schematic diagram of self-excited asynchronous generator

4. SIMULATION RESULTS OF THE SEAG

In order to evaluate the operating principles of the self excited asynchronous generators we consider two situations: three phase operation in grid connection mode and single phase connection mode.

4.1. Three phase grid connected operation of the SEAG

The equivalent model of the SEAG operating in three phase mode is presented in fig. 4.

The equivalent per phase impedance seen by the terminals [7] represented in equation (6) is:

$$\underline{Z} = R_1 + jX_1 + \frac{1}{\frac{1}{jX_m} + \frac{1}{R_m} + \frac{1}{R_2/s + jX_2}} \qquad (6)$$

where R_1, X_1 is stator resistance and reactance, R_2, X_2 is rotor resistance and reactance R_m , X_m magnetizing equivalent resistance and reactance, s is slip , F is frequency , $v = n_s/n_r$.

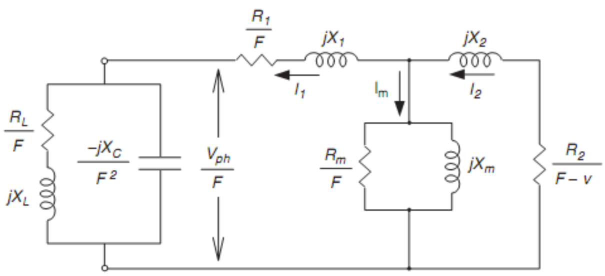


Figure 4 Equivalent circuit diagram of self-excited asynchronous generator

In order to simulate the operation of the SEAG it is necessary to use the d-q model of the SEAG. The d-q model of the induction generator in flux linkage state variables is given in equation (7):

$$\begin{cases} p\lambda_{qs} = V_{qs} - (R_s / L_{1s})(\lambda_{qs} - \lambda_{mqsat}) \\ p\lambda_{ds} = V_{ds} - (R_s / L_{1s})(\lambda_{ds} - \lambda_{mdsat}) \\ p\lambda_{qr} = \omega_r V_{qr} - (R_r / L_{1r})(\lambda_{qr} - \lambda_{mqsat}) \\ p\lambda_{dr} = \omega_r V_{qs} - (R_r / L_{1r})(\lambda_{dr} - \lambda_{mdsat}) \end{cases} \quad (7)$$

where V_{ds} V_{ds} represents d, q axis voltages $\lambda_{qs}, \lambda_{ds}$ d, q axis flux linkages, $\lambda_{mqsat}, \lambda_{mdsat}$ d-q saturated magnetizing flux, R_s, R_r stator and rotor resistance, L_{1s}, L_{1r} stator and rotor inductance , ω_r rotor speed.

The d-q model of the load side that consists of the excitation capacitors C_s in parallel with an inductive load is given by equation (8):

$$\begin{cases} pQ_{qs} = -I_{qs} - I_{qL} \\ pQ_{ds} = -I_{ds} - I_{dL} \\ pI_{qL} = (V_{qs} - R_L I_{qL}) / L \\ pI_{dL} = (V_{ds} - R_L I_{dL}) / L \end{cases} \quad (8)$$

where I_{qs}, I_{ds} is d, q axis current, Q_{qs}, Q_{ds} charge across excitation capacitor, R_L, L load resistance and inductance, Q_s represents the charge across the excitation capacitor. The mechanical equation that describes the prime mover is:

$$\frac{d\omega_r}{dt} = \frac{P}{2J}(T_L + T_e) \quad (9)$$

$$T_e = (3/2)(P/2)(\lambda_{ds} I_{qs} - \lambda_{qs} I_{ds}) \quad (10)$$

where T_e is the asynchronous generator electromechanical torque, T_L is the mechanical load torque , p is the induction generator number of poles, J is the total inertia of the generator and the prime mover machine.

The parameters of test machine are given table 1. The simulation model of the SEAG is build in PSIM software (figure 5). The setup consists in two asynchronous identical machines from which one acts as prime mover. The prime mover machine is a electric drive running a constant speed above the synchronous speed of the SEAG generator.

Table 1. SEAG data

Parameter name	Symbol	Value
Stator resistance	Rs	0.294
Stator inductance	Ls	0.00139
Rotor resistance	Rr	0.156
Rotor inductance	Lr	0.00074
Magnetising inductance	Lm	0.041
Moment of inertia	J	0.0131
Friction factor	F	0.002985
Pole pairs	p	2

The main steady state characteristics of SEAGs are to be obtained at constant (given) speed though a prime mover, such as a constant speed small hydroturbines, does not have constant speed if unregulated.

The self excitation transients of the of the three phase generator operating in grid conection mode with three phase output are presented in fig. 6 and 7.

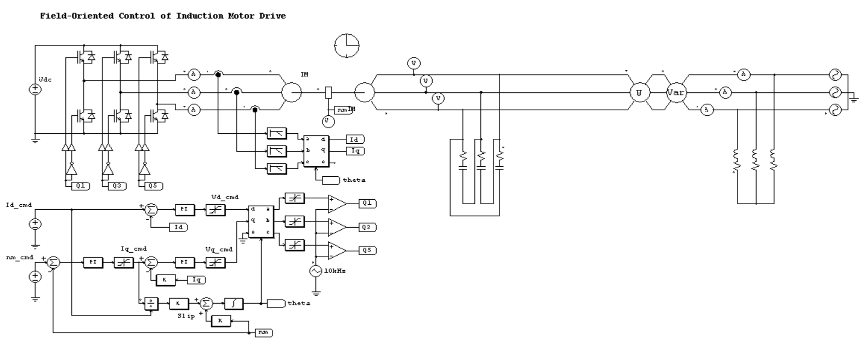
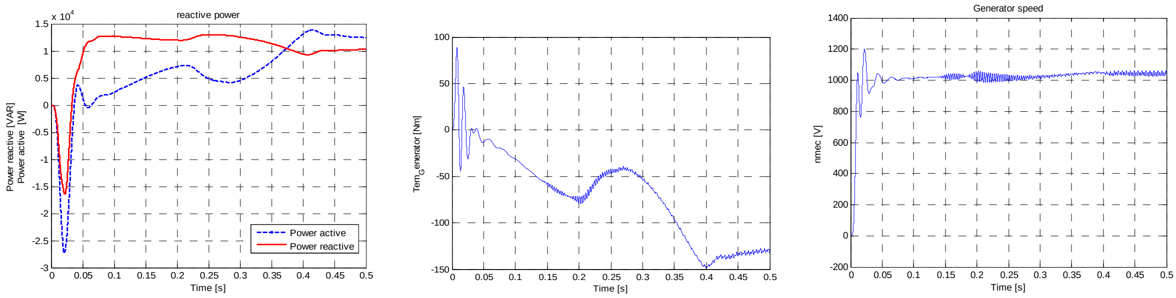
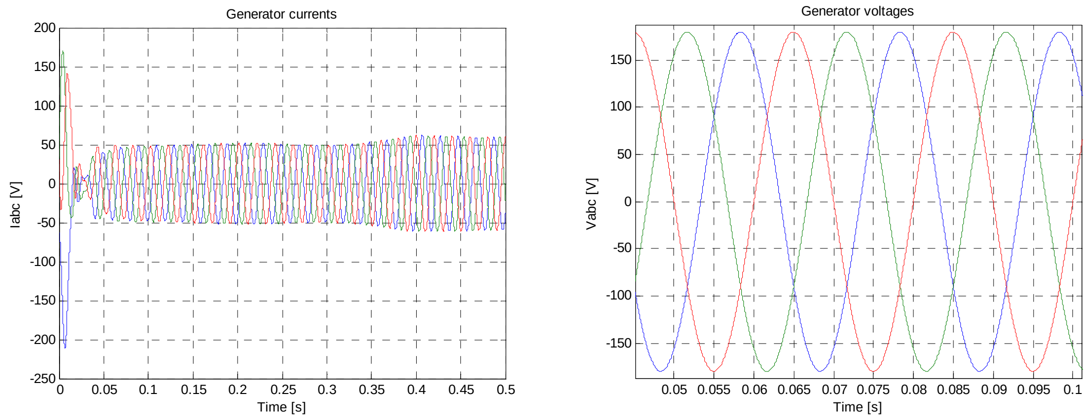


Figure 5 PSIM model of the tree phase SEAG



a) b) c)

Figure 6 Simulation results when SEAG is connected to a 3 phase grid
a) active and reactive power; b) electromagnetic torque; c)speed



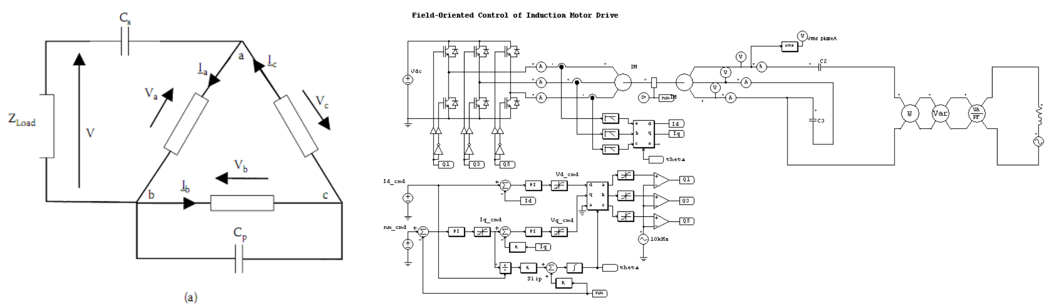
a) b)

Figure 7 Simulation results of generator currents and voltages

The reactive and active energy of SEAG during the startup function working as stand alone generator in three phase grid is presented in fig. 6a. As it can be noticed the required reactive energy varies during generator wakeup and reaches a minimum when the generator is running in steady state mode. The active power in the three phase grid also changes sign during generator wakeup injected/absorbed. The electromagnetic torque of the generator presents no pulsations.

4.2. Simulation of three-Phase SEAG with Single-Phase Output

When the SEAG is operating with a single phase load, the machine operates under unbalanced conditions thus it is imposed a different connection of the SEAG excitation capacitors. We consider here Steinmetz capacitor excitation connection [8] presented in figure 8 a.



a) b)

Figure 8 SEAG Steinmetz excitation connection and PSIM simulation test model

For the simulation of the SEAG in this operation mode we have implemented the generator model into the PSIM software figure 8 b. The single phase electromagnetic torque of the SEAG is presented in fig. 9.

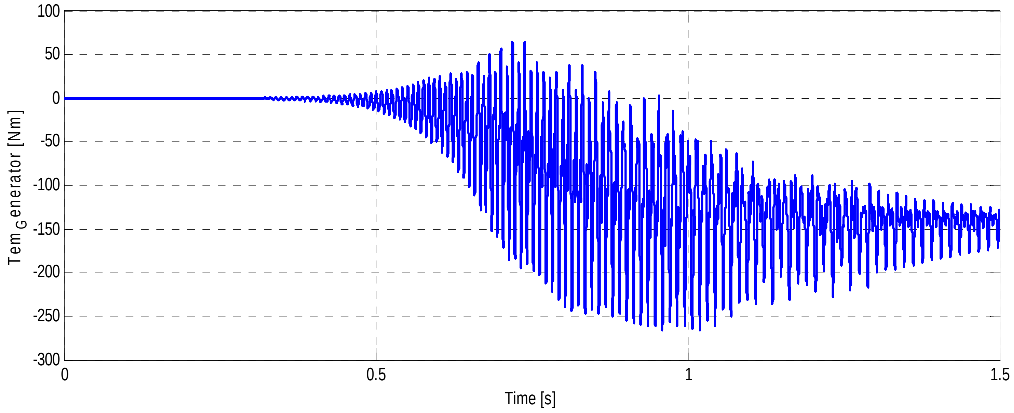


Figure 9 Electromagnetic torque of the SEAG operating in single phase grid connection

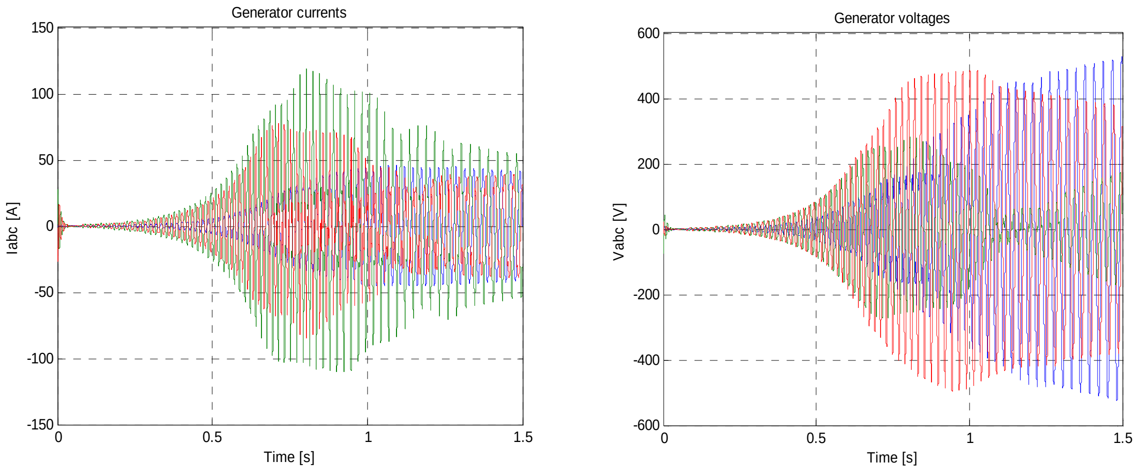


Figure 10 Generator currents and voltages when the SEAG is connected to one phase grid

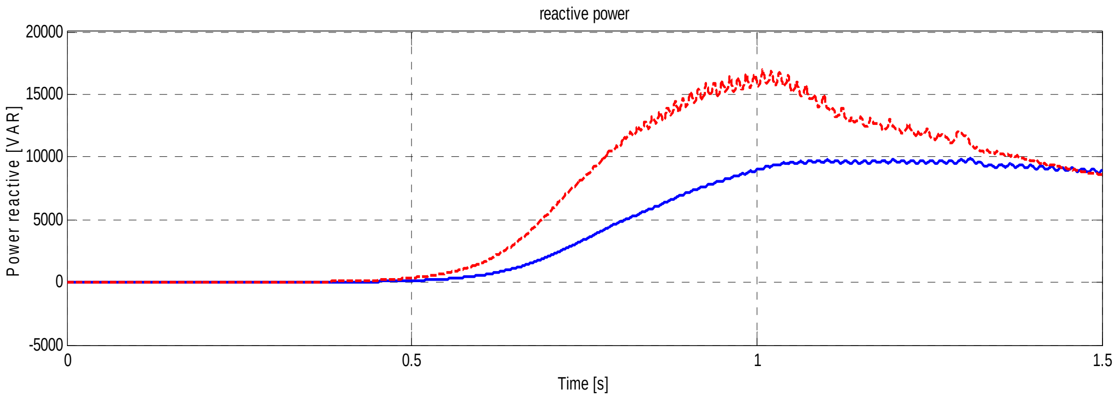


Figure 11 Active power and reactive power of the SEAG

Figure 10 and 11 shows transients of the SEAG during startup of the generator.

5. CONCLUSION AND FUTURE WORK

In the present paper we consider the operation of the single phase SEAG during self excitation process for two situation three phase grid operations and single phase grid operation. The necessary reactive power is evaluate in both cases. As it can be observed the torque pulsations are not negligible and the current pulsations are present. In order to operate the SEAG in single phase grid connection a special attention should be accorded to symmetrisation scheme and capacitor selection.

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