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Grid connection transients of small hydropower generator

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Abstract. This paper presents a transients of an cage induction generator connected to the power grid as it is in small hydropower station. In such power station, there is no control of prime mover speed. The no load speed of water turbine and then induction generator depends on reservoir water level and water pipe diameter. The transient state during connection of the cage induction generator to the power grid is discussed in dependence on generator initial slip. The negative impact of connected cage induction generator on the line is described. The transient current to grid connected generator is very high and produces transient overload of the supply system. The reduction of that negative influence is proposed by using a power electronics converter which works as reactive power compensator. The power electronic compensator is used in steady state to reduce demand of the grid reactive power needed by induction generator and in transients to reduce surge current. The computer model of the generation system, made form induction generator and power electronic compensator, has been designed and used to preliminary verification. Moreover a laboratory generation system has been built and tested.

Key words

hydropower, cage induction generator, reactive power compensation, three level DC/AC converter

1. Introduction

Small hydropower plants are usually equipped in cage induction generator connected directly to power grid. Such an arrangement is very simple because does not need and synchronisation facilities. The cage induction generator may be connected to the grid at any speed. So primitive hydro power station, without a speed controller or even without speed measurement is a very popular arrangement. The produced active power is depending on water level and sometimes is adjusted by water flow using speed governor [1]. However, there are two significant disadvantages of the generation system using cage induction generator. First is great demand of reactive power by the cage induction generator. Hence this induction generator to produce active power needs reactive power. Second disadvantage is high current in transient state of connection to power grid. The amplitude and transient time is depending on initial speed (slip) in connection while, generator power (data) and power grid impedances. This transient state of high current has negative impact on supply voltage causing non controlled voltage drop effecting other loads connected to power system.

The demand of reactive power is partly reduced by application of capacitor compensation Fig. 1. As the demanded, by the generator, reactive power varies continuously and the capacitor bank may by changed stepwise then there is an unwanted and danger coincident to produce higher excitation of the generator resulting in high voltage [2]. To avoid such overvoltage incident the applied capacitor does not fully compensates the generator reactive power.

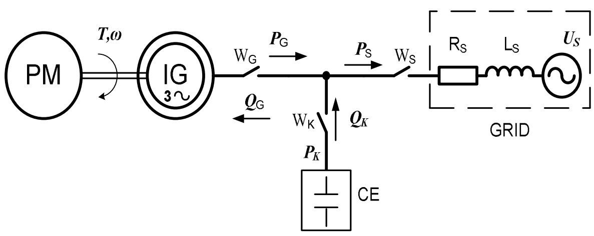

Fig. 1. Power flow in cage induction generator system using capacitor compensator (PM- prime mover, IG- induction generator)

The systems [2], [3] generate the continuously capacitive- reactive power using the capacitors bank and the power electronics switches such thyristors or transistors.

Another, proposed in this paper compensation system, offered to hydro station uses power electronic DC/AC converter producing continuously fully controllable reactive power (Fig. 2) [4], [5], [6], [7].

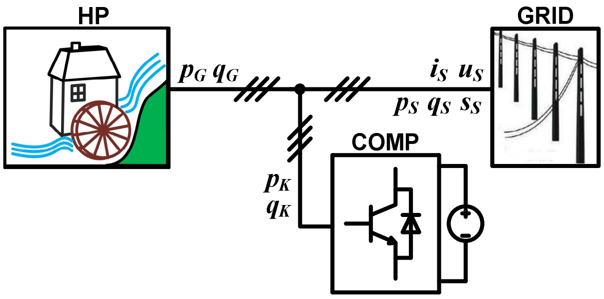

Fig. 2. The main scheme of small hydro plant with power electronic reactive power compensator (i_S- grid current, u_S- grid voltage, p_S- active grid power, q_S- reactive grid power, s_S- apparent grid power, HP- hydro plant, COMP- compensator)

The power electronic compensator COMP has features of instant bidirectional control of active and reactive power. These advantages are used additionally to reduce negative impact on supply system during transients related to connection the induction generator to supply system.

The paper presents results of computer and laboratory investigation of the compensation arrangement operating in transient state caused by connection the generating system to power grid. As the compensator a three level three leg DC/AC converter is applied [8], [9]. This topology allows to reduce the power losses in comparison to two-level converter, while current quality can be kept high [10], [11].

2. Grid connection of an induction generator

The driving water turbine speed is practically not controlled what results connection the induction generator every time at different speed. Therefore, the simulation of the transient states are carried for different initial slips. Data of power system and the generator are presented in Tab. I and Tab. II.

Tab. I. Cage induction machine data used as generator

Generator data	Value
P_N [kW]	7.5
U_N [V]	3 x 220
I_N [A]	27.1
R_S [Ω]	0.328
L_S [mH]	1.3
R_R [Ω]	0.195
L_R [mH]	1.3
L_M [mH]	32.5
$\cos\varphi_N$	0.82
n_S [rpm]	1500
n_N [rpm]	1450
s_N	0.033

Tab. II. Grid data

Grid data	Value
R_S [Ω]	0.15
L_S [mH]	0.4
f_S [Hz]	50
U_S [V]	3 x 220

Results of simulation provided for given initial negative slip are presented in Fig. 3. Fig. 3a and Fig. 3b respond cases of higher than rated (s = 0.033) absolute slip, whereas Fig. 3c shows the case lower (s = 0.025) absolute slip.

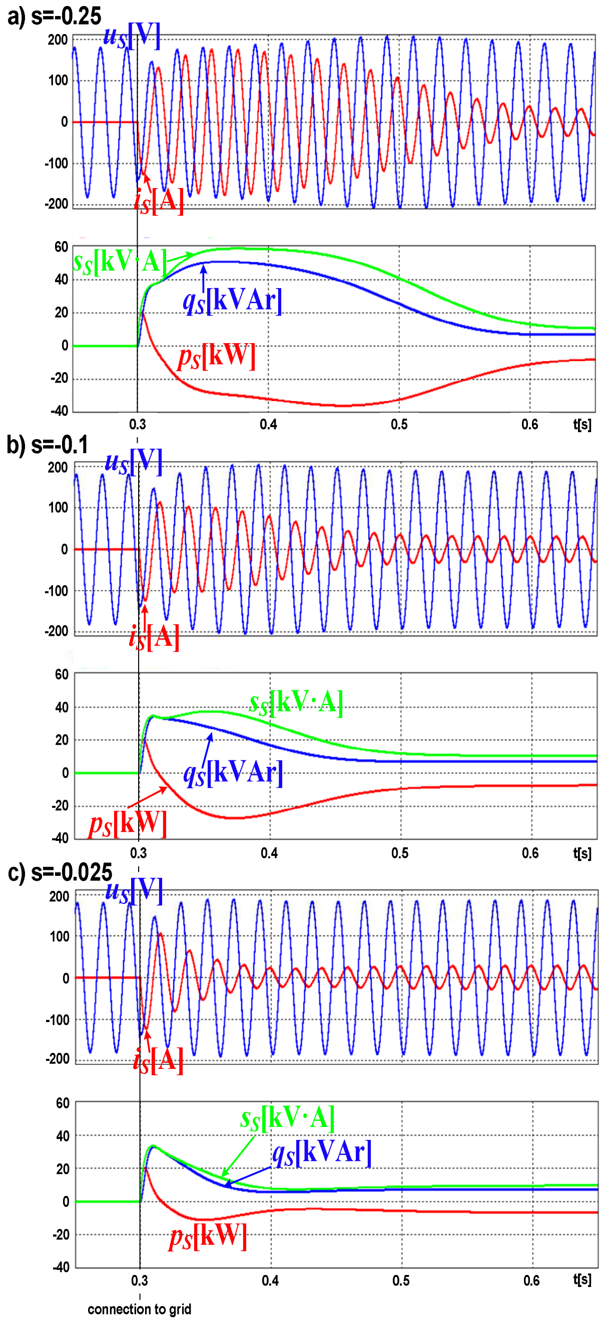

Fig. 3. Transient state connection induction generator to grid with given initial slip; a) s= -0.25; b) s = -0.1; c) s = -0.025

Initial current i_s = f(t) is several times higher than rated (rated amplitude is 38A) and time of high current is longer for higher absolute slip. High current in first period produces significant voltage drop. These transients are well illustrated by instantaneous active (p_s = f(t)), reactive (q_s = f(t)) and apparent power (s_s = f(t)). The active power is in initial state positive, which responds charging inductances of the generator. In initial state the reactive power is very high. More precise presentation of transient currents for a case s = -0.1 is shown in Fig. 4.

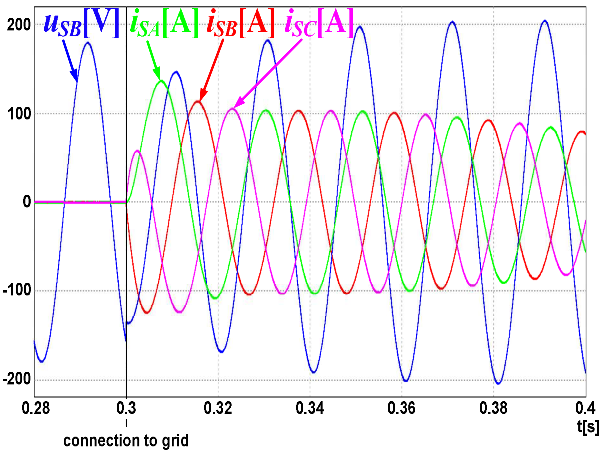

Fig. 4. Phase voltage and currents in transient state connection induction generator to grid - case of initial slip s= -0.1

The peak current rises to 130 A (Fig.4) whereas the rated peak current is only 38A. The 20 % voltage drop is observed.

3. Grid connection supported by power electronics converter

Topology of the generation system is shown in Fig. 5.

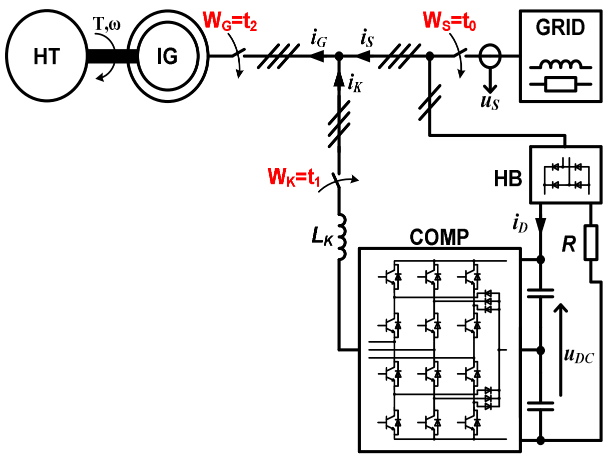

Fig. 5. Schematic diagram of generation system with active compensator COMP

The induction generator IG driven by the water turbine HT is connected to the utility through switch W_G and switch W_S. The three level NPC converter COMP is connected to the power system via switch W_K. An additional input (through rectifier HB) of the compensator COMP is used to preliminary charging capacitors of the DC-link compensator.

The set of power switches W_G, W_K and W_S is used to demonstrate transient states of the generation system. The W_S is switched as a first (say at time t_0). Then the switch W_K at time t_1 (to activate compensator). Finally the switch W_G at time t_2 causing the transient state of the generating system.

The generator control scheme with active compensator is presented in Fig. 6. It is based on Direct Power Control with Space Vector Modulation (DPC-SVM) method [9], [12]. Control scheme consists of four controllers. Rq_K and Rp_K control reactive and active power of compensator. The Ru_{DC} keeps compensator DC-side voltage on the required reference value u_{DCr}. The fourth controller Rq_S controls reactive power of the grid.

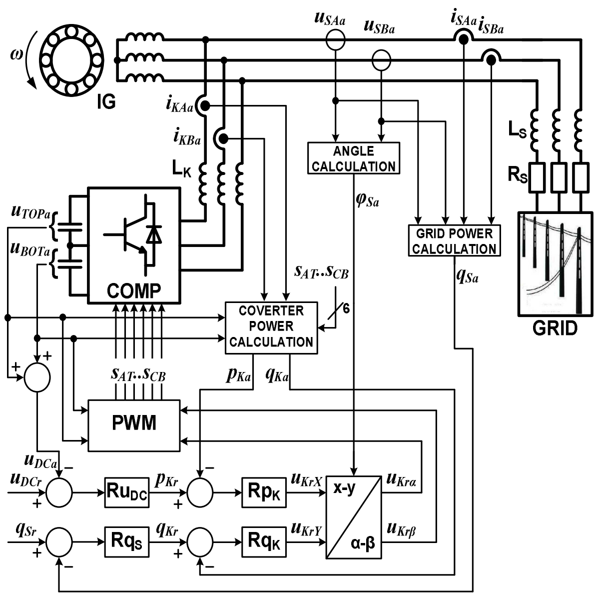

Fig. 6. Control scheme of shunt reactive power compensator

The starting compensator COMP, equipped in DC link capacitor, causes also transients related to high charging current. To avoid high charging current there are three stage of compensator activation. First, the W_S switches on at t_0 = 0.05 s and starts the preliminary charging of DC link capacitors. Second, W_K switchs on at t_1 = 0.2 s, which causes additional increasing of DC voltage. Third, control system of power electronics compensator starts at t = 0.25 and results in increasing and maintaining u_{DCa} voltage on u_{DCr} value. The three stage preparation of power electronic converter to work is presented in Fig. 7. The DC voltages are presented in Fig. 7a, the grid current is presented in Fig. 7b, and the active and reactive power of compensator are presented in Fig. 7c.

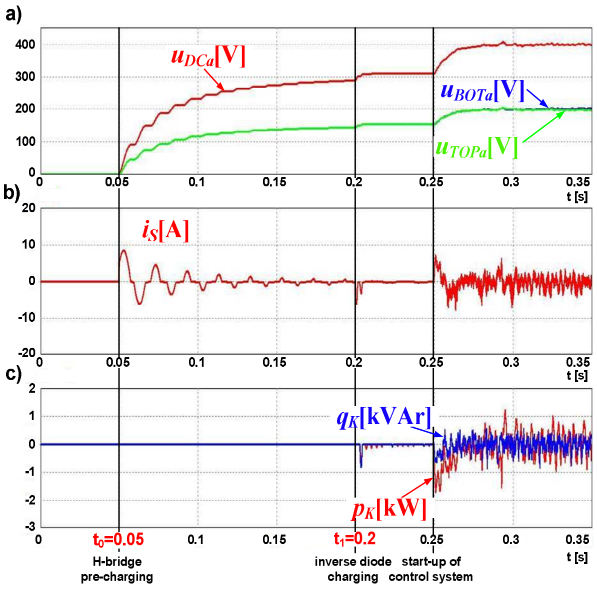

Fig. 7. Preparation of reactive power compensator to operation: DC link preliminary charging starts at t_0 = 0.05 s, W_K switchs on at t_1 = 0.2 s, control system of power electronics compensator starts at t = 0.25 s; a) compensator DC side voltages: DC link voltage- U_{DCa}, capacitor C_{TOP} voltage- U_{TOPa} and capacitor C_{BOT} voltage- U_{BOTa}; b) grid line current i_S; c) active power p_K and reactive power q_K of compensator

After the active compensator reached reference DC link voltage, the induction generator is connected by the switch W_G to the grid (Fig. 8). The compensator limit of generating reactive power is set to q_{KMAX} = 12 kVAr (i_{KMAX} = 30 A). The W_G is switched on at t_2 = 0.4 s and at the generator rotating initial slip s = -0.1. The initial current of generator is in peak 130 A. Considering time of the first 10 ms, we notice that result of compensator operation the peak of grid current is reduced from 130 A to 110 A. Further (t > 0.41), the reduction of initial grid current is significant. During next periods the grid current is reduced more than 30 %.

4. Laboratory setup

Proposed method of grid connection of induction generator supported by power electronics converter has been tested in laboratory on 7.5 kW machine which data were presented in Table I. The laboratory system is connected to transformer which data are presented in Tab. III.

Tab. III. The laboratory transformer data

Transformer data	Value
S_N [kVA]	10
U_{GN} [V]	3 x 400
U_{DN} [V]	3 x 185
P_{CU} [W]	210
$U_{Z\%}$ [%]	3.23
P_Z [kVA]	309.6
Tr. con.	Yy0

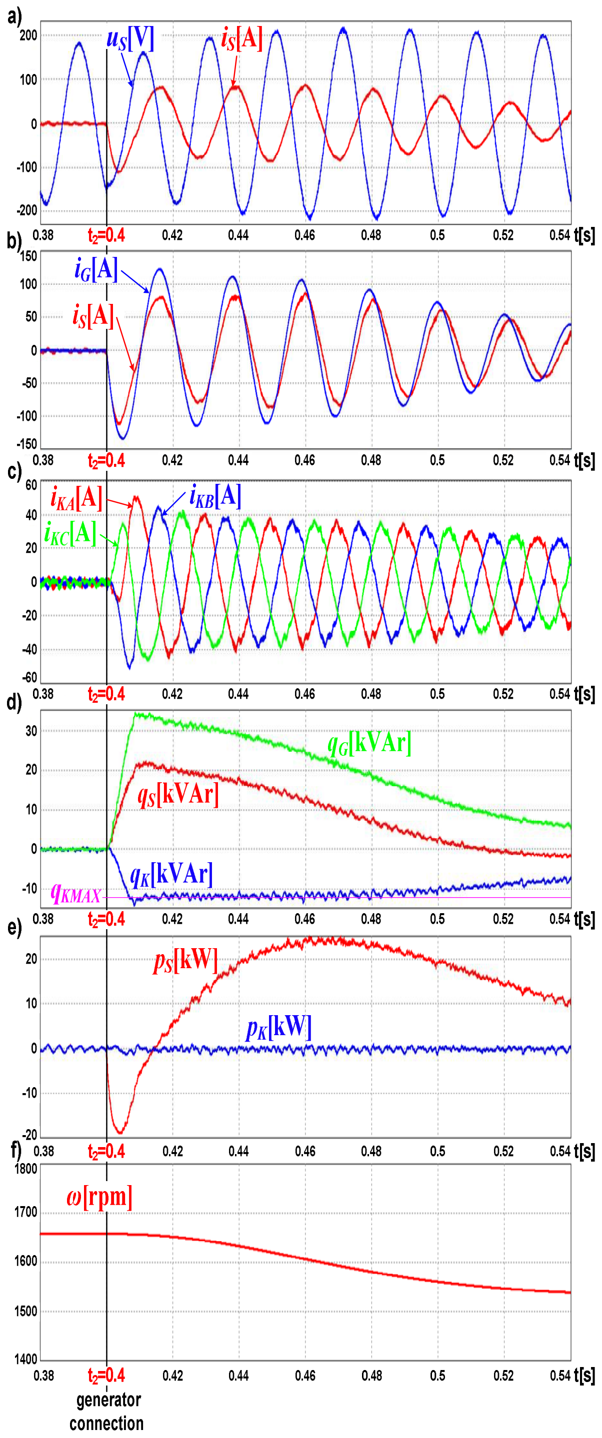

Fig. 8. Connection of induction generator (initial slip s= -0.1) to grid supported with power electronic compensator; a) grid voltage u_S and grid line current i_S; b) generator phase current i_G and grid line current i_S; c) compensator phase currents i_{KA}, i_{KB}, i_{KC}; d) grid q_S, generator q_G and compensator q_K reactive power; e) grid p_S and compensator p_K active power; f) generator rotating speed ω

As a prime mover, induction motor supplied by power electronic converter is used (Fig. 9). The power electronics converter (Fig. 10) is controlled by the DSP processor.

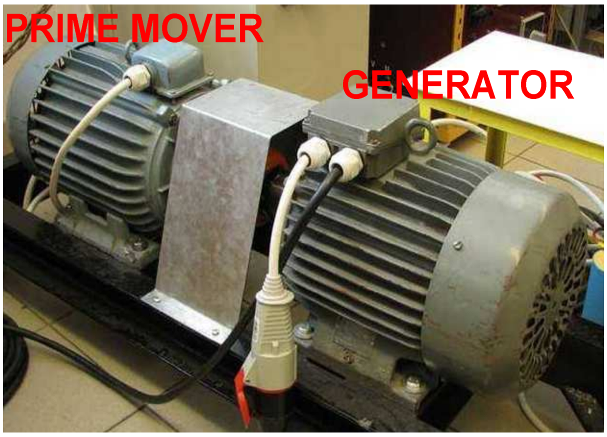

Fig. 9. The laboratory turbine- generator system

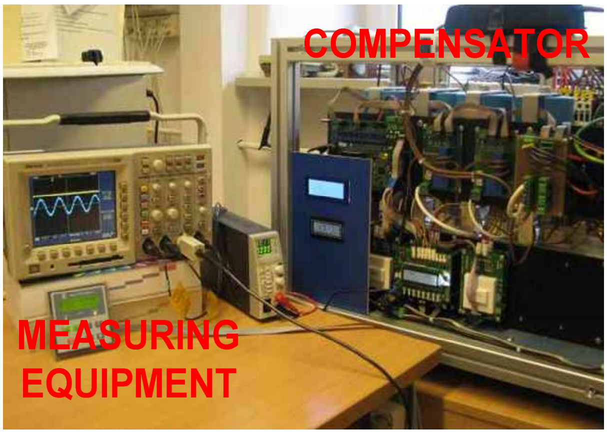

Fig. 10. Power electronics converter with control system based on the DSP processor

The laboratory results are shown in Fig. 11-13. In all laboratory tests the generator initial slip was s = -0.066.

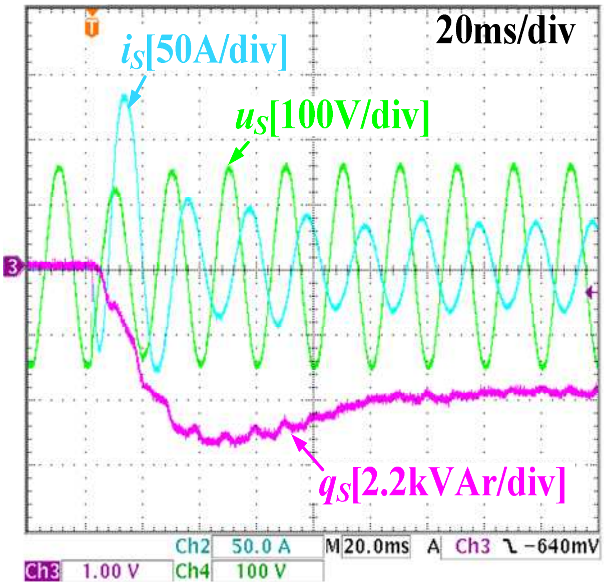

Fig. 11. Connection of induction generator with initial slip s = -0.066 to the grid (20ms/div)

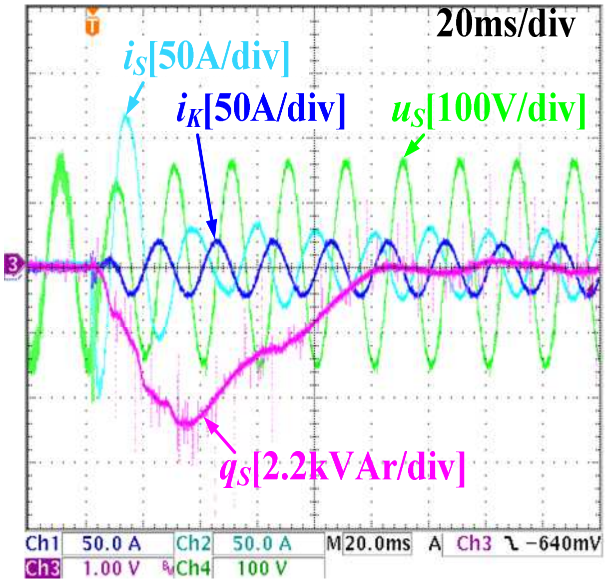

Fig. 12. Connection of induction generator with initial slip s = -0.066 to the grid supported with the reactive power compensator (20ms/div)

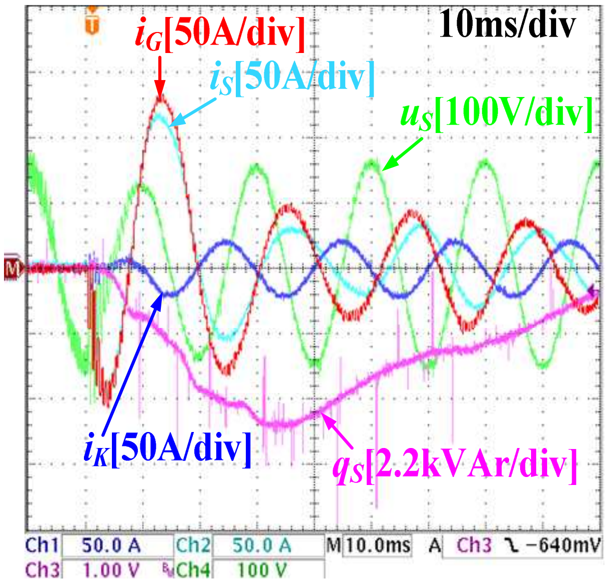

Fig. 13. Generator i_G, grid i_S and compensator i_K currents during connection of induction generator (initial slip s = -0.066) to the grid supported with the reactive power compensator (10ms/div)

The Fig. 11 shows the connection of induction generator to laboratory grid. All reactive power is taken directly from grid. The initial current of generator is three times bigger than current in steady state. This great current results a 20 % voltage drop.

The Fig. 12 shows the connection of generator to grid supported with reactive power compensator. The maximum of reactive power of laboratory compensator is q_{KMAX} = 6 kVAr (i_{KMAX} = 15 A), while the generator in steady state needs q_G = 4 kVAr (i_G = 10 A) of reactive power. These compensator limitations reduce the peak of reactive power in 15 % and the time of transients in about 20 %. The voltage drop is only 10 %.

In Fig. 13 the comparison of grid, generator and compensator currents are presented. The peak of initial generator current is 130 A and is three times bigger than peak current in steady state (40 A).The active compensator reduced the grid current to 115 A in first period of transient state. And in next periods the reduction of initial grid current reached 30 % in comparison to generator current. This difference is a result of the time of increasing currents in converter to their maximum value.

5. Conclusions

In this paper, the impact of induction generator connection to the supply line has been investigated.

The maximal overshooting of grid current amplitude and transient time depend on initial slip of generator. Higher absolute slip causes longer transient and higher current.

Moreover, the initial current of generator causes a voltage drop of the supply line.

The proposal of that impact reduction has been described in the paper. The power electronic converter has been used as a shunt compensator. The converter has been built using NPC topology. The control structure has been presented and described. It is based on direct power control.

The computer model of small hydro power station with cage induction generator and reactive power compensator was built and tested.

Simulation results show that the shunt compensator allows the grid current to be reduced more than 30 %. It was achieved at compensator current limitation set to i_{KMAX} = 30 A (q_{KMAX} = 12 kVAr).

Laboratory tests were performed on 7.5 kW induction generator. The initial peak of grid current was reduced by the compensator. It was about 30 % less. The time of transient was also reduced. It was about 80 ms for the system without compensator and about 60 ms for the system with active compensator. Due to converter limitations, the maximal compensator current was set to i_{KMAX} = 15 A (q_{KMAX} = 6 kVAr). Carried out results have been presented in the paper. It confirms that grid current and transient time can be reduced by power electronic reactive power compensator.

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