

Restoration of Power System after Blackout and Synchro-Check Relays Setting in Transmission System

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Abstract: - Connection of power lines in transmission system is activated after defined conditions are met in the setting of synchro-check relays; namely ΔV – difference in voltage amplitudes, Δf – frequency difference, and $\Delta \alpha$ – difference in phase angles. The aim of this contribution was experimental verification of the connection condition focused on transient phenomena course on connected line, the transient stability of generators, and the analysis of their influence on power system. As the past critical situations (state of an imminent blackout threat) in transmission system has shown, inability to connect line into the power system because the connection conditions are not met (blocking of a power switch) could have severe negative influence on the continual operation of the power network. Setting of synchro-check relays as connection conditions can influence also the process of electric power system restoration after collapse. Thus, this paper discusses also the actual state of synchro-check relays setting in transmission system.

Key-Words: - Transmission system, Connection of power line, Voltage phase shifts, Synchro-check relay.

1 Introduction

Blackout, resp. splitting of the power system is serious situation in the operation of power systems. Restoration of its operation can be realized in two basic ways: restoration of the network by handing in of voltage from other systems abroad, or by the restoration of domestic power plants.

In the second way of power system restoration are progressively established larger islands around the power plants, which are then interconnected into single network. Reconnection of the islands is realized by the connection of particular transmission line. However, before the connection of the line, conditions of the power lines connection must be met.

Our contribution deals with one of those conditions – the difference in voltage phase angles on connected bus bars of substations. Severe phase shift could occur during the splitting of the network, and so our paper analyzes influence of the voltage phase shift value on the transient phenomena after connection of the transmission line, mainly considering dynamic stability of individual generators in the connected islands.

This paper is summing up the results of simulation experiments of island reconnection after splitting of power system with various voltage phase shifts at power substations, where the connection to

an island is realized. We can define the conditions of power lines connection, i.e. synchro-check relays setting or verification of their correct setting, mainly considering preservation of generators' dynamic stability.

Currently, the threshold value for circuit connection of lines is set on the 30-degree level (voltage phase shift as one of the conditions of circuit connection of lines).

Experiments have been realized for 3 values of phase shift: 10°, about 30°, and about 60°.

Results that are stated:

- curves of power, voltage and revolutions of particular generators,
- curves of current (RMS value) and power flow on line connecting the island,
- curves of voltage (RMS value) in power substations, where the connection of islands is realized.

The experiments should demonstrate particularly the influence of island connection with various conditions of individual generators' stability.

Simulations have verified:

- Connection of the island with 420 MW capacity (3 generators in HPP (hydro power plant), one in IGCC (integrated gasification combined cycle) and one in NPP (nuclear power plant)) and the

island with single 110 MW generator in TPP (thermal power plant).

- Connection of two same (small) islands with 100 MW capacity (1 generator in TPP (thermal power plant)). The line connecting of islands was relatively long.

2 Simulation Experiments of Island Reconnection after Splitting of Power System

Transient event during the islands connection (course of voltage in substations, or “swinging” of generators) is positively correlated with voltage phase shift in power substations.

Simulations proved that even with phase shift 60° are generators capable to maintain its stability. Realized simulations verified one of the conditions of power line connection, i.e. voltage phase shift during the connection of islands in power system (during the restoration of power system operation) mainly considering preservation of generators' dynamic stability.

Considering the results, we can conclude that actual threshold value of voltage phase shift set on synchro-checks (30° for circuit connection of lines) is satisfactory for the restoration of power system operation during connection of the island considering preservation of generators' dynamic stability.

2.1 Connection of the island with 420 MW capacity and the island with single 110 MW generator

In simulation experiments was connecting of the island with 420 MW capacity (3 generators in HPP (hydro power plant), one in IGCC (integrated gasification combined cycle) and one in NPP (nuclear power plant)) and the island with single 110 MW generator in TPP (thermal power plant) with various conditions (various values of voltage phase shift).

2.1.1 The 1st experiment

Voltage in substations before power line connection:

Sub1	235,7 kV $\angle -6,4^\circ$
Sub2	229,3 kV $\angle -2,9^\circ$
at the end of line	230,1 kV $\angle -2,9^\circ$
voltage phase shifts:	$3,5^\circ$

Results of the simulation for this relatively small difference in voltage phase shifts did not demonstrate

any problems with maintaining dynamic stability of individual generators. Generators in all types of power plants can cope with the transient phenomena. Not even the connected 220 kV power line faced any current surge.

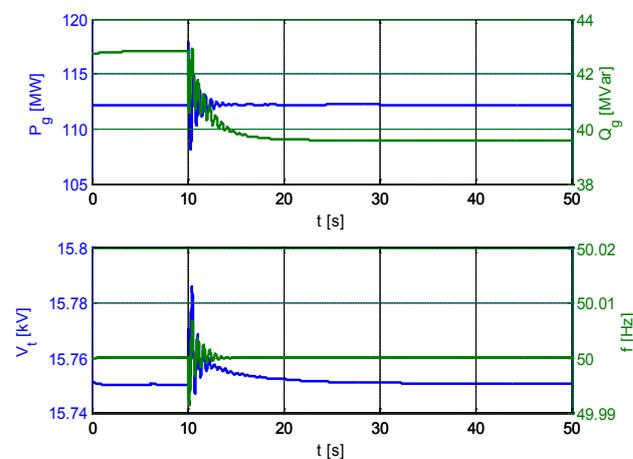


Fig. 1 Generator in NPP

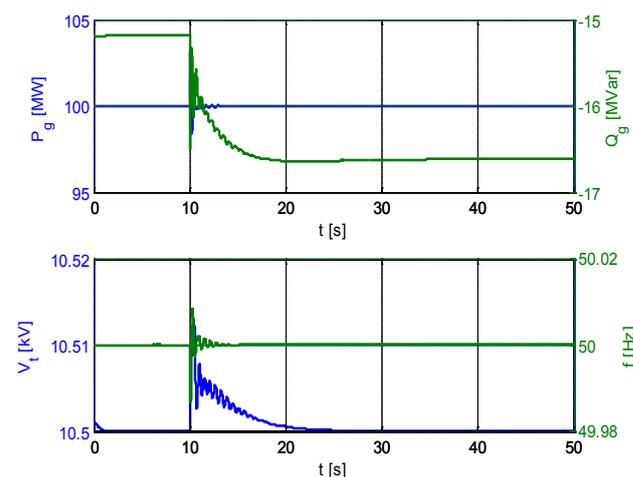


Fig. 2 Generator in IGCC

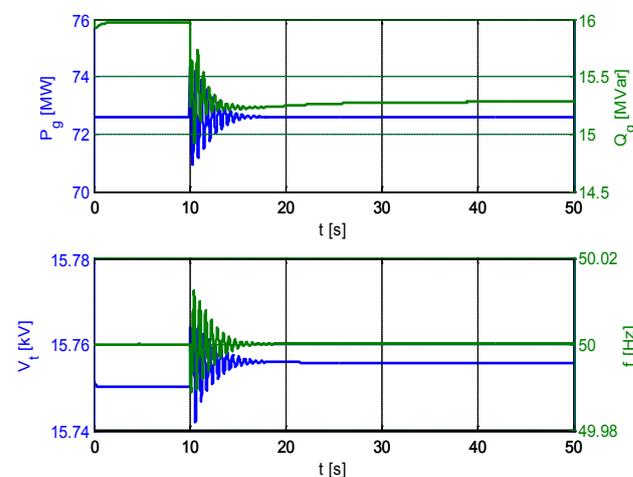


Fig. 3 Generator in HPP

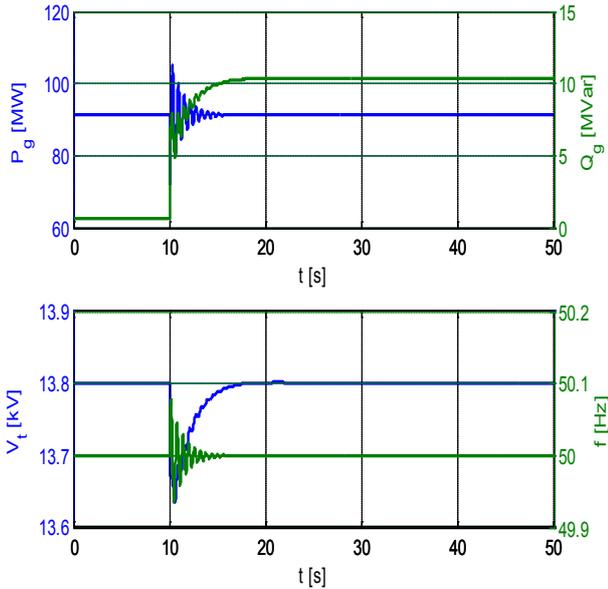


Fig. 4 Generator in TPP

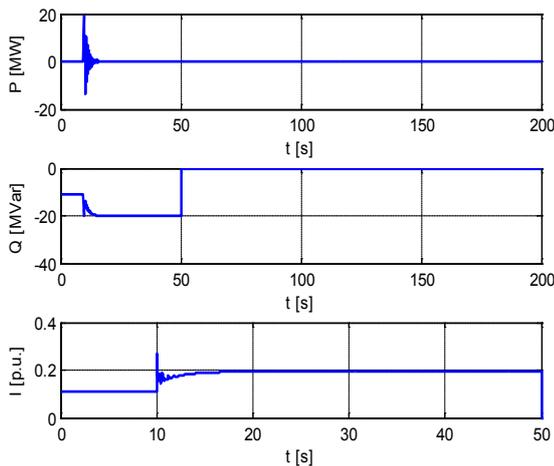


Fig. 5 Power flow on line

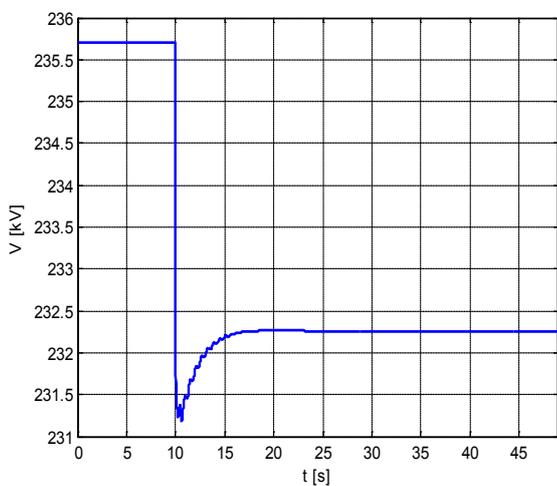


Fig.6 Voltage in substation 1

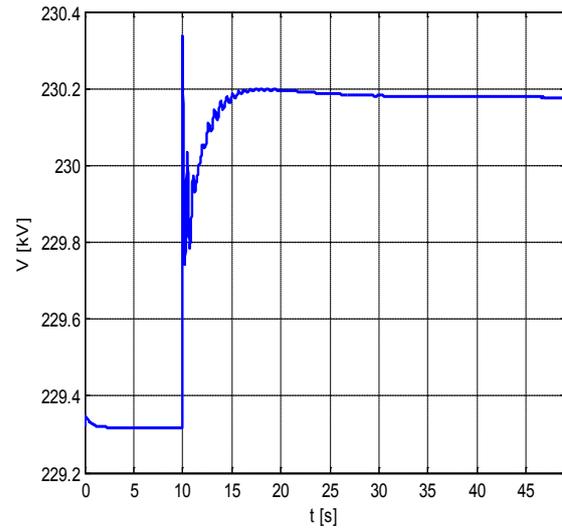


Fig. 7 Voltage in substation 2

2.1.2 The 2nd experiment

Voltage in substations before power line connection:

Sub1 235,7 kV $\angle 23,6^\circ$

Sub2 229,3 kV $\angle -2,9^\circ$

at the end of line 230,1 kV $\angle -2,9^\circ$

voltage phase shifts: 26,5°

Difference in voltage phase angles in this simulation resembles the value set in currently used synchro-checks. Not even for this large voltage phase shift occurred any problem involving dynamic stability on the examined generators. However, generator swinging is more important than in previous example.

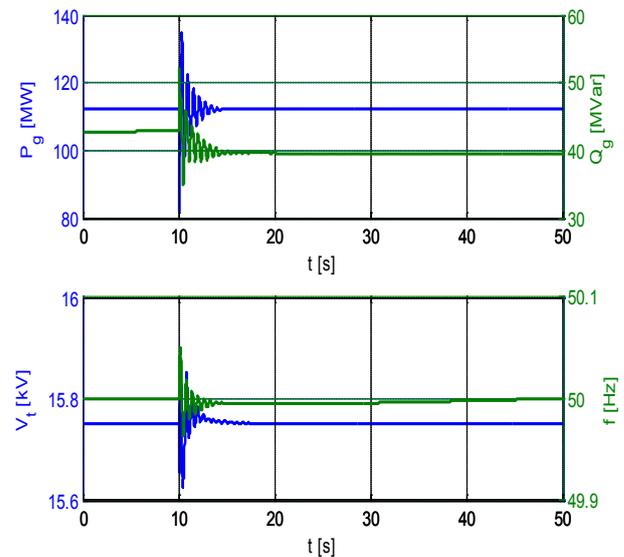


Fig. 8 Generator in NPP

When we are evaluating correct setting of synchro-checks, we can state that current value 30° is not too high, because even with this high difference in voltage phase angles would be the connection of the islands (after splitting of the power system) successful (as the generators would not fell out of synchronism) and that is the prerequisite for a successful restoration of transmission power system using the local sources.

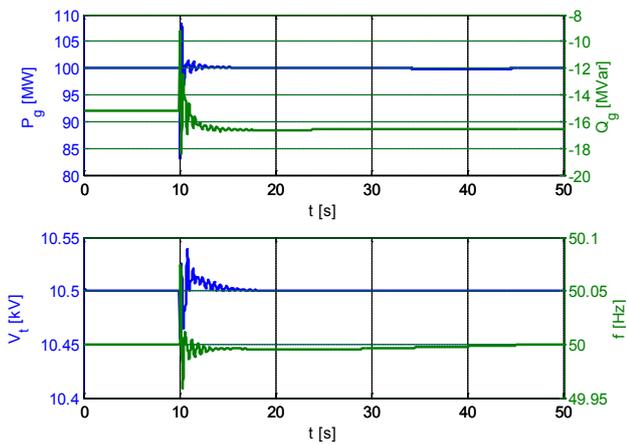


Fig. 9 Generator in IGCC

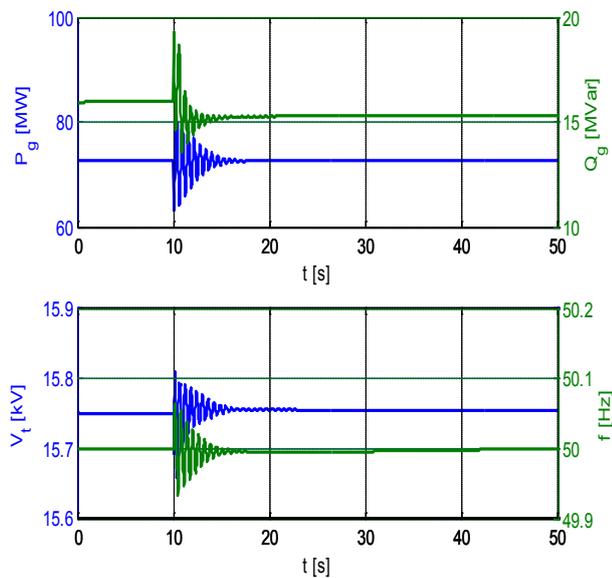


Fig. 10 Generator in HPP

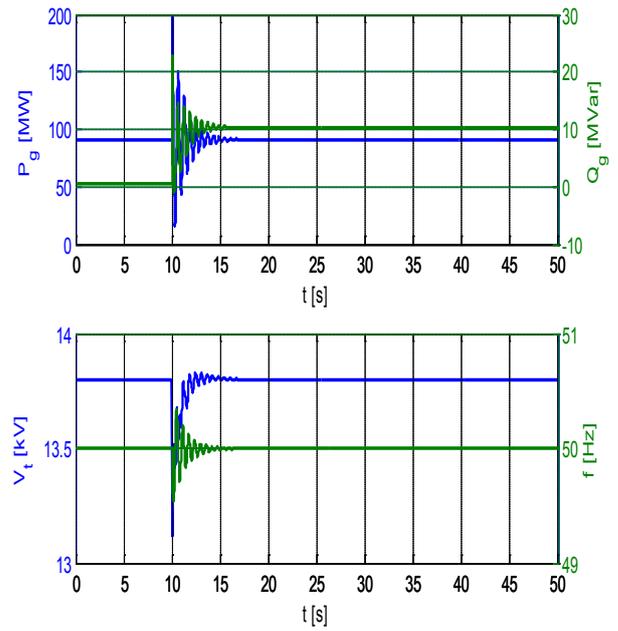


Fig. 11 Generator in TPP

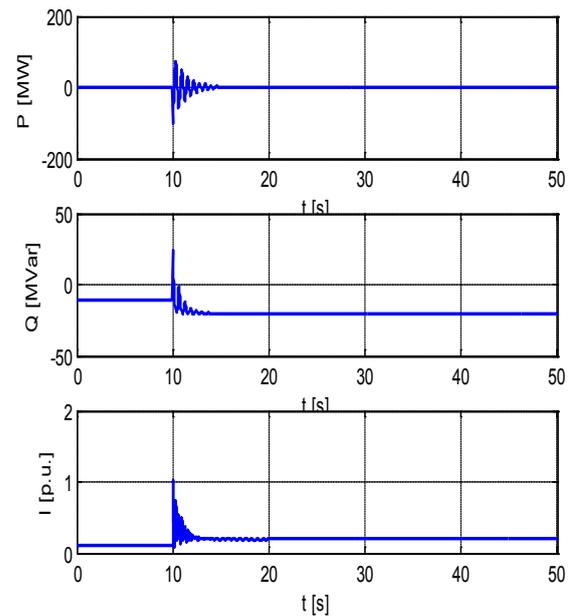


Fig. 12 Power flow on line

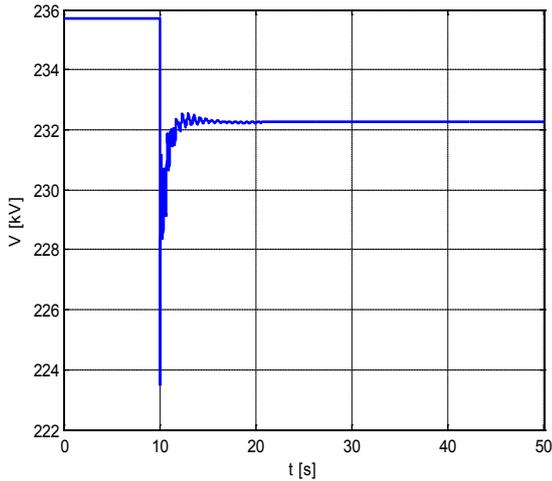


Fig. 13 Voltage in substation 1

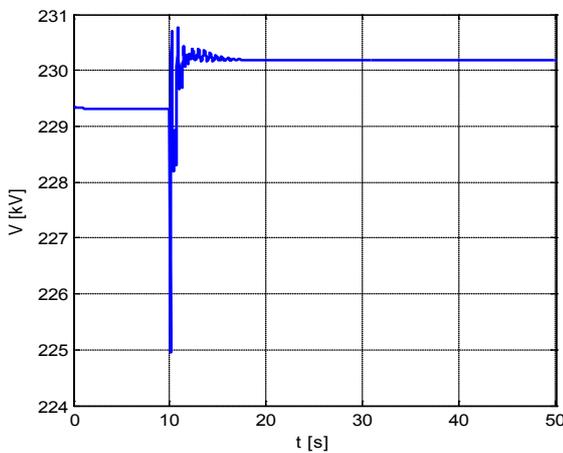


Fig. 14 Voltage in substation 2

2.1.3 The 3rd Experiment

Voltage in substations before power line connection:

Sub1	235,7 kV $\angle 23,6^\circ$
Sub2	229,3 kV $\angle -32,8^\circ$
at the end of line	230,1 kV $\angle -32,8^\circ$
voltage phase shifts:	56,4 $^\circ$

The third experiment was conducted for value of voltage phase shift above the current setting of synchro-checks.

The test verified that even for such high values of voltage phase shift are generators able to sustain their dynamic stability and that the setting of synchro-checks could be even higher. Remaining question is, if this setting could be considered as condition of circuit connection of lines in normal operating state of power system, resp. if it is technically possible to change setting of the synchro-checks remotely according to the actual situation.

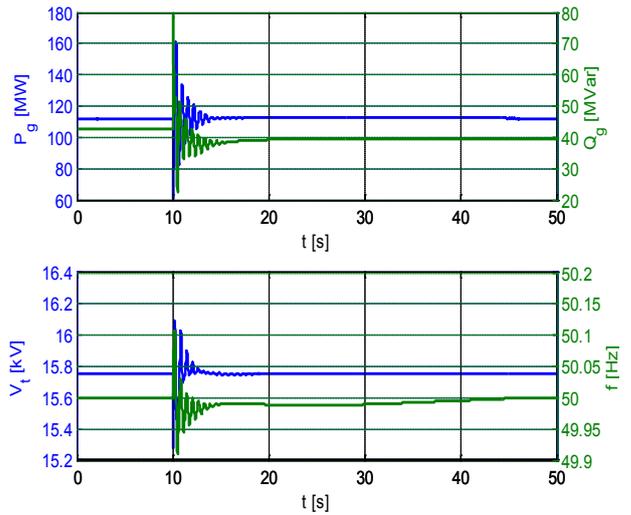


Fig. 15 Generator in NPP

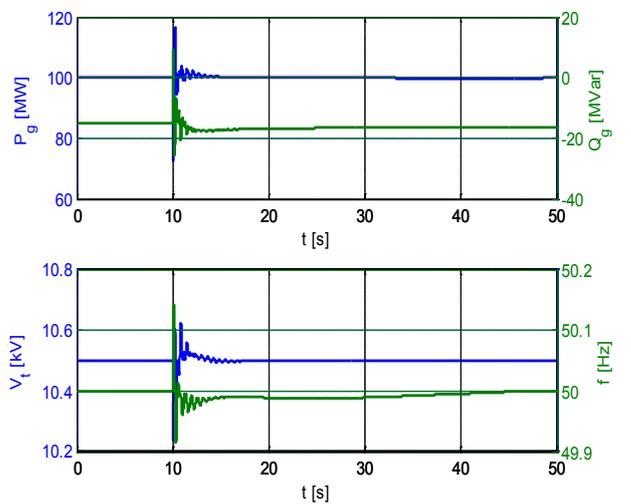


Fig. 16 Generator in IGCC

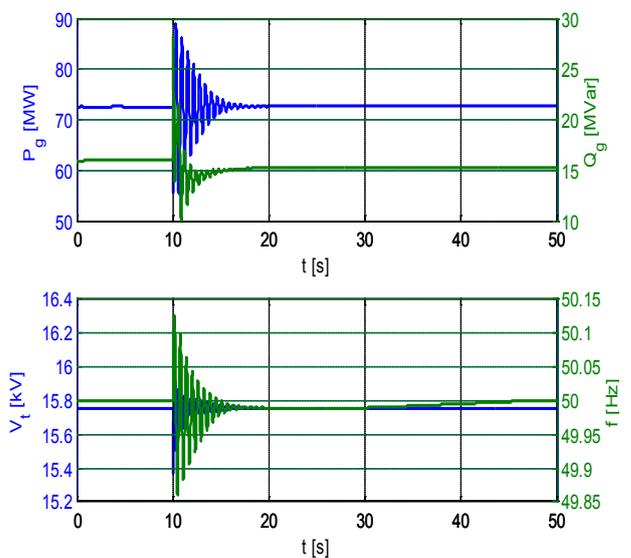


Fig. 17 Generator in HPP

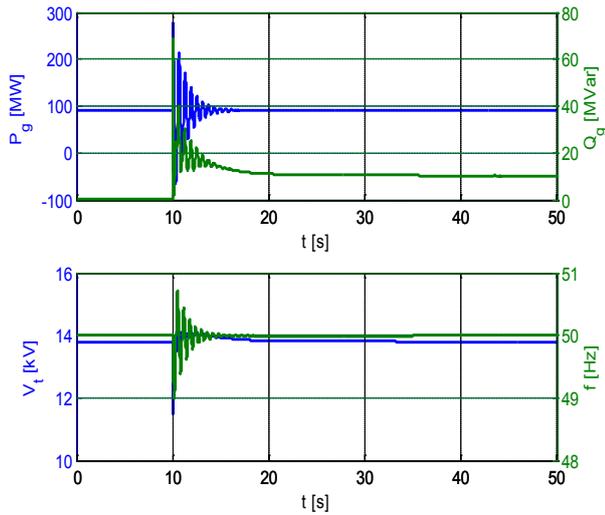


Fig. 18 Generator in TPP

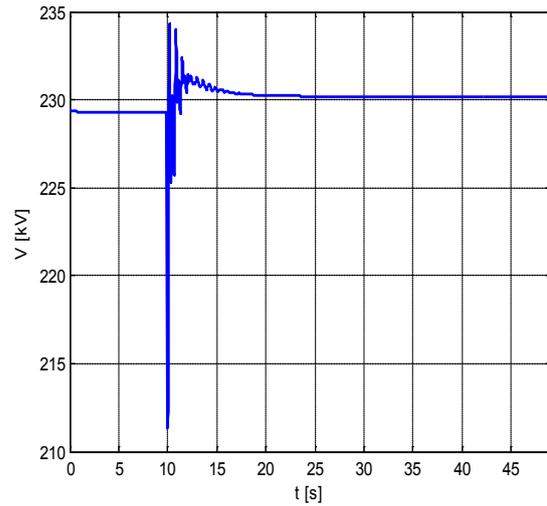


Fig. 21 Voltage in substation 2

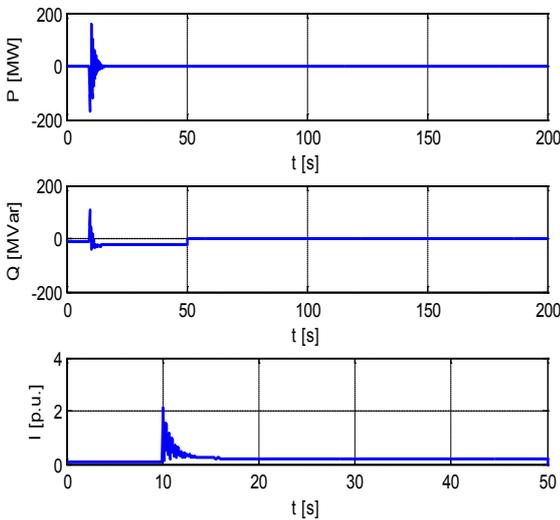


Fig. 19 Power flow on line

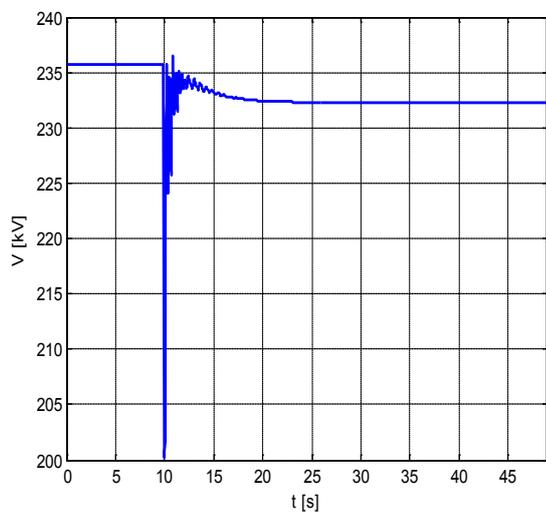


Fig. 20 Voltage in substation 1

2.2 Connection of two same (small) islands with 100 MW capacity

In simulation experiments was connecting of two same (small) islands with 100 MW capacity (1 generator in TPP (thermal power plant)) with various conditions (various values of voltage phase shift). The line connecting of islands was relatively long.

2.2.1 The 1st experiment

Voltage in substations before power line connection:

Sub1	235,7 kV $\angle -6,4^\circ$
Sub2	237,5 kV $\angle -14,3^\circ$
at the end of line	238 kV $\angle -14,3^\circ$
voltage phase shifts:	7,9°

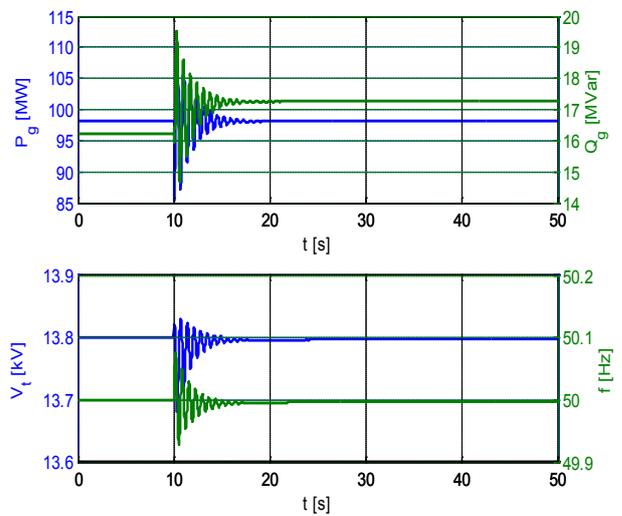


Fig. 22 The 1st generator

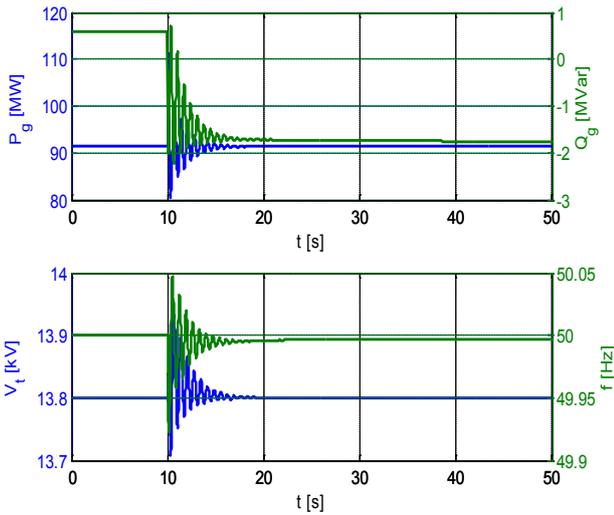


Fig. 23 The 2nd generator

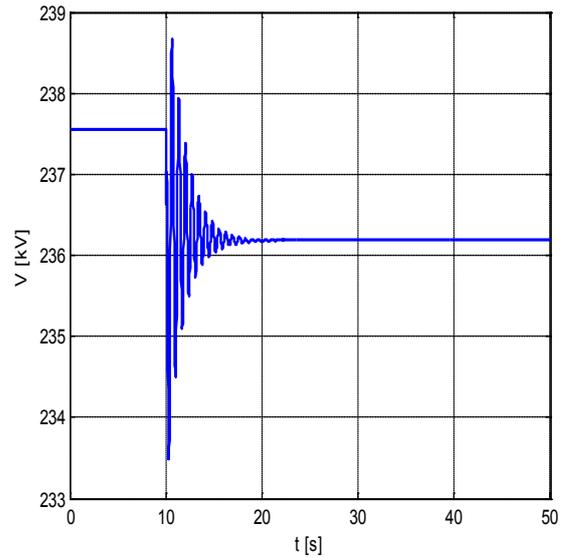


Fig. 26 Voltage in substation 2

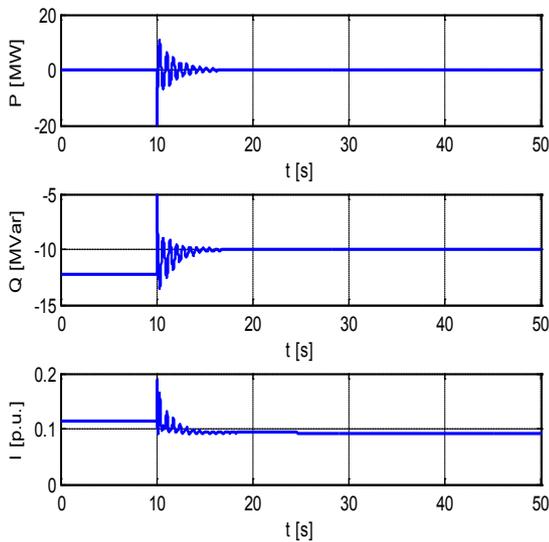


Fig. 24 Power flow on line

2.2.2 The 2nd experiment

Voltage in substations before power line connection:

Sub1 235,7 kV $\angle 13,6^\circ$

Sub2 237,5 kV $\angle -14,3^\circ$

at the end of line 238 kV $\angle -14,3^\circ$

voltage phase shifts: 27,9°

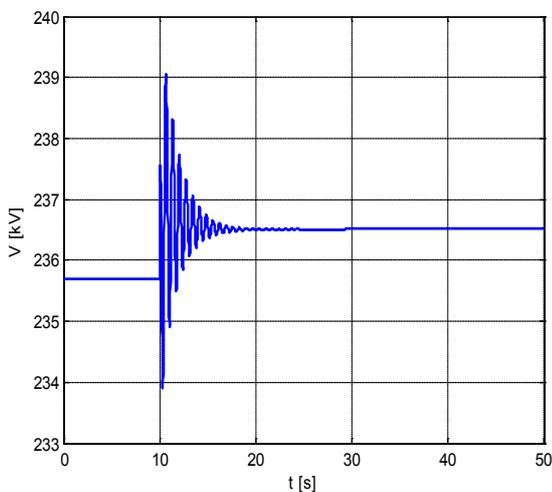


Fig. 25 Voltage in substation 1

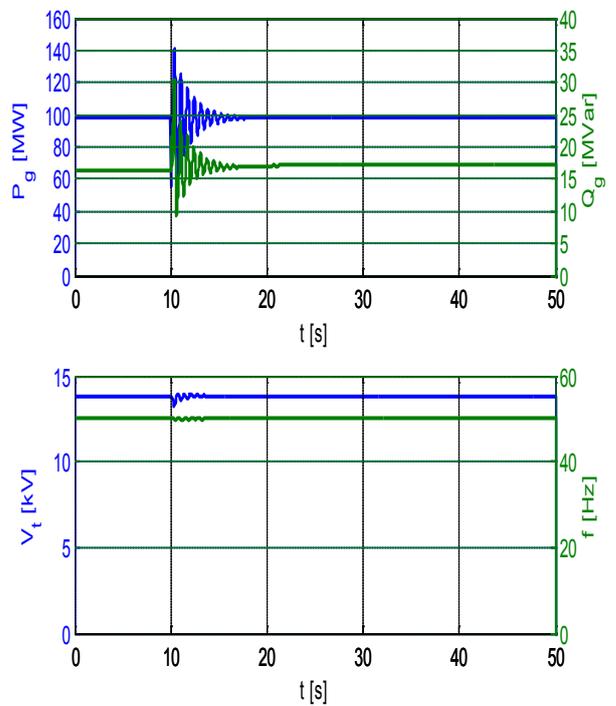


Fig. 27 The 1st generator

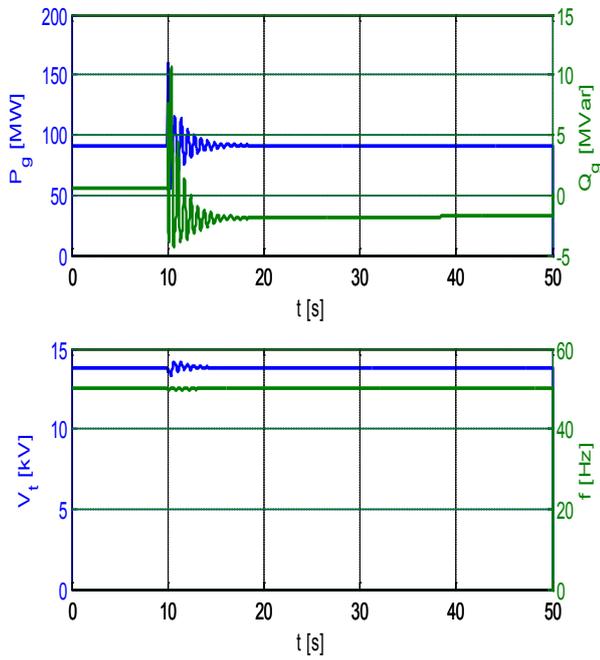


Fig. 28 The 2nd^t generator

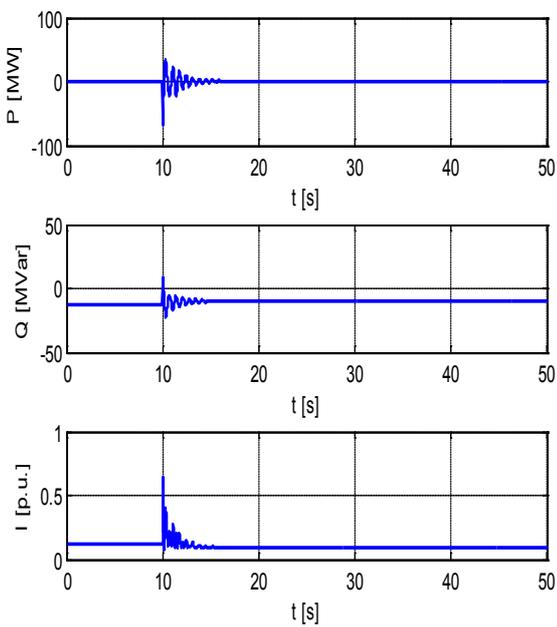


Fig. 29 Power flow on line

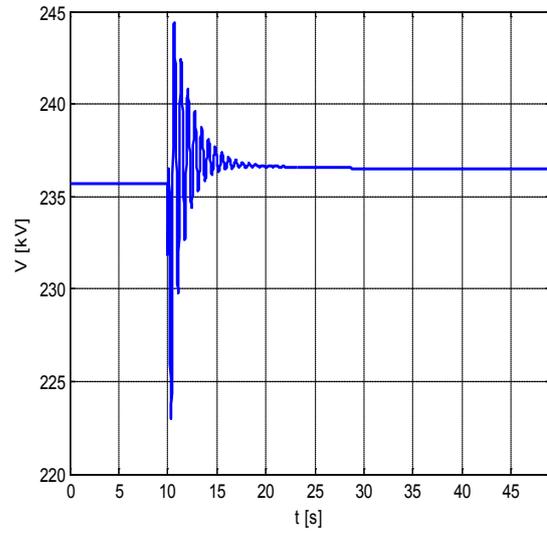


Fig. 30 Voltage in substation 1

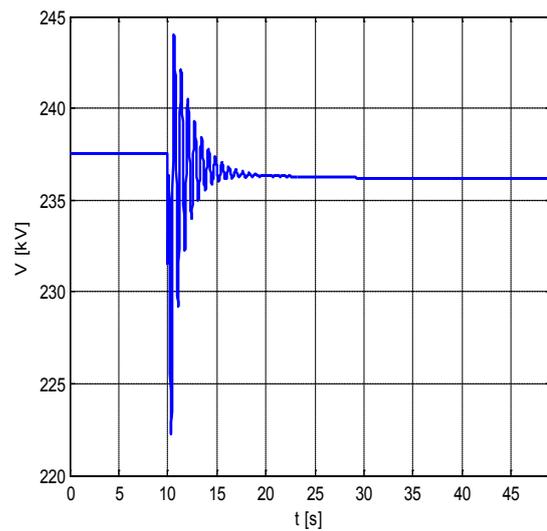


Fig. 31 Voltage in substation 2

2.2.3 The 3rd Experiment

Voltage in substations before power line connection:

Sub1 235,7 kV $\angle 43,6^\circ$

Sub2 237,5 kV $\angle -14,3^\circ$

at the end of line 238 kV $\angle -14,3^\circ$

voltage phase shifts: 57,9°

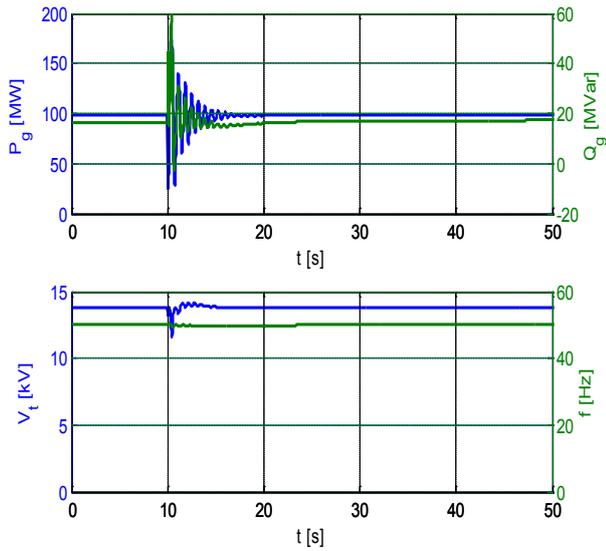


Fig. 32 The 1st generator

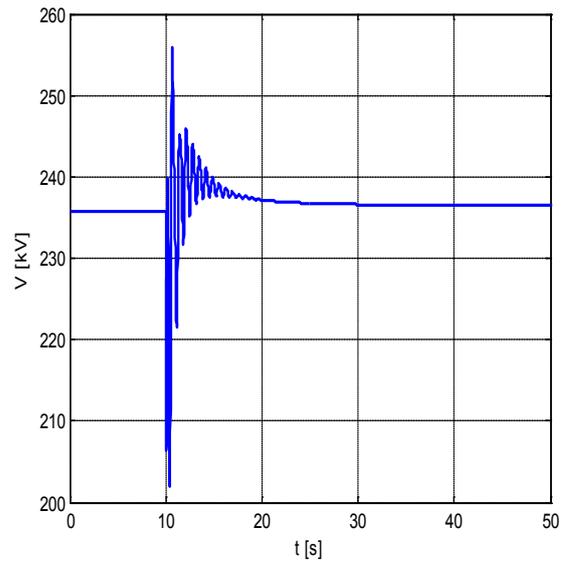


Fig. 35 Voltage in substation 1

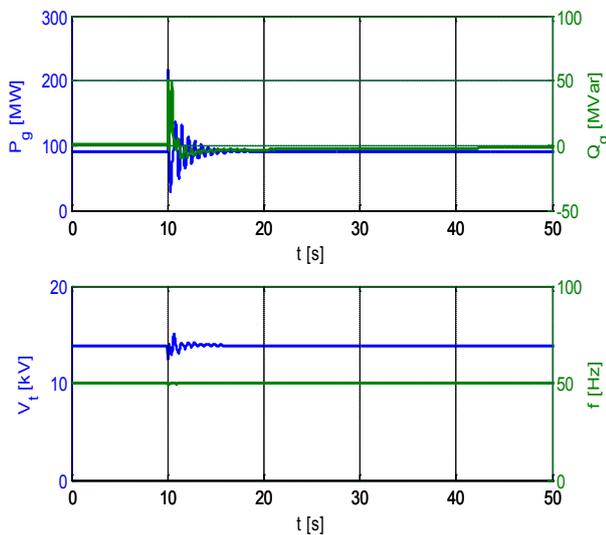


Fig. 33 The 2nd generator

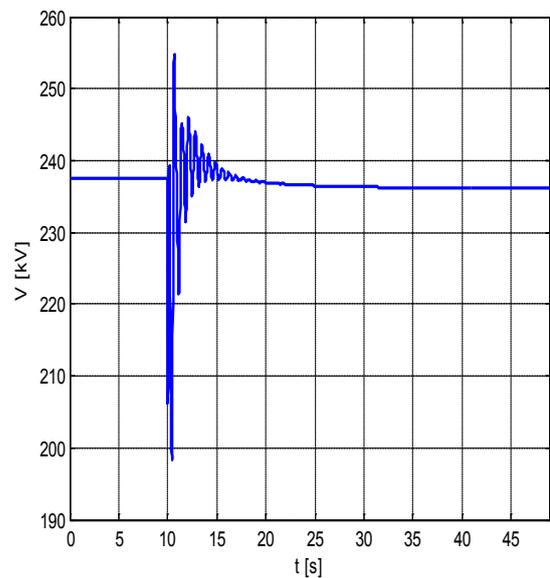


Fig. 36 Voltage in substation 2

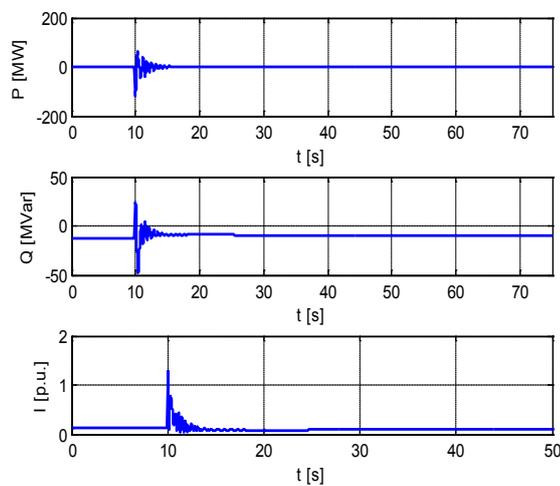


Fig. 34 Power flow on line

3 Conclusion

Realized simulations verified one of the conditions of power line connection, i.e. voltage phase shift during the connection of islands in power system (during the restoration of power system operation) mainly considering preservation of generators' dynamic stability.

Considering the results, we can conclude that actual threshold value of voltage phase shift set on synchro-checks (30° for circuit connection of lines) is satisfactory for the restoration of power system operation during connection of the island considering preservation of generators' dynamic stability.

In normal operation of power system to set the threshold value of power lines – maximal voltage phase shift can be chosen as criterion – maximal value of steady-state current on power line after the transient event fades away.

In accordance with criterion “n-1” is the value set as 60% of allow current I_{allow} . For the 400 kV power line with $I_{allow} = 2000$ A it is about 1200 A.

Criterion was chosen due to the following reasons:

- transmission power lines are not protected by current protections, and so current surge after power line connection would not cause its disconnection.
- course of impedance is out of the scope of distance protections protecting the line.

Simulation results of the power lines connection are showing that in the case of parallel synchro-checks setting to 30° , the steady-state current in the lines of transmission system eventually would exceed 60% I_{allow} after the fading of transient event. With the knowledge of real steady-states in transmission system of Slovak Republic is safe to establish that voltage phase shifts in transmission system are significantly lower than 30° . Thus it is safe to assume, that during standard (failure-free) operation should

not occur any problem with circuit connection of power lines.

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