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PRESENT PROBLEMS OF POWER SYSTEM CONTROL

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PQ CONTROL OF PHOTOVOLTAIC POWER STATION IN MICROGRID OPERATION

The numerical modelling of the photovoltaic module and the solar inverter interconnected with the microgrid has been carried out with the use of PowerSys in Matlab/Simulink. Algorithms of P, Q controllers have been proposed. The capability of the active and reactive power reference tracking has been tested for various conditions.

1. INTRODUCTION

The contribution of distributed generation in the power system is still rising. Solar power plants become more popular each year and their presence sets new challenges for power systems. Electrical low and medium voltage grids are of radial topology and no power flow from the low to medium voltage level was anticipated in their design. New distributed generation needs the control mode allowing for cooperation with commercial electrical grid. As PV solar panels are DC sources they are connected to grid by inverters which, to generate power of specific parameters, need to be controlled.

Microgrid generators can basically operate in two modes, either connected to a commercial network or in islanding mode [1]. Islanding mode is not subject of this paper. In the network mode the solar inverter can be controlled in the Vf or PQ mode [2, 5]. The PQ mode ensures greater flexibility in satisfying electrical system requirements and is taken into account in this paper.

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The complexity of photovoltaic cell V-I characteristics call for using special control algorithms in the PQ mode. Output power of photovoltaic cell depends on two dominant quantities namely the light illuminance and the environment temperature. Photovoltaic model described in [4, 6] is proposed as a circuit consisting of a diode, two resistances, and direct current source linearly dependent on the light density. The relation between output voltage and current presented as V-I characteristic is specific for each cell type. It is a monotonically decreasing function, however, almost constant for low voltages. It means that forced increase of one quantity causes decrease of the second. Maximal power point (MPP) is a point on V-I characteristics at which the system generates maximum power [7]. When MPP cannot be achieved by any reason the property of a monotonic decrease may lead to instability.

The PQ controllers design for inverters operating with photovoltaic modules is a compromise between requirements set by the power system state, the maximal power point tracking, the power system stability provision and an acceptable settling time. Solutions proposed in this paper were tested on the numerical model of a microgrid with local loads which well corresponds to real microgrids.

2. INVERTER CONTROL

The inverter is a device that converts DC voltage into AC voltage with specified parameters. In can be modeled as a function f: $R^3 \rightarrow C[\mathbb{R}]$.

$$f(U, U_m, \phi) = U \sin(2\pi f t + \phi) \tag{1}$$

where U is the output voltage magnitude, ϕ is the voltage phase, f is the nominal frequency.

Voltage magnitude U cannot exceed voltage provided by photovoltaic cells, so that $U \leq U_m$. The voltage magnitude and phase (U, ϕ) influence the active and reactive power generation. The PQ control consists in setting the active and reactive power reference values and modulating the phase and magnitude of the inverter output voltage to keep the generated power as close to the preset values as possible.

The active and reactive power flow in a power system depends on parameters of powers system quantities and system topology. Controllers investigated in this research were constructed in such a way that voltage phase ϕ was dependent only on the active power generation demand. The output voltage magnitude U depended only on the reactive power flow Q. Assumption that neither ϕ is influenced by reactive power nor U is influenced by the active power allowed to simplify the mathematical model of the inverter. However, this type of controllers may be unable to keep stability in some critical conditions. The diagram of the control system of the inverter is shown in Fig. 1.

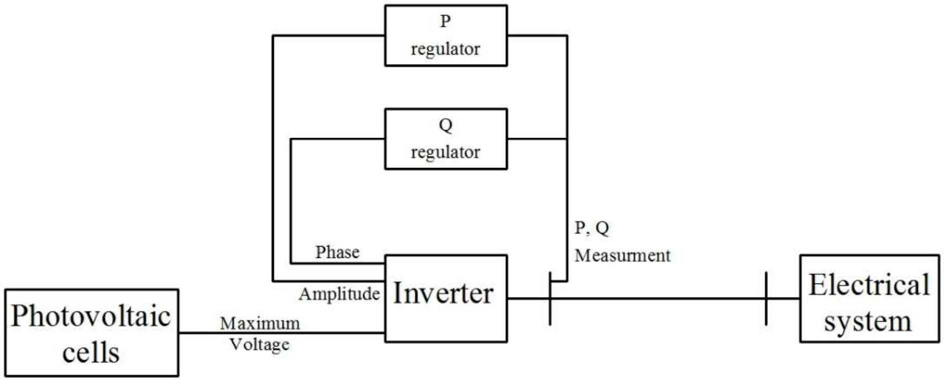

Fig. 1. Model of inverter with PQ controllers

PQ controllers are integrating elements modelled as follows

$$\frac{\partial \phi(t)}{\partial t} = \mathcal{L}^{-1}\left(\frac{a}{s+b} \mathcal{L}(P(t) - P_{\mathrm{Ref}}(t)) \right) \tag{2a}$$

$$\frac{\partial U(t)}{\partial t} = \mathcal{L}^{-1}\left(\frac{a}{s+d} \mathcal{L}(F_m(Q(t) - Q_{\mathrm{Ref}}(t))) \right) \tag{2b}$$

where $\mathcal{L}^{-1}$ is the inverse Laplace transform, F_m is a saturation function of the upper and lower limit of m and $-m$, respectively. Phase and amplitude change rates are also limited to prevent stability loosing during power flow fluctuations

$$-\phi_d \le \frac{\partial \phi(t)}{\partial t} \le \phi_d \tag{3a}$$

$$-U_d \le \frac{\partial U(t)}{\partial t} \le U_d \tag{3b}$$

Constants a, b, c, d, ϕ_d, U_d were obtained empirically to fulfill the compromise between stability loosing and a settling time.

3. MODEL DESCRIPTION

The diagram of the modeled network is shown in Fig. 2. Its arrangement allows the study of the photovoltaic module operation to be carried out under various network configuration at different loads.

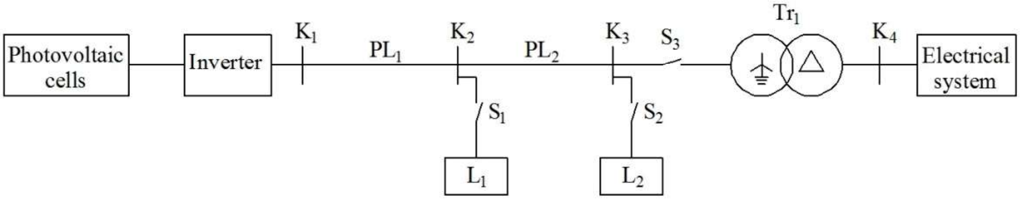

Fig. 2. Diagram of modeled section of power network

The photovoltaic power farm is connected to the network on the low voltage level 400 V at node K_1. Loads modelling local power demand are supplied at nodes K_2 and K_3 from the overhead power line PL_1. Nodes K_2, K_3 are interconnected with cable line PL_2. Since MV grid is not the subject of the study it has been modeled as a voltage source of fixed short circuit capacity. Simulations were performed for following parameters:

- Photovoltaic 11 kW power station composed of 192 Solarex MSX60 modules grouped in 8 rows of 24 modules each.
- Cable line L_1 4 × 95 XLPE of 200 m length, the per unit length resistance and reactance of 0.32 Ω/km and 0.082 Ω/km, respectively.
- Overhead line L_1 AL 70 of 300 m length, the per unit length resistance and reactance of 0.44 Ω/km and 0.31 Ω/km, respectively.
- Electric power system of 100 MVA short circuit capacity.

4. SIMULATION RESULTS

Results presented in this section concern the transients in the photovoltaic power station which can result from switching operations, changes of reference quantity values in inverter controllers, load variations, or from changes of such quantities as temperature or the illuminance dominantly influencing generating power of the photovoltaic cell. The active power diagrams presented in Figs. 3–5 relate to single phase power divided by $\sqrt{2}$. This corresponds to 2.5 kW maximal power of one phase inverter. However, the modelling was not carried out for this exact value owing to mathematical restrictions of the model and exponential error rate of calculations performed for currents close to the maximal current of the solar cell.

4.1. REFERENCE POWER CHANGE

The PQ control performance under reference power change has been investigated in the system shown in Fig. 2 with switches S1–S3 permanently closed, so that no external limits for maximal generation existed in this configuration as excess of local power could be exported to the power system. The references of active and reactive power were functions of time as presented in Table 1.

Table 1. Active and reactive power reference values vs. time

t [s]	P_{Ref} [kW]	Q_{Ref} [kVar]
0.0–0.1	0.0	0.0
0.1–0.6	0.8	0.5
0.6–1.2	1.5	0.0
1.2–1.8	2.0	0.0
1.8–2.2	2.5	0.0

Diagrams of active and reactive power in time domain in node K_1 are shown in Fig. 3. Both controllers are activated at $t = 0.1$ s. They cannot be active from the beginning due to some model restrictions. One can observe that before the activation of the controllers, the active and reactive power flow were equal to 700 W and 1.1 kVar, respectively. This values are determined by local loads L_1, L_2 and are independent of the voltage phase. The activation of controllers initiates strong power oscillations which can be observed also at $t = 0.6$ s. These oscillations are due to the fast Q control after the step change of reactive power reference. However, application of the fast Q controller almost negated overshoot after the active power reference change in instants $t = 1.2$ s and $t = 1.8$ s. One should be conscious that the overshoots of the active power are extremely dangerous when the system works close to the maximum power of solar cells what may lead to the stability loss.

The aforementioned oscillations can be eliminated by forcing ramp active loading instead of the step change. The relevant simulation results are shown in Fig. 4 where Q reference signal Q_{Ref} is ramped from 1 kvar at 0.1 s to 0 kvar at 0.6 s. It can be observed that varying Q_{Ref} extended the settling time for the active power generated. In the first case active power oscillations vanished after 300 ms. In the second case P could not be equal to P_{Ref} until reactive power reference value became constant.

4.2. NETWORK TOPOLOGY CHANGE

Generation control studies presented in Fig. 5 allows to verify capability of the controller for keeping reference power generated after the change of the local load. Active and reactive power shown in Fig. 5 are for switch S_1 closing at $t = 1.5$ s and opening at $t = 2.5$ s. Closing S_1 increases total power demand and solar cells current. In accordance with U-I cell characteristic of solar cells output voltage decreases rapidly,

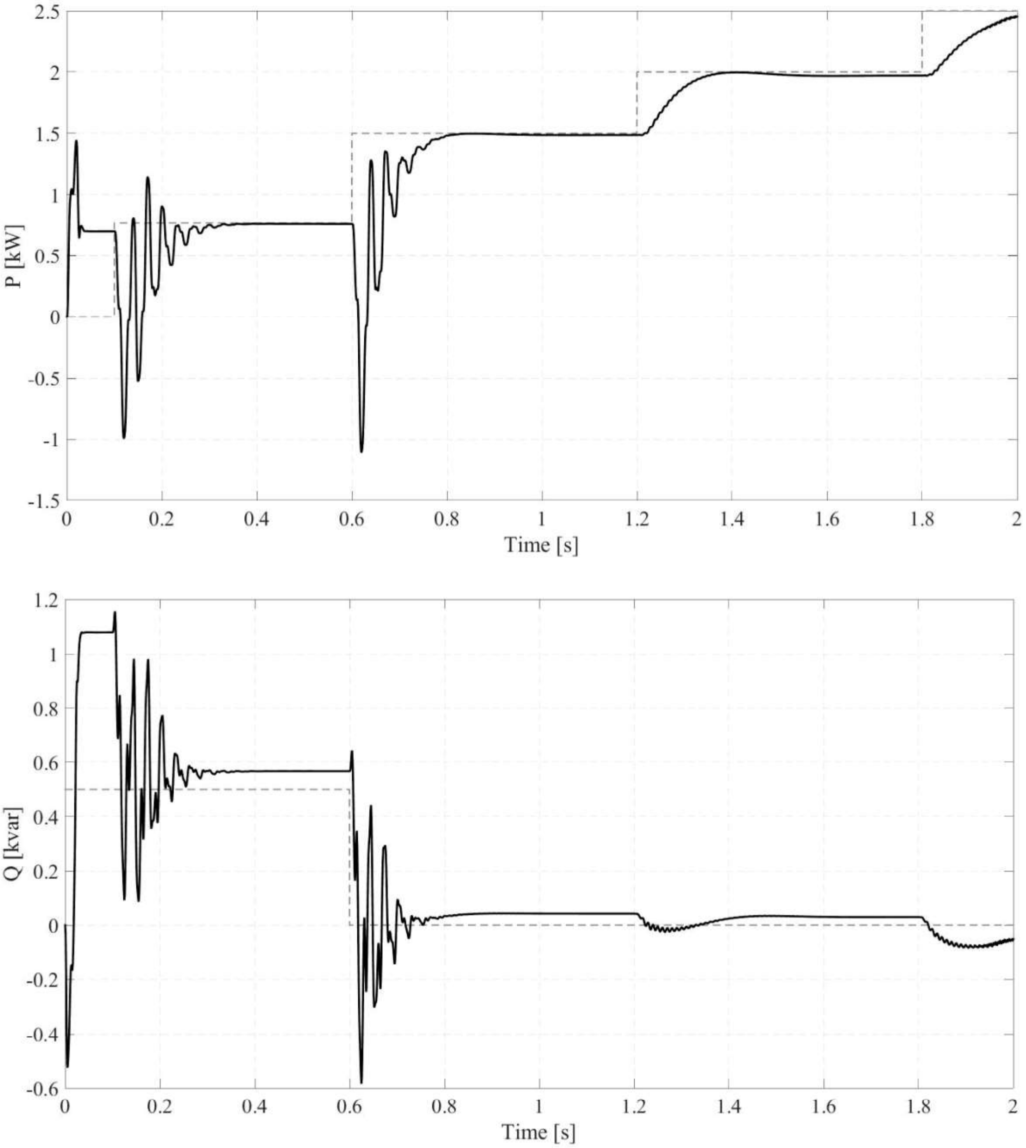

Fig. 3. Active (top) and reactive (bottom) power generation responses to step changes of the active power reference. Dashed lines are for reference signals

so that generated active power is lower. P controller changes voltage phase, reduces current and restores power flow to the reference value. Opening S_1 decreases load, and so the solar cell current. Load L_2 is R-L type therefore the switch opening results in negative Q power flow. Fast Q type control increases voltage rapidly forcing the increase of active power flow up to maximal available value, until voltage U reaches final value at $t = 2.9$ s. Then P controller forces active power falling below the reference value. After 2.9 s the control is performed in the same way as for switch opening.

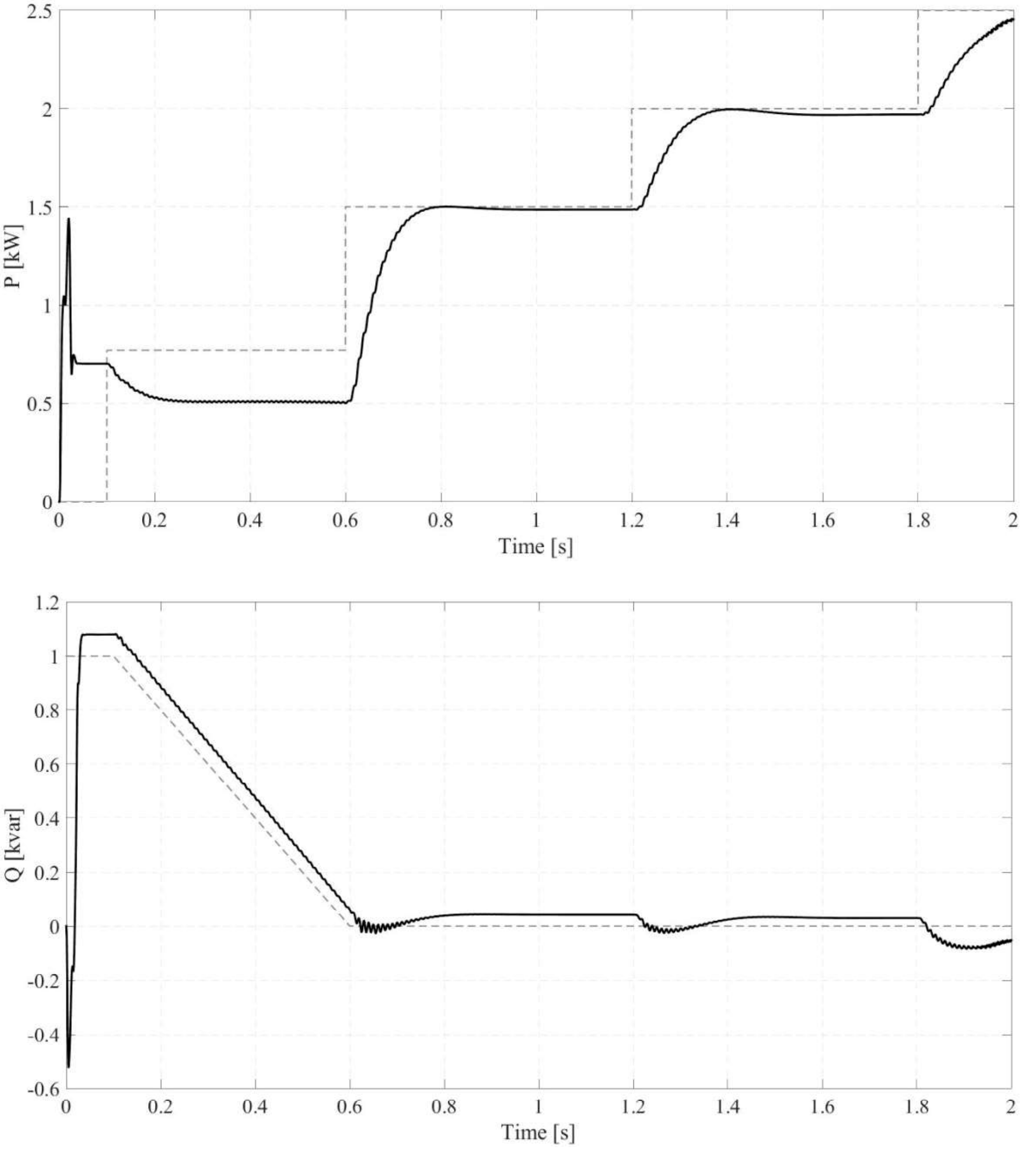

Fig. 4. Active (top) and reactive (bottom) power generation response to ramp changing of reactive power reference. Dashed lines are for reference signals

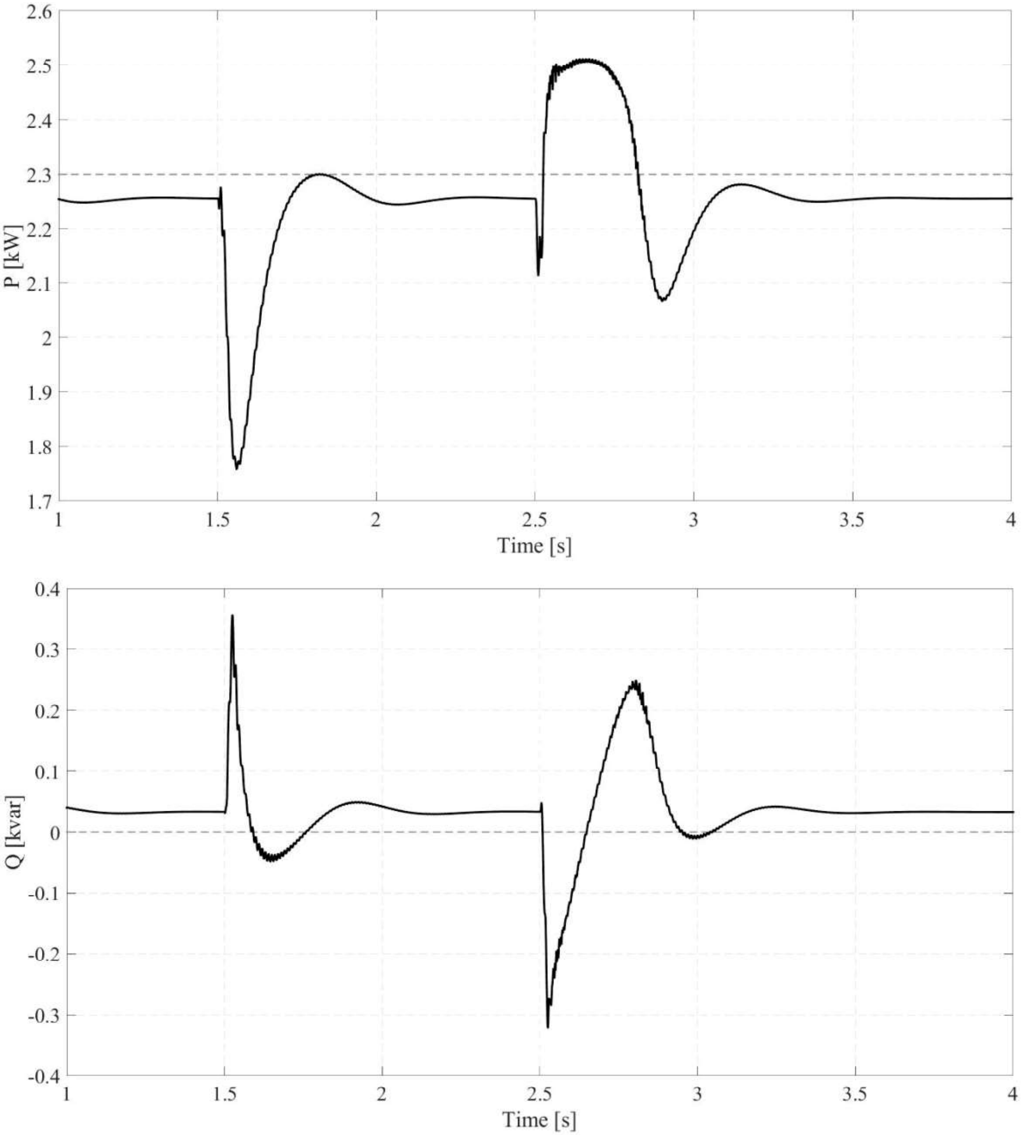

Fig. 5. Active (top) and reactive (bottom) power generation responses after S_1 on–off switching. Dashed lines are for reference signals

5. CONCLUSION

Results of PV generation control studies carried out for various grid operation modes have been presented. The goal of the research was to analyze ability of proposed P and Q controllers to stability keeping after the reference power or topology change.

It can be observed that difference between reference and real power values in steady state are dependent on the reference power value. When P_{Ref} was less than 1.5 kW then the steady state real power and the reference power were almost equal. After P_{Ref} was set to 2.4 kW, the steady state difference was more than 50 W what is due to the mathematical model specification. Photovoltaic current cannot exceed maximal cell current, even during overshoot period. Lacking 50 W was used to ensure overshoot. Excluding aforementioned problem, proposed P and Q controllers satisfy basic demands, i.e. stability is ensured with the acceptable settling time.

Depending on the user demands modified controllers can be proposed. When a settling time requirements are not so strict the ramp change of the reference signals can be applied with the change rate dependent on the required settling time. However, this modification can be related only to the reference value change mode.

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