PROPOSAL OF GRADUAL CONTROLLER FOR STATIC COMPENSATOR OF REACTIVE POWER

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Abstract

The electrical appliances with reactive consumptions, such as motors, transformers, compensative equipments etc, use for the operation the reactive power. This power is needed to create a magnetic field, which is necessary to their operation. Reactive power has the peculiarity that is not converted directly to useful work (useful energy), but circulates between the appliance of its consumption and generator. [1] Connecting the source of reactive power to the point of consumption will reduce the reactive power flow from remote source to the minimum. This phenomenon, respectively technical action is called „ Compensation“. The compensation doesn't change the value of reactive power equipment, which means, the reactive consumption is the same before and after connecting the compensative device. Without the compensation the reactive energy is transmitted over long distances. Nowadays the solutions are focused to achieve economical operation of electrical networks. Increasingly congested electrical networks require reliable voltage regulation because of the risk of voltage stability, which ultimately can lead to voltage collapse. These phenomenon can occurs in congested long electrical lines, when the power losses due to reactive power transferring causes the decreasing of voltage level in some electrical network nodes. Distribution and transmission system operators are responsible for the safe and reliable operation of the system and one of the possibilities to prevent the transmission of reactive power is also the penalty on the basis of pricing decisions. Control of reactive power is divided by a number of respects. One of the most widely used methods of reactive power regulation in the industry is a central compensation. This paper deals with proposal of controller using gradual control of static reactive power compensator.

1. Theoretical part:

Transfer of reactive power at long distances results in an increasing of power losses on individual electrical equipments connected in the transmission and distribution system. The losses are directly proportional to the square of the effective current, it follows that the reactive power contributes to the electrical network overload. The behavior of each element in electrical network can by represented via their impedances, which includes active and reactive part (inductive or capacity) [2]. The impedance is generally given by:

$$Z = R \pm jX \quad [\Omega] \tag{1}$$

Where

R – real (active) part of the impedance (resistance)

X – imaginary (reactive) part of the impedance (reactance)

The power losses in 3 ph. electrical circuit are given by

$$\Delta P = 3RI^2 = 3RIr^2 \frac{1}{\cos^2 \varphi_2} = P_1 - P_2 \quad [\mathrm{W}] \tag{2}$$

Where

Ir – real part of the current

cosφ2 – power factor of consumption

P1 – active power supplied

P2 – active power consumed

From this formula results, that reducing the consumption (or transfer) of reactive power, the power factor on the demand side cosφ2 increased and losses reduced. Reducing the value of reactive current part via compensation will achieve losses decreasing on the power system appliances.

Dependence of reduced losses to the size of the compensation is given by:

$$\Delta P_{ušet} = \Delta P - \Delta P_K = \frac{R^2}{U^2}\left[\left(P^2 + Q^2\right) - P^2 + \left(Q - Q_k\right)^2\right] = \frac{R^2}{U^2}[Q_k\left(2Q - Q_k\right)] \text{ (W)} \quad (3)$$

Where

ΔP – the losses without compensation

ΔPk – the losses with compensation

U – voltage

R – resistance

The compensation is therefore:

- to eliminate the losses in electrical networks and reduce voltage drops at the same value of transmitted active power.
- the possibility of maintaining smaller diameter of conductors at higher transmitted power
- to keep the power factor in defined range with decreasing transmission of reactive power by the same active power and to avoid penalizing for power factor out of range.

Upper harmonics in electrical networks may cause resonance and thus damage compensation device. Therefore, the appropriate filters are added to compensatory devices, particularly in those areas where the dangerous spectrum of upper harmonics is expected.

2. Gradual compensation

The gradual compensation is one of the most widely used methods of reactive power compensation. The principle is in gradual switching, mostly of capacitance banks. The area of reactive power compensation is determined by parallels for each switched on compensation level that is proportional to cosφ = 0,95 (tgφ = 0,33, where (tgφ = Q/P). This area is always below the corresponding parallels of amount of switched on levels. Fineness of controlling power factor is set by the number and size of individual compensation levels.

The following equation describes the change of cosφ, depending on the value of active and reactive power consumption and the number of switched levels.

$$\cos\varphi = \cos arctg\left(\frac{Q_L - Q_{C1}N}{P}\right) \quad (4)$$

where QL – consumption of reactive power at the same time as active power

QC1 – the size of one compensation level

N – the amount of switched on levels

The choice of the number of necessary levels depends on the actual size of one level and the total amount of necessary compensation power and the compensation required for the desired value, ie the value of power factor cosφ. (Usually a requirement to cosφ ≥ 0,95).

For the levels of with the same compensation power is given the formula:

$$\frac{Q_L - NQ_{C1}}{P} \leq tg\varphi_0 \Rightarrow N \geq \frac{Q_L - Ptg\varphi_0}{Q_{C1}} \quad , \qquad \mathrm{tg}\varphi \leq 0{,}33 \approx \cos\varphi \geq 0, \tag{5}$$

These relations apply to physical level-sequencing, when each level is the same and switched on separately. This design is impractical since it requires many contactors and required outputs of the controller, which is equal to the number of degrees of compensation. This problem is removed by combining physical levels to one, thereby saving on the number of contactors, a smaller requirements controller itself, the necessary compensation power is achieved for less handling capacitor etc. This coupling of physical levels is called up electrical levels of compensation.

3. The proposal of gradual controller for static compensator of reactive power:

The proposal of controller and simulation of its operation was carried out using the software MATLAB / SIMULINK. Electrical circuit and the controller for the simulation of reactive power compensation was modeled as is shown at the figure (fig. 1). This picture shows a simply block diagram - single-phase circuit.

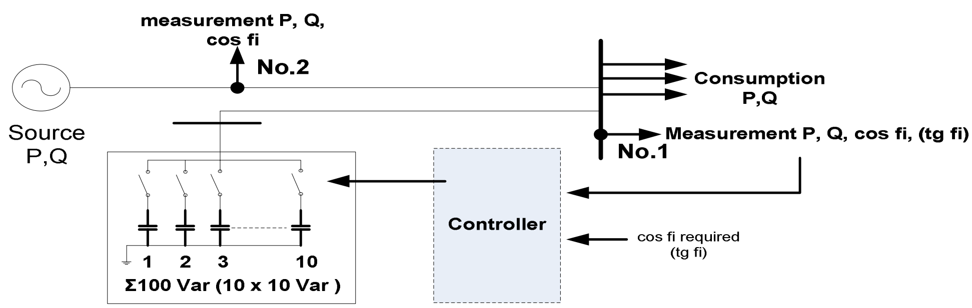

Fig. 1 – The block diagram of circuit

The power factor value depends on the current active and reactive power flow. To create the change of the current value of this flow, switching of four RL blocks with different values were used (consumption 1 to consumption 4). Switching of this blocks in different times causes the change of current active and reactive power and thus also a change of power factor. The last change of power factor (t > 7s) was deliberately set to the value tg φ = 0,29, which is the same as cos φ = 0,96. According to the required range of power factor set to 0,95 to 1, in these phase of simulation the compensatory device should by unconnected. (compensatory reactive power from capacitors equals to zero).

The switching progress of the RL blocks via switches S1 to S4 is shown in figure (fig 2.) – time change of consumption

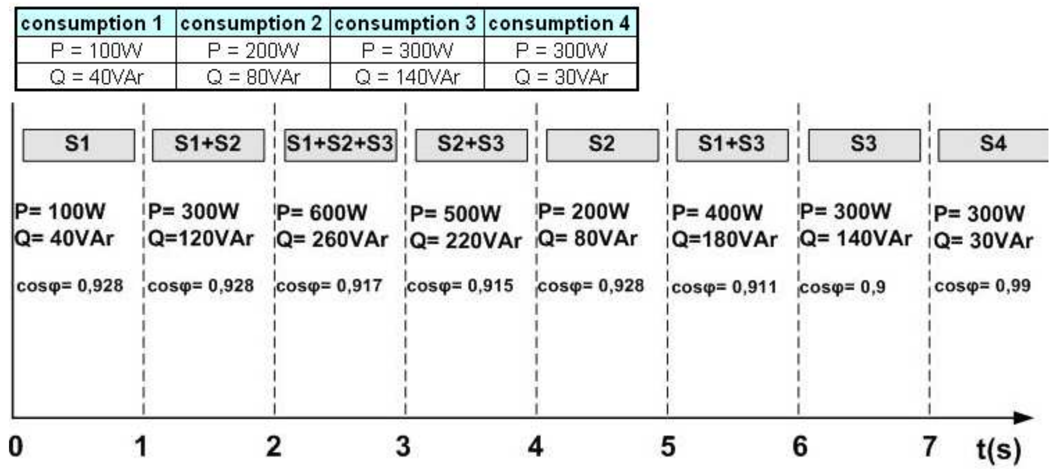

Fig. 2 – time change of consumption (power factor change)

After running the simulation the individual blocks will start switching , This causes the time change of active and reactive power consumption (change of power factor)during the period of simulation. The time simulation is set to 8s. The measurements are installed in two places – measurement No.1 and measurement No. 2. Measurement without compensation is installed after the place of compensatory device (measurement No.1) and measurement with the compensation is installed in front of compensatory device (measurement No.2). These two measurements were chosen to evaluate the controller functionality.

On the basis of voltage and current measurement the active and reactive power, and very tgφ is evaluated at the both places. Consequently, in the subsystem where the controller is modeled is calculated the necessary number of relay grades for the required tg φ, respectively cos φ. Because of the analogy between tg φ and cos φ ($\cos\varphi \geq 0,95 \approx \mathrm{tg}\,\varphi \leq 0,3286$), the required power factor value is given by tg φ. The model scheme and scheme of controller are are listed in the Annexes (Annex A – Model scheme, Annex B – Controller scheme).

Description of the principle of controller functionality

Variables entering the controller are active and reactive power consumption - Pcons and Qcons and the value of desired power factor - tg φ. The active and reactive power flow is obtained from measurement No. 1 and the desired power factor is defined manually by the user. The proposed controller operates on a principle of comparison of two straight lines displacement. One line represents the consumption of active and reactive power. This line is led by penetration of active consumption Pcons and reactive consumption Qcons, the value of gradient of this line is equivalent to the desired power factor cosφ, (respectively tgφ). Other lines represent different graduals of compensation and define the area of compensation. Displacement of these lines on the y-axis, which represents the setting of compensation levels, is directly defined and its value depends on the value of a selected compensation level. It follows that condition, how much compensation levels, so many lines with given displacement on the y-axis. The following figure (fig. 3) illustrates the principle of that proposal of controller operation. At this the is shown the situation at the simulation time from 4. s to 5. s , when Pcons = 200W and Qcons = 80VAr, consumption 2 according to figure (fig. 2).

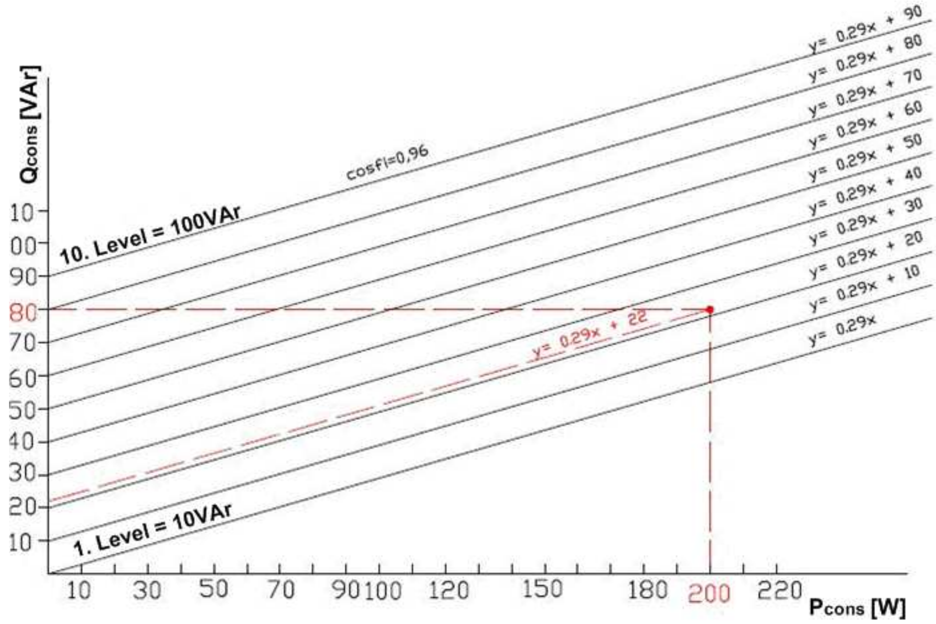

Fig. 3– the controller principle – comparison of lines displacement on the y-axis (desired value of power factor is 0,96)

The controller monitors the consumption of active power Pcons and reactive power Qcons. These variables substitute to the line equation and release the number of necessary switched levels in the following way:

a) Line equation – linear equation

A common form of a linear equation of line equation in the two variables x and y is

$$y = cx + q \tag{6}$$

where c and q designate constants. In this particular equation, the constant c determines the slope or gradient of that line, and the constant q determines the point at which the line crosses the y-axis, otherwise known as the y-intercept. According to these rules, the controller creates the line equation as:

$x = P_{cons}$

$y = Q_{cons}$

c = the gradient of line equals to the desired value of power factor

Parameter c is set to the controller as an input manually by the user. (In this way is possible to set the desired power factor for which the regulator has to compensate the value of reactive power consumption.) Substituting variables P_{cons} and Q_{cons} into the line equation, the program will calculate the displacement of the line (parameter q):

$$80 = 0{,}29 * 200 + q \rightarrow q = 22$$

b) comparison:

In the second step, the controller calculates the displacement of line which represents the consumption (q = 22, red dashed line) and compares it with the displacement of the lines of individual compensation levels. In the first level the parameter of displacement q is always equal to zero. If the displacement of line consumption q is greater than the displacement of line compensation level, the controller turn on the corresponding level. Otherwise, the compensation level stays switched of. As shown in figure above (fig. 3) controller compares the size of computed displacement q = 22 > 0, 10, 20 . The third level is switched on, it means the compensation power is 30VAr. The resulting value of tgφ

$$tg\varphi = \frac{Q_{odb} - 30}{P_{odb}} = \frac{80 - 30}{200} = 0{,}25 \Rightarrow \cos\varphi = 0{,}97$$

Turning the compensation power of the value 30VAr 30, the power factor has been changed from the previous value cos φ = 0,928 to the value cos φ = 0,97. The following figures (fig. 4 and fig. 5) shows the simulation results with varying consumption as shown in figure above (fig. 2) and desired power factor cosφ ≥ 0,96 (ie, tan φ ≤ 0,29).

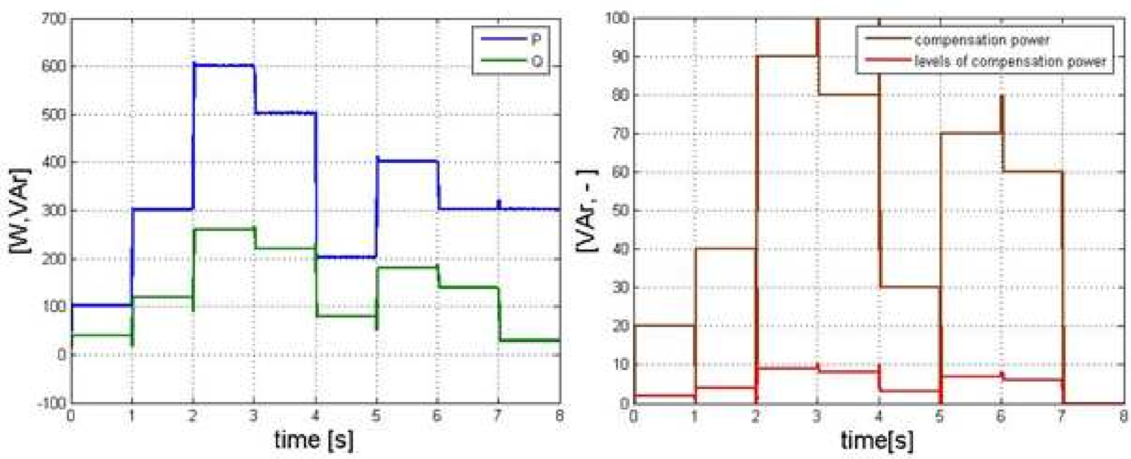

Fig. 4 – the active and reactive power consumption and compensation output power with the switched levels

The next figure (fig. 5) shows the course of power factor measured at the No.1 and No.2 according the circuit in Figure (fig. 1). This figure shows how the power factor has been changed depending on by the controller output signals (output compensation power). The resultant power factor with compensation in all cases meets the users desired value of cosφ ≥ 0,96.

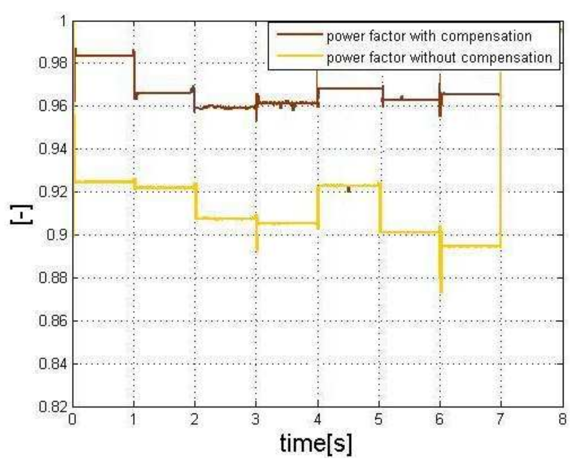

Fig. 5 – The course of power factor with and without compensation

4. Conclusion:

The results of the power factor during the simulation using the compensation and without compensation, it can be stated that the regulator is working correctly. This also confirms the fact that in the simulation time from 7.s and 8.s , the controller did not switch on any compensation level, since value of power factor without compensation was in required range. This proposal of operation of gradual regulator on the basis of lines comparison can by use for the compensation and thus to reduce the real losses during the energy transfer.

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0546-07. Author is grateful for support to the Grant VEGA No. 1/0687/09.

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Annex A – Model scheme

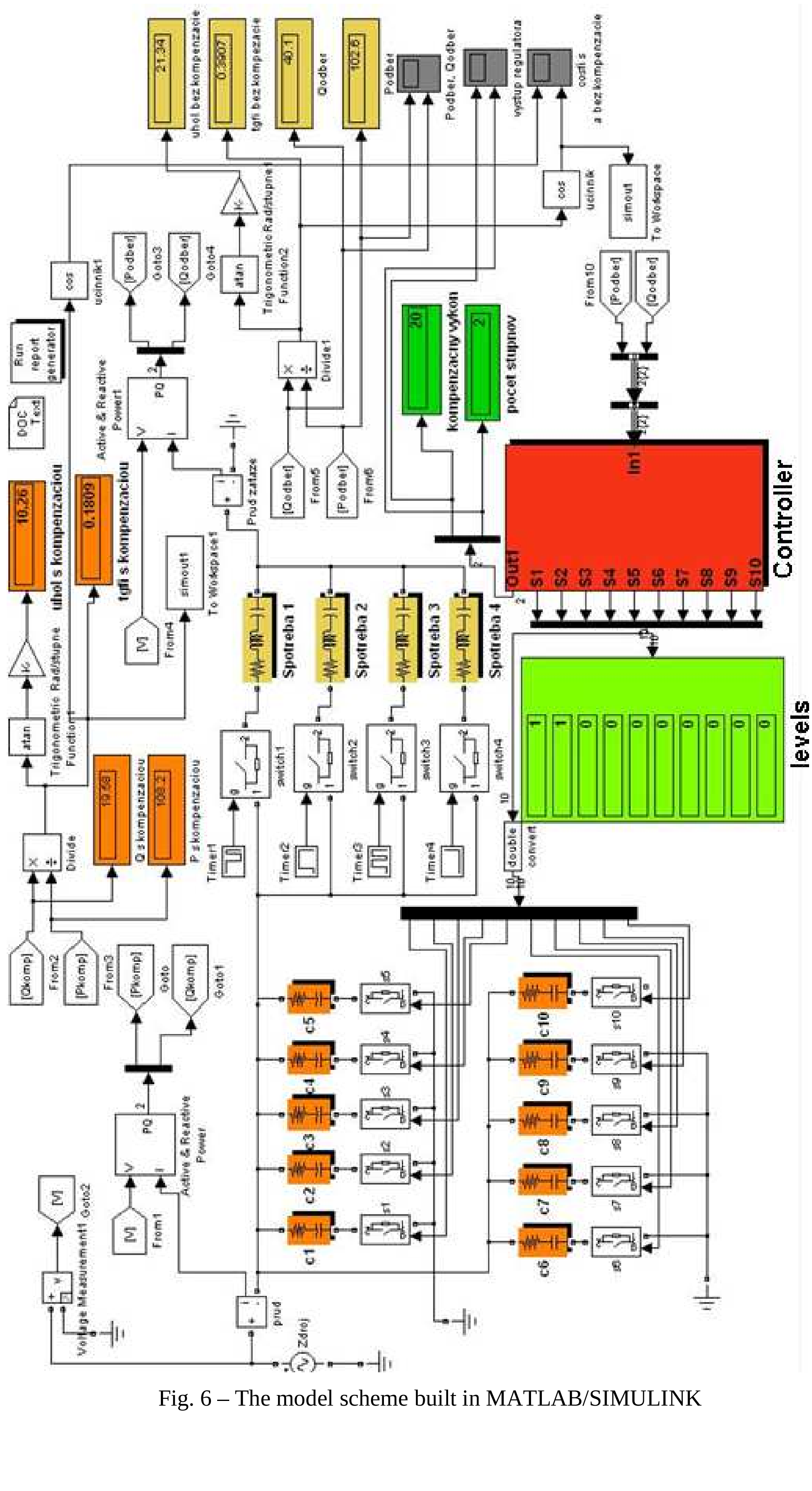

Fig. 6 – The model scheme built in MATLAB/SIMULINK

Annex B – Controller scheme:

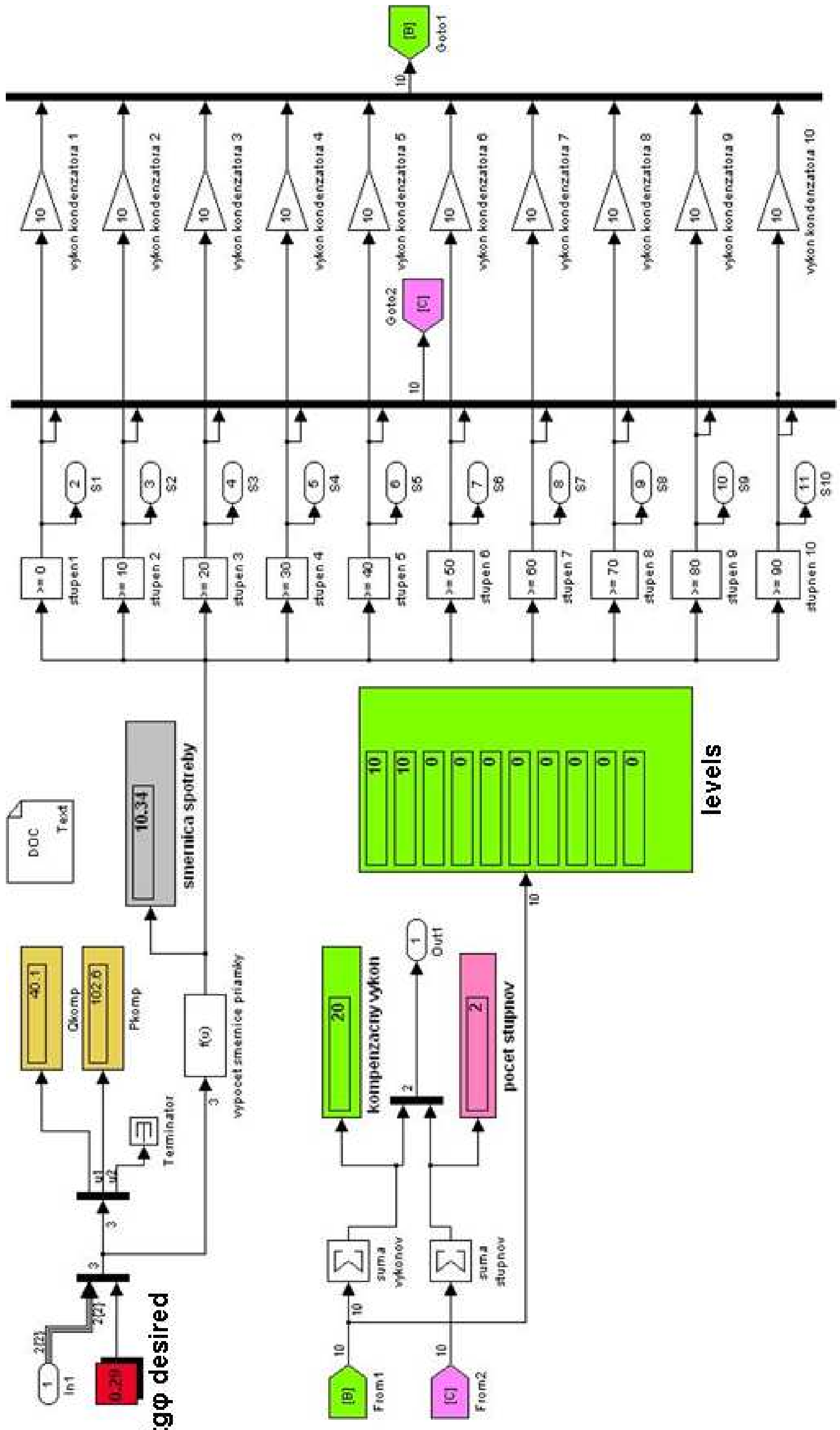

Fig. 7 – The model of controller built in MATLAB/SIMULINK