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COMPUTER SIMULATION OF THE CONTROL SYSTEM OF NETWORKING MULTILEVEL VOLTAGE INVERTER

Computer model, including the improved control law of the networking multilevel voltage inverter of solar module is developed, it enables to maintain the operation mode of solar module in the area of maximum power take-off point and takes into consideration solar module temperature value that increases its performance. Computer model of the regulator of longitudinal component of inverter current is suggested, the given module takes into account current and set voltage of the grid and the voltage of solar module, that enables to optimize the operation of the inverter both on the side of solar module and on the side of the grid by the voltage. Computer model of the regulator of inverter current longitudinal component is suggested, this model takes into consideration active power value of grid node and the set value of the longitudinal component of the current, that is necessary for inverter operation in the area of maximum power take-off point, that enables to optimize the inverter operation by the frequency.

Key words: *computer model, multilevel voltage inverter, control, solar module, temperature.*

Introduction

Nowadays photovoltaic systems become more and more popular [1, 2]. Photovoltaic systems can operate both as an independent system and as grid-connected system. [3 – 5]. Photovoltaic system, connected to the grid is economically efficient , as it does not require the usage of the batteries for electric energy accumulation . In such systems the algorithm of the point of maximum power take-off search is used that increases the efficiency of the system [6]. Multilevel networking voltage inverters are widely used for the formation of output alternative voltage as matching devices. In [7, 8] models of multilevel voltage inverters are considered in the process of operation with electric drive in motoring mode but these papers do not contain the analysis of parallel operation of the inverters with the grid. That is why, it is necessary to synthesize the control system of multilevel inverter, oriented on application in solar power plants .

Multilevel voltage inverters in the process of operation in solar power plants have two main problems: the first- formation of sinusoidal current and voltage on their outputs for supplying into the grid, the second- decrease of harmonies level [9]. The aim of the research is computer simulation of the synthesized control system of the networking multilevel voltage inverter in the process of operation within solar power station for determination of inverter control quality indices, admissible operation modes, computation of the parameters of the filter of electromagnetic compatibility.

Results of the research

In the systems of inverters vector control the reduction of three-phase system of inverter currents to orthogonal d-q coordinate system is used. Output voltage at the inverter output is set to be proportional to longitudinal component of the current I_d and output power is provided by the corresponding value of the transversal component I_q. In case of coordinated operation of multilevel inverter with the grid for monitoring quasi-extremum point of voltage-current characteristics of solar module longitudinal and transversal components of multilevel inverter current will provide voltage and power, that on the side of inverter input will be taken from the solar module and from the side of the output will be supplied into the grid. In [10] it is indicated that the harmonics of low order have strong impact on the operation of the inverter, that is why, it is expedient to install L - filter between the output of voltage inverter and the grid. Taking into account the above- mentioned and the structure of control system, presented in [11] the structure of the internal contour of multilevel inverter control system and its power circuit will have the form, shown in Fig. 1 (on the example of three-level inverter). Temperature correction of the output power of solar power module in the suggested system is provided by measuring channel, consisting of the unit IS and unit CBQ

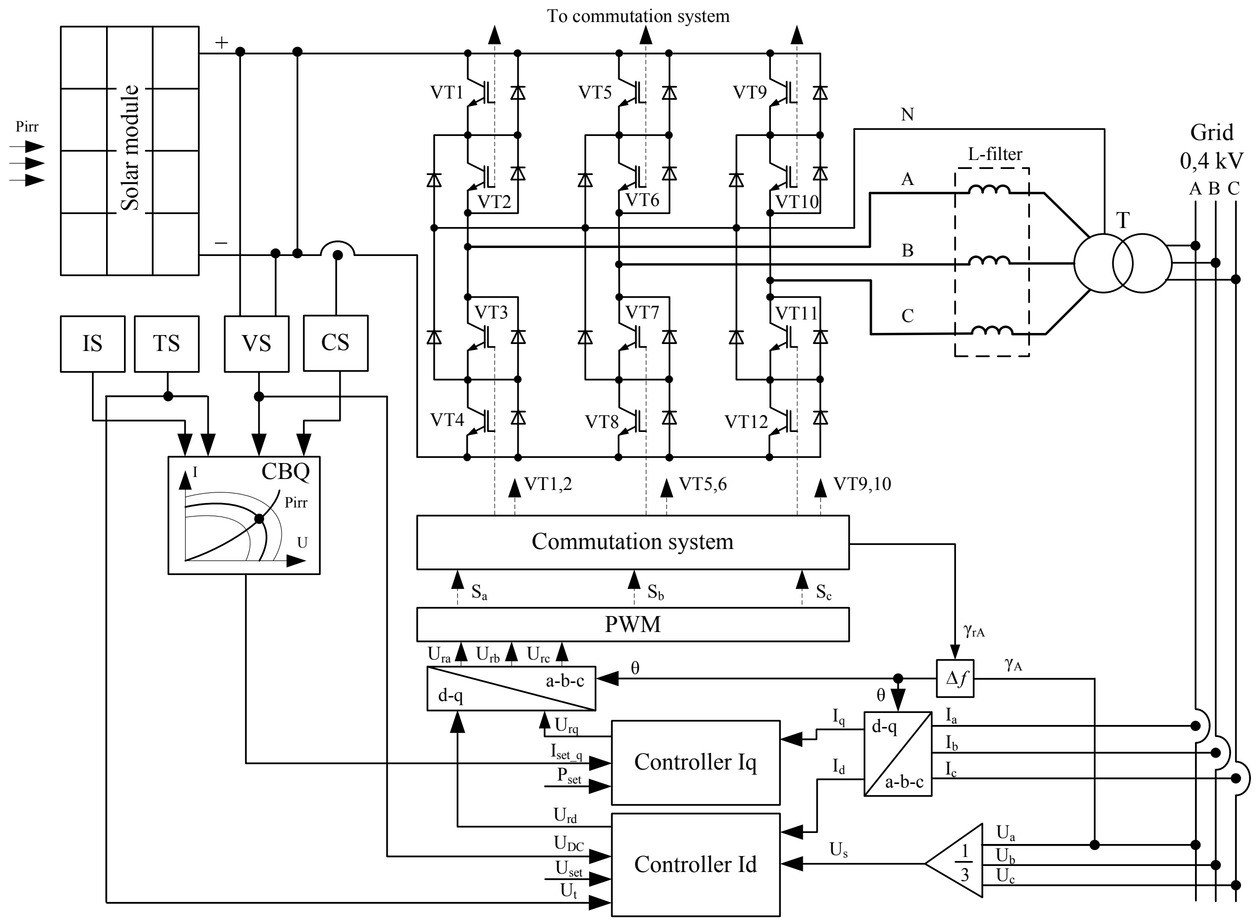

Fig. 1. Functional diagram of three-level networking inverter with internal circuits for regulation of the currents I_d and I_q

In Fig. 1: IS-lighting sensor; TS - temperature sensor; VS- voltage sensor; CS- current sensor.

Quasi- extremum computation unit (CBQ) calculates the coordinates of maximum power take-off point area and forms the task signal by the current *Iq.set* for the regulator of transversal component of I_q the inverter current. Output voltage sensor of the solar module forms the task signal by voltage U_{DC} for the regulator of longitudinal component I_d of the inverter current. Feedbacks of the above-mentioned regulators are realized by means of converting three phase system of currents I_a, I_b and I_c into orthogonal system I_d and I_q. Such conversion is realized relatively the angle of electromagnetic loading of the inverter θ, that corresponds to loading angle of electric machine, that operate in parallel with the grid.

Angle of electromagnetic loading of the inverter θ is calculated by the system in time interval as the difference of voltage frequencies of the grid and the inverter, correspondingly

$$\theta = \int_{0}^{\pi} \Delta f dt. \tag{1}$$

Frequencies difference is determined in time interval at corresponding interval as the time from the moment of signal issue by switching system for closing of VT1 key till the moment of passage across 0 of voltage grid curve (by phase A) in positive direction (signal γ). Unit of conversion of three phase system of currents “a-b-c” into orthogonal “d-q” is described by the system of equations

$$\begin{cases} I_d = \dfrac{2}{3}\left(i_a \cdot \cos\theta + i_b \cdot \cos\left(\theta - \dfrac{2\pi}{3}\right) + i_c \cdot \cos\left(\theta + \dfrac{2\pi}{3}\right)\right) \\ I_q = \dfrac{2}{3}\left(i_a \cdot \sin\theta + i_b \cdot \sin\left(\theta - \dfrac{2\pi}{3}\right) + i_c \cdot \sin\left(\theta + \dfrac{2\pi}{3}\right)\right). \end{cases}, \tag{2}$$

Unit of reverse conversion of orthogonal system of computed optimal values of currents *Ird* and *Irq* to three phase system of control voltages by the shoulders of inverter bridge *Ura-Urb-Urc* operates according to the system

$$\begin{cases} U_{ra} = I_{rd} \cdot \sin\theta + I_{rq} \cdot \cos\theta, \\ U_{rb} = \dfrac{1}{2} \cdot \left(\left(\sqrt{3} \cdot \sin\theta - \cos\theta\right) I_{rq} - \left(\sin\theta + \sqrt{3} \cdot \cos\theta\right) I_{rd}\right), \\ U_{rc} = -U_{ra} - U_{rb}. \end{cases} \tag{3}$$

It is known that the value of the voltage at the output of photovoltaic elements of the solar module constantly changes as a result of certain factors, namely: weather conditions, time of the day and panels temperature[12]. State of the capacitor of the solar cells battery also changes, depending on whether it is charged or discharged. The important factor from the point of view of the development of inverter control system is to provide the operation of solar module in the area of maximum power take-off. Dependence of the power, solar module can supply to grid inverter in the process of operation with real output power greatly depends on the temperature of solar panel. That is why, the value of solar panel temperature should be taken into consideration in control law of network multilevel voltage inverter.

To provide the mode of maintaining solar module in the point of maximum power automatic voltage regulators (of longitudinal current component of the inverter I_d) and power (transversal current component of the inverter I_q) will operate in accordance with PID-regulation law and are described by the system of equations [13]:

$$\begin{cases} I_{set\_q} = k_P \cdot k_{g\_irr} \cdot P_{irr} + k_P \cdot P_{set} + k_u \cdot U_{DC} - k_{sl} \cdot I_{DC}, \\ U_{rq} = k_{pq} \cdot \left(k_{g\_rq} \cdot \left(I_{set\_q} - I_q\right) + \dfrac{1}{T_{iq}} \cdot \displaystyle\int_0^t \left(I_{set\_q} - I_q\right)dt + T_{dq} \cdot \dfrac{d\left(I_{set\_q} - I_q\right)}{dt} \right) \\ I_{set\_d} = k_{b\_c} \cdot \left(U_{set} + U_{DC} \cdot k_{g\_DC} - U_s \cdot k_{g\_s} + k_t \cdot \left(\dfrac{T}{T_{ref}}\right)^2 \right), \\ U_{rd} = k_{pd} \cdot \left(k_{g\_rd} \cdot \left(I_{set\_d} - I_d\right) + \dfrac{1}{T_{id}} \cdot \displaystyle\int_0^t \left(I_{set\_d} - I_d\right)dt + T_{dd} \dfrac{d\left(I_{set\_d} - I_d\right)}{dt} \right). \end{cases}, \tag{4}$$

where K_{pd} and K_{pd} – amplification factors of the regulators of longitudinal and transversal current components of the inverter, correspondingly; *Tid* and Tiq – constants of time integration of regulators; Tdd – constant of regulation channel differentiation time Id; U_{rd} and U_{rq} – output signals of the regulators of longitudinal and transversal components of current inverter ; k_P – coefficient with the conductance dimensionality for reduction of the power to corresponding value of the current; k_{g_irr} – weight coefficient of power value amplification, arriving at illumination sensor; P_{set} – set value of solar module power; k_u – coefficient with conductance dimensionality for reduction of the voltage in the channel of regulator setting to corresponding current value at the input of measuring unit of the regulator; U_{DC} – voltage at the output of the voltage sensor of solar module; k_{sl} – slope coefficient of regulating characteristic; I_{DC} – value of the current, arriving at CBQ from the output of current sensor; k_{g_rq} – amplification factor of P-component of the output voltage U_{rq}; k_{g_i} – coefficient of voltage signal reduction to the current; U_{set} – set value of the voltage to be maintained by the solar module; U_{DC} – value of the voltage at the output of voltage sensor; k_{g_DC} – amplification factor of the voltage from the output of voltage sensor; U_s – average value of grid voltage; k_{g_s} – amplification factor of grid voltage value; k_{s_rd} – amplification factor of voltage P-component $\underline{U}_{rd}$; T – solar cell temperature value; T_{ref} - temperature difference between solar cell and environment.

The considered control law requires specification of setting coefficients, which will correspond to stability criteria of the control system, determination of the system of stable operation area, determination of dynamic characteristics for their analysis and further optimization.

We will perform the investigation of the models of longitudinal and transversal components of the inventor current and verification of stability. In order to determine optimal parameters of current components of the inventor, we compose the computer-based model (fig 2), built in accordance with the synthesized law (4).

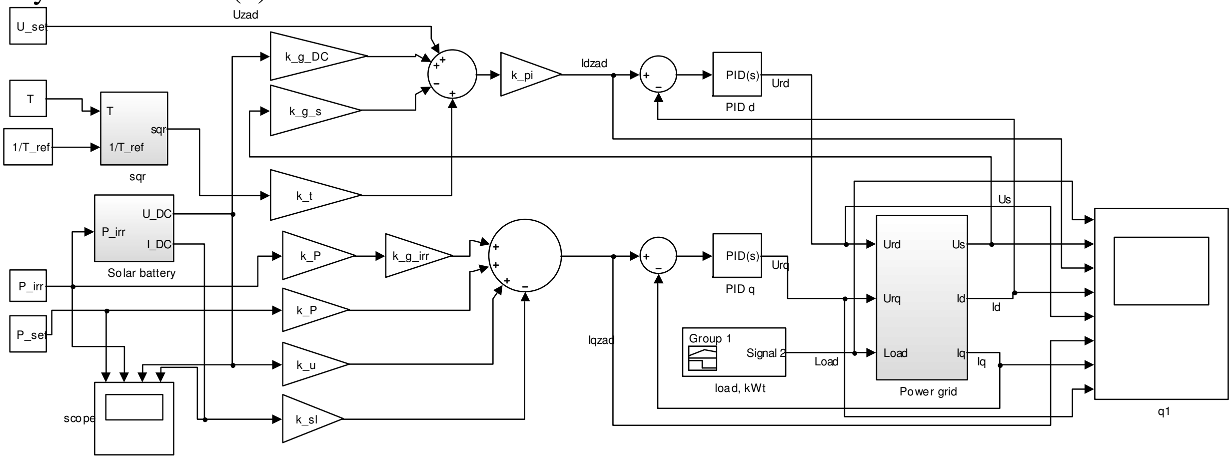

Fig. 2. Computer-based model for verification of operation adequacy of regulators d and q of current components of the inverter

In the given model: *Uset* – set value of the grid voltage; *P_irr* – value of the power, obtained from the illumination; *P_set* – set value of solar module power; *Solar battery* – model of solar battery; *sqr* – square value of the relation of solar battery temperature to the difference of temperatures between solar battery and the environment; *PID d* – PID-regulator of longitudinal current component of the inverter; *PID q* – PID-regulator of transversal current component of the inverter; load – specified load schedule; *Power grid* – model of the grid.

The results of the simulation for PID regulators of longitudinal and transversal current components of the inverter are shown in Fig 3.

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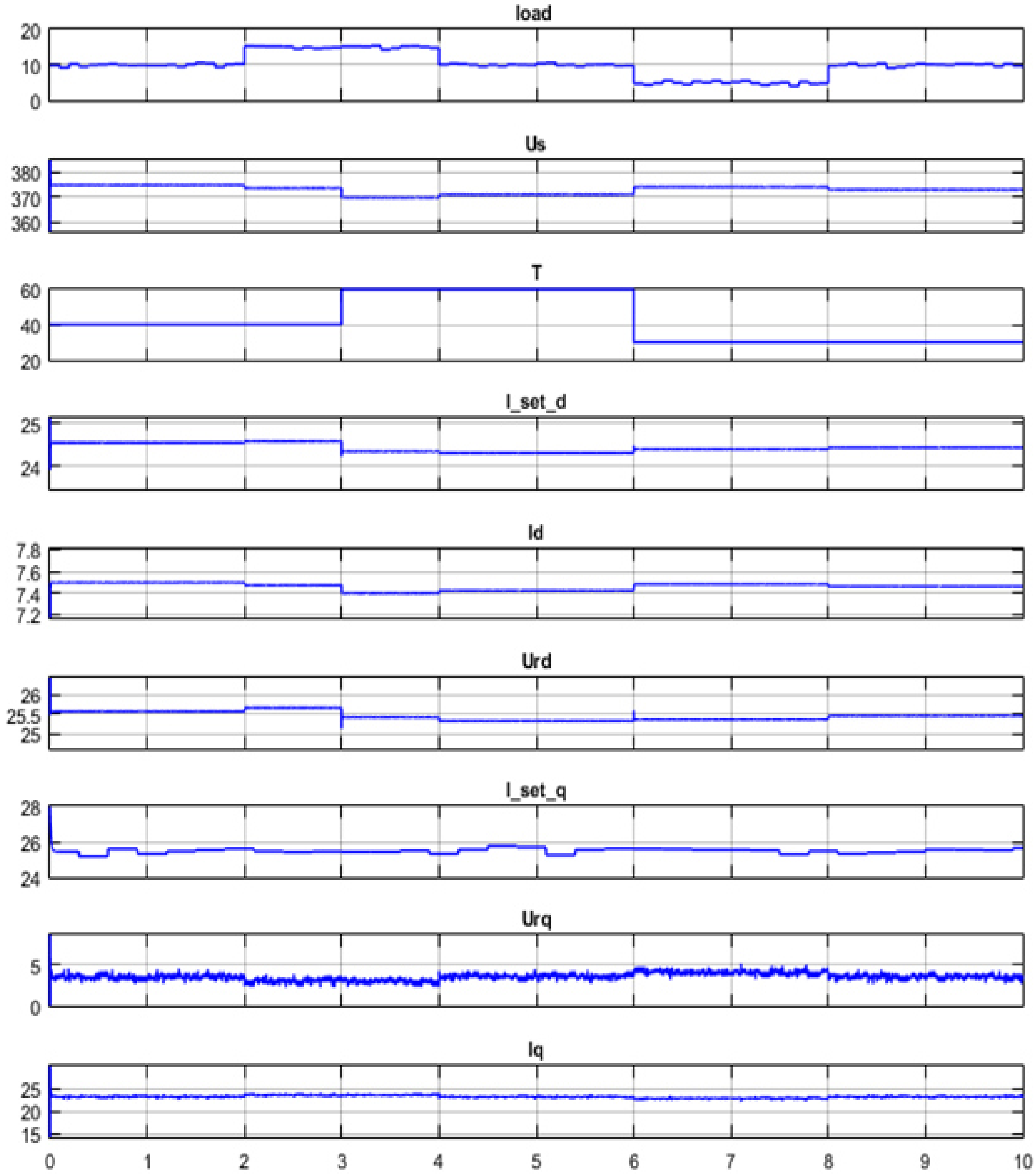


Fig. 3. Simulation results for PID-regulators of longitudinal and transversal components of inverter current

Specified and real values of illumination level, output current and solar cell voltage are shown in Fig 4.

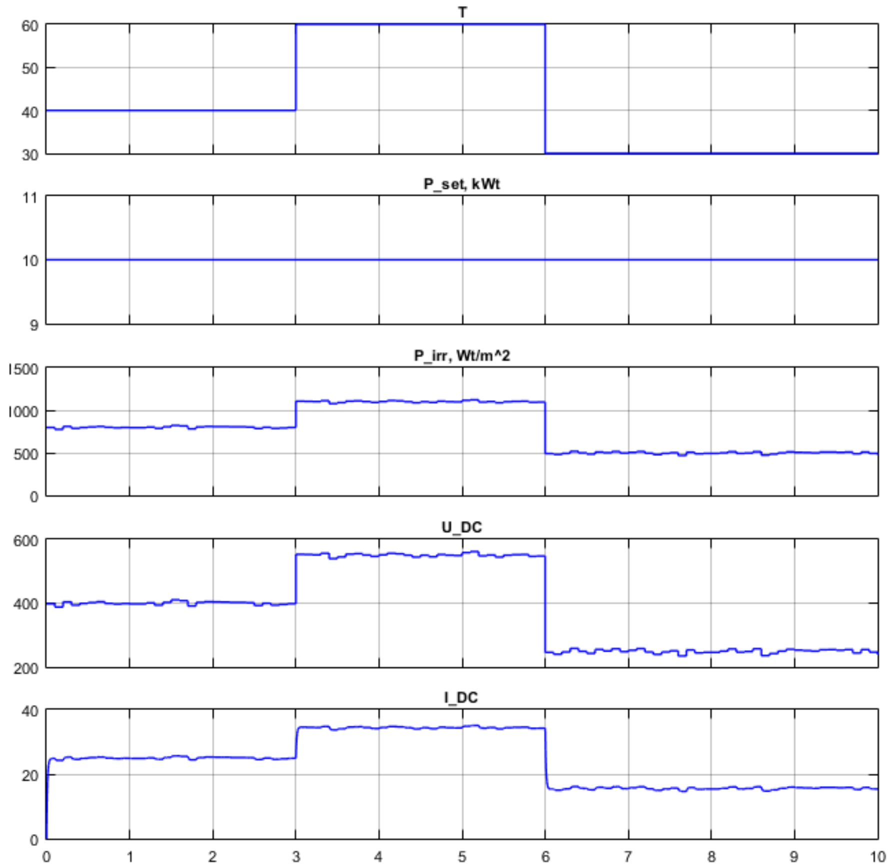


Fig. 4. Specified and realvalues of lightening level, output current and solar cell voltage

Computer-based model, that corresponds to circuit hardware components of multilevel voltage inverter and operates according to the law (4), is shown in Fig 5. The model comprises functional units: solar module, three-level voltage inverter, transformer, L-filter, load, grid, commutation system, controller Id, controller Iq.

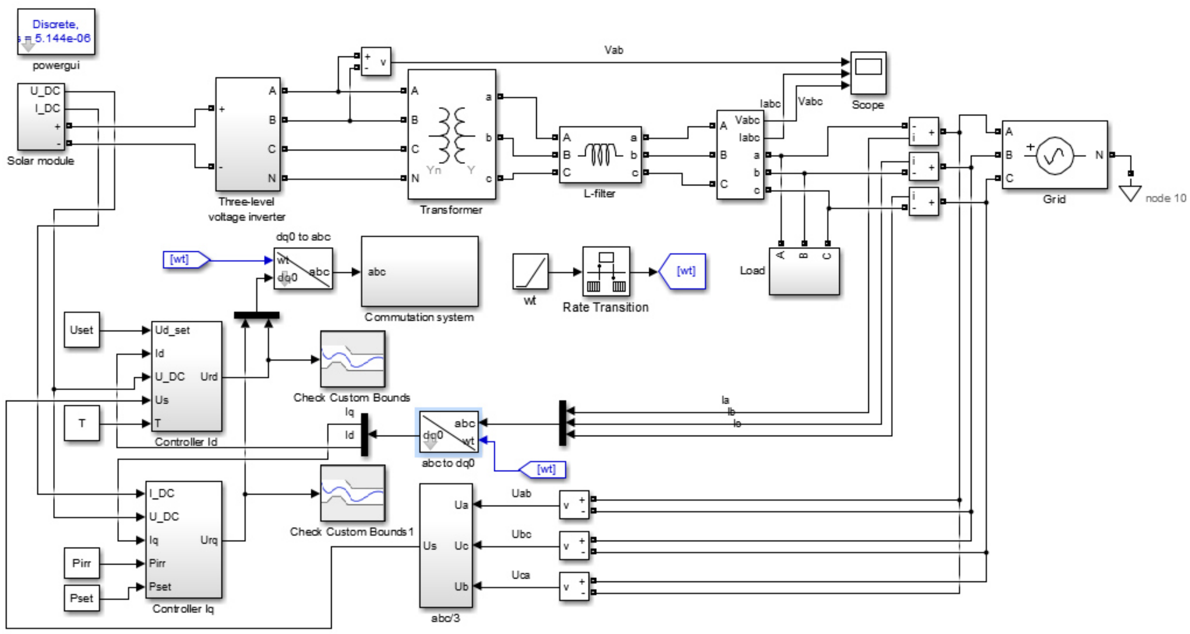


Fig. 5. Computer-based model, that corresponds to circuit hardware components of multilevel current inverter

Having performed the modeling of control system of multilevel networking voltage inverter in the process of operation with solar module and the grid, graphs of transient processes of current and voltage at the output of the transformer, active and reactive powers for various operation models are obtained: at various levels of illumination (Fig. 6), at various settings of regulators (Fig. 7), without the account (and with the account) of L-filter in the system (Fig. 8).

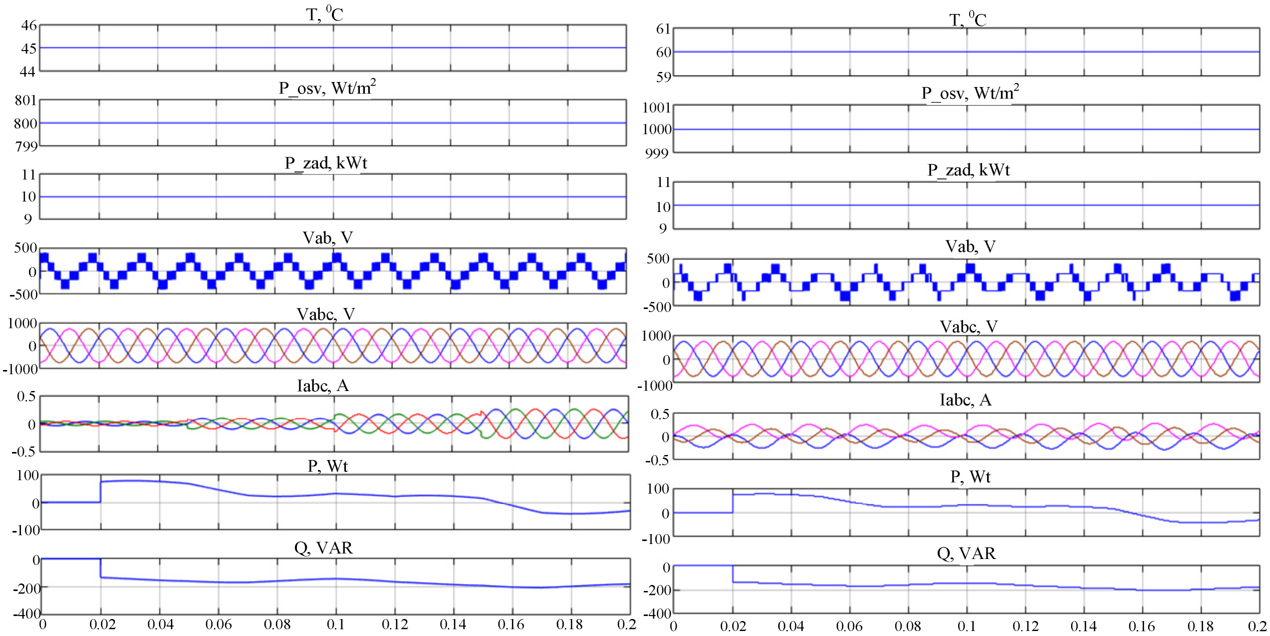


Fig. 6. Graphs of transient processes of the control system of multilevel networking voltage inverter at various levels of illumination

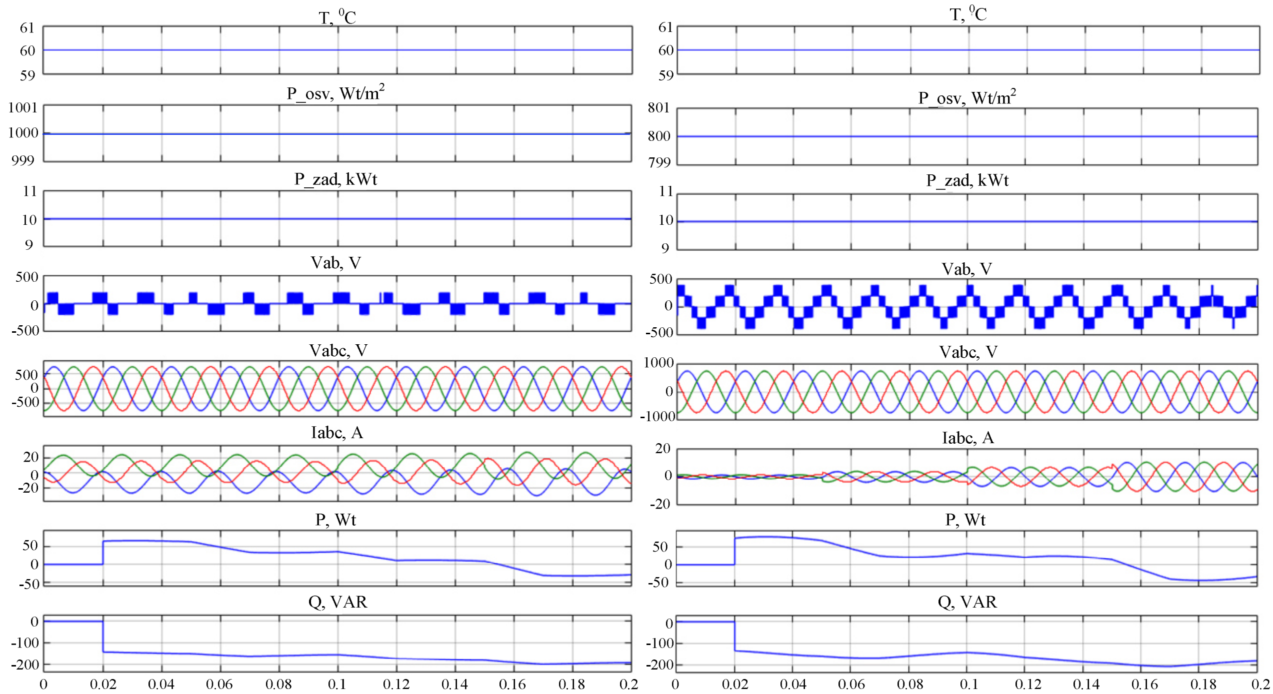
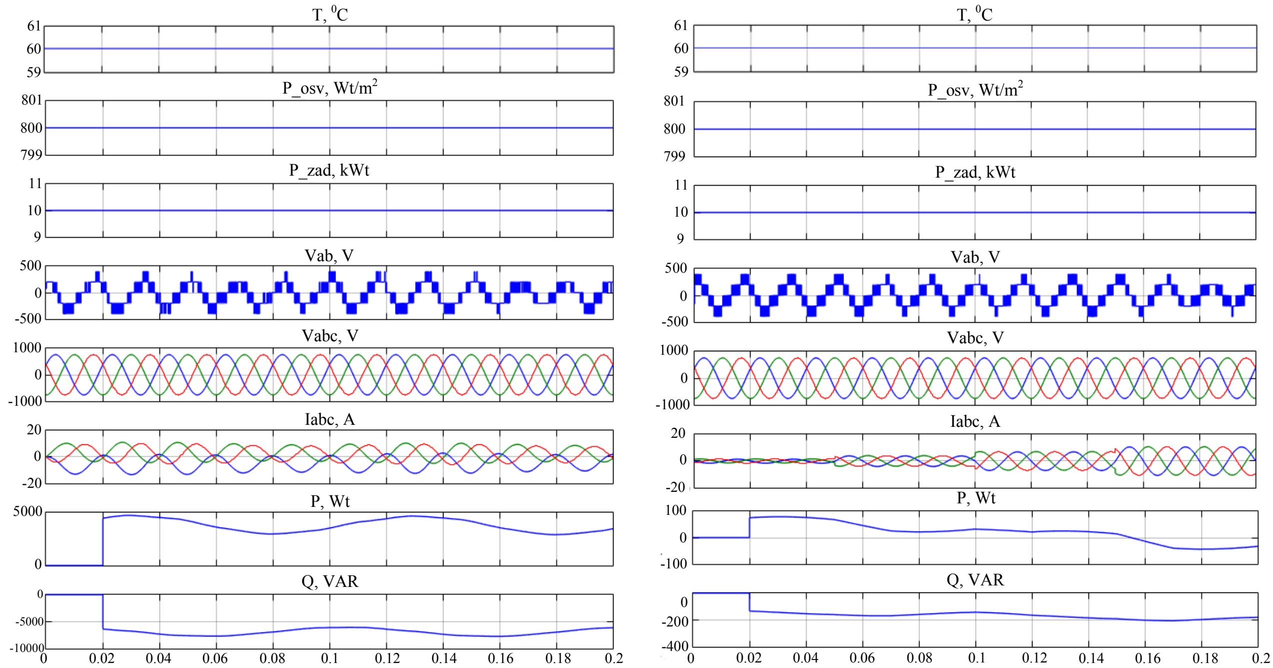


Fig. 7. Graphs of transient processes of the control system of multilevel voltage inverter at various settings of regulators



a) b)

Fig. 8. Graphs of transient processes of the control system of multilevel networking voltage inverter with non-compensated filter (a) and filter with automatic compensation (b)

In the process of modeling optimal settings of system regulators were determined, they were obtained by means of optimization tool Check Custom Bounds (Fig 5). In the process of optimal setting parameters values search feedback channels of the system (P,U,f) were used, their values are given in the table 1.

Table 1

Optimal settings of system regulators

Weight coefficient	k_{g_DC}	k_{g_s}	k_{g_i}	k_P	k_u	k_{g_irr}	k_{sl}	k_t
Value	2	1	0.03	2	0.01	0.1	0.1	0.2

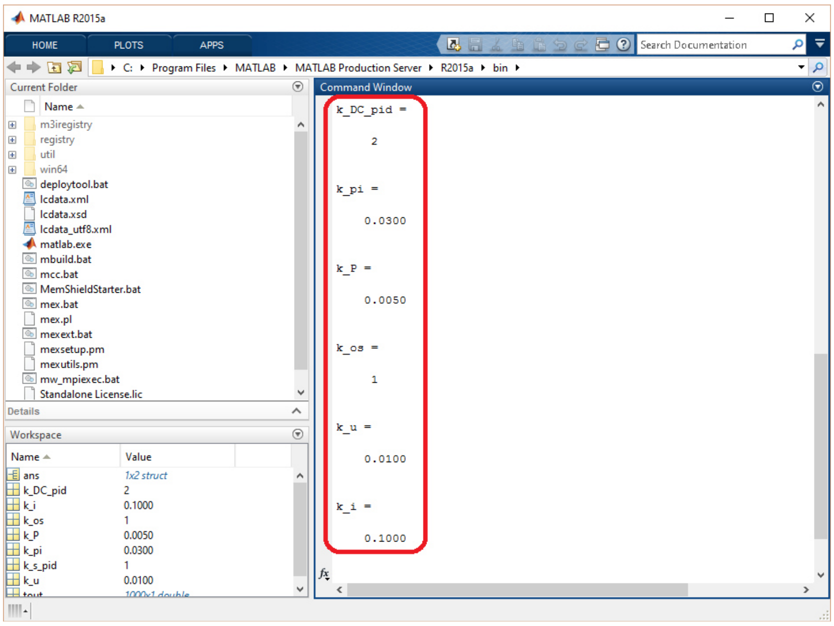


Fig. 9. Optimal settings of the regulators

Having analyzed the results of modeling, it became obvious, that control system of multilevel networking inverter of solar module will operate incorrectly if L-filter at the output of the inverter will not be available, this will be shown by the assertion of unsinusoidality of the output current. In case of incorrect settings of the regulators, the output voltage of the inverter does not correspond to the expected value. Transient processes on the control system of multilevel networking inverter will be satisfactory if the filter with automatic compensation is used and in case of optimal settings of the regulators, determined in the research.

Conclusions

Computer-based model of control system of multilevel networking inverter of solar power plant, that solves the problems of maintaining the operation mode of the solar module in the point of maximum power take-off and takes into account the value of solar module temperature that enables to increase solar module performance, put in correspondence the balance of electric power, generated by solar module and consumed power in real time mode, is developed.

Computer simulation of longitudinal component of inverter current of the regulator, that takes into account current and set voltage of the grid and solar module voltage is performed. Computer simulation of transversal component of inverter current regulator, that takes into account the set active power value from the node of the grid and set value of the transversal current component, that is required for inverter operation in the area of maximum power take-off point, is carried out.

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