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Selection of components for photovoltaic system

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ABSTRACT

Purpose: The aim of the paper is to determinate basic parameters for components of demonstrative system which is traffic light pedestrian crossing.

Design/methodology/approach: Photovoltaic module was produced from monocrystalline silicon solar cells which were joined in series. Photovoltaic system consists of solar module, astable generator, step-down converter and battery pack.

Findings: It`s necessary to protect photovoltaic system from external factor like unstable light conditions, variable input voltage, shading. Taking this fact into account photovoltaic system with step-down converter was designed. Step-down converter adjust the voltage of photovoltaic module to the voltage of battery protecting them from overcharging and discharging.

Research limitations/implications: The main goal of this work is to show the practical use of widely available, renewable energy source, which is the Sun through the selection of component for the demonstrative photovoltaic system -traffic light pedestrian crossing.

Practical implications: In order to provide access to electricity in areas with limited access to power network, there irreplaceable are stand-alone photovoltaic systems, which can supply both AC and DC devices.

Originality/value: The produced photovoltaic system confirms the usefulness of solar energy in every place where sunlight is available. In order to provide steady supply at night and in low sunlight the battery stores energy was applied.

Keywords: Electrical properties; Solar cells; Photovoltaic system; Astable generator; Step-down converter

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PROPERTIES

1. Introduction

Crystalline silicon solar cells (both monocrystalline and polycrystalline) are widely used in current photovoltaic industry. Monocrystalline silicon is the best known representative of materials used in photovoltaics because of the fact it is the base material in the production of microelectronic devices.

The main groups of materials that play a role in the development of today's photovoltaic cells production are [1,2]:

- silicon (monocrystalline, polycrystalline and amorphous),

- semiconductor compounds (halides, compounds of III-V group of periodic system),
- thin film chalcogenide (CIGS and CdTe),
- photochemical (dye sensitised),
- organic.

The market for photovoltaic solar contribution made from crystalline silicon exceeds 80%, of which one third comprises monocrystalline silicon and two thirds - polycrystalline silicon. The rest of the market falls on thin-film solar cells, most of them on structure of amorphous silicon and only 4% on the other materials. By using only a very thin layer (thickness of single micrometers) of expensive semiconductor material on low-cost large-area substrates, thin-film solar cells can significantly reduce the total cost of solar cells [2-4].

A single photovoltaic cell is a unit of low power and voltage, insecure against external factors. Therefore, to obtain a device for producing higher electric current and voltage, single PV cell is combined in tens of solar cells into a photovoltaic module (PV), and then encapsulated [5].

In order to obtain higher voltage, solar cells are connected in series. The voltage is then the algebraic sum of the voltage of all solar cells. In this connection, the weakest cell determines the quality, which means that the current of PV module is equal and depends on the current value of the weakest solar cell in the chain. If even one solar cell is shaded, for example by electric poles, wires, trees, foliage, dust, bird droppings, the voltage across the cell changes the direction of polarization and such a cell becomes a burden for the other.

In practice, complete elimination of shading is not possible, and therefore solar module is protected from damage by using shunt diodes, so-called bypass diodes that normally are polarized in the reverse direction and do not cause any losses of power. In the case of shading, photovoltaic cells are polarized in the direction of conduction. Electricity generated by the rest of the solar cell begins to flow through the bypass diodes, skipping shaded cells. The ideal would be to shunt each photovoltaic cell, but that solution is used only in aerospace engineering. In practice usually groups of 15-20 solar cells are shunted [6-8].

In order to increase the current, photovoltaic cells are connected in parallel. With this combination, the current value is the algebraic sum of the current of all solar cells. [9,10].

In a parallel connection, in the case of shading, single photovoltaic cell can also become a burden to others. However, placing a serial diode in each branch containing a number of cells connected in series prevent this effect. In the case of shade one of the solar cells, serial diode is blocked, branch is not damaged, but it does not produce any energy [7,9].

In order to protect photovoltaic module against damage, dirt, influence of the environment and reaching the mechanical rigidity, combined photovoltaic cells are subjected to lamination. Lamination method depends on the type of solar cell and method of their production technology [10,11].

There are three basic configurations of photovoltaic systems [5,12]:

- stand-alone systems,
- hybrid systems,
- systems attached to the energy grid.

Stand-alone systems (autonomous, unattached to the energy grid) are using only the energy produced by photovoltaic system. Such a system consists of:

- photovoltaic panel,
- battery,
- voltage regulator (DC/DC converter that adjusts the voltage to the receiver),
- charge controller (protects the battery from overcharging or discharging).

The battery stores energy and ensure its steady supply at night and in low sunlight. Typically used are: nickel - cadmium (NiCd), nickel - metal hydride (NiMH), lithium - ion, leaden and capacitors. Example autonomous photovoltaic system which supply DC device is shown in Fig. 1. By replacing inverter in the Fig. 1 by voltage regulator, AC power system is received (Fig. 2) [10,13].

Hybrid systems (Fig. 3) are a combination of panel or photovoltaic module and auxiliary generators, which of the most important are [10]:

- diesel generators,
- gas turbines,
- thermodynamic transformers with external combustion,
- fuel cells,
- thermoelectric generators,
- solar thermal generators,
- wind turbines,
- micro turbines.

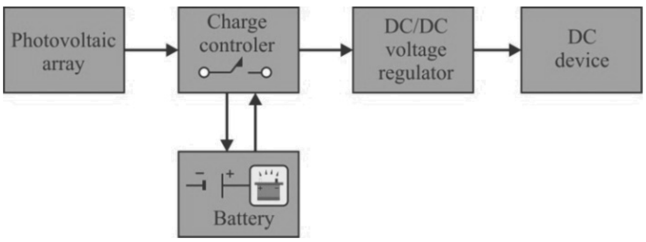

Fig. 1. Diagram of an autonomous photovoltaic system which supply DC devices [10]

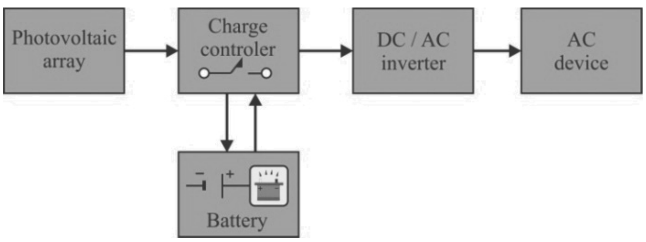

Fig. 2. Diagram of an autonomous photovoltaic system which supply AC devices [10]

Systems connected to the energy grid (Fig. 4) can return the generated energy to the grid, which means that batteries are not required. Such systems may have the form of a solar power station with a large number of photovoltaic panels which donate energy to the grid. They can also supply the buildings where the energy from the local energy grid is collected only when the demand exceeds the energy production of solar cells. System performance depends on the intensity of solar radiation incident on the solar panels [5,12].

The aim of this work is to determinate basic parameters for components of photovoltaic system - traffic light pedestrian crossing supplied by crystalline silicon solar cells.

Demonstrative photovoltaic system - traffic light pedestrian crossing consists of the following elements (Fig. 5):

- PV module,
- step-down converter,
- battery pack,
- a-stable generator,
- cover of traffic lights.

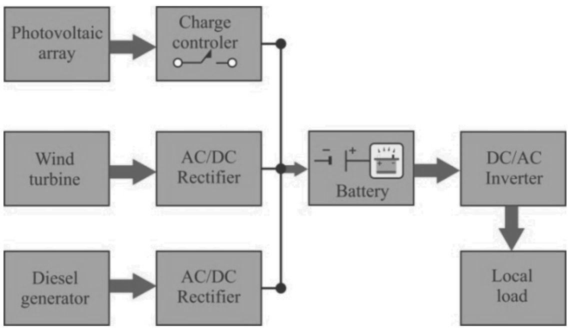

Fig. 3. Diagram of a hybrid photovoltaic system [10]

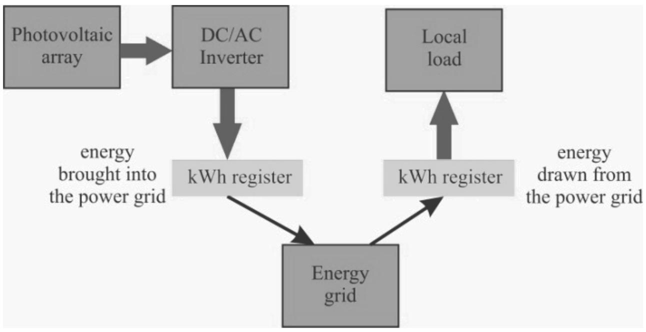

Fig. 4. Diagram of a photovoltaic system directly connected to the energy grid [10]

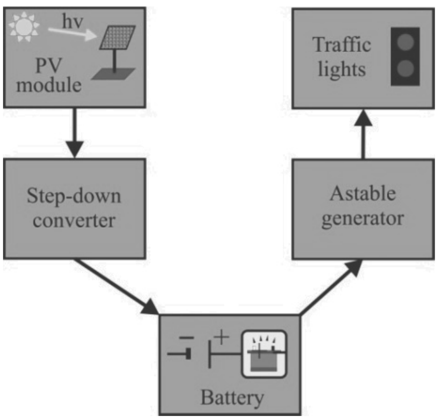

Fig. 5. Schematic diagram of the traffic lights powered by solar energy

Simplified Electrical diagram of traffic light powered by photovoltaic module is shown in Fig. 6. The photovoltaic system uses two basic systems:

- step-down converter,
- a-stable generator,

between which are rechargeable battery pack.

In order to convert solar energy into electricity, photovoltaic module is composed of 31 solar cells connected in series. Photovoltaic module load four NiMH batteries with a voltage of 1.2 V each. Batteries store electrical energy and ensure its steady supply during the night, when the generator consumes only with batteries. In order to adjust the voltage of the photovoltaic module to the battery voltage converter is applied which simultaneously protects the batteries from overcharging and prevents the system from a variable input voltage. Pulse converter MC34063 together with the elements making up the step - down converter, lower the voltage and serves a function of charge controller and DC-DC regulator converter in a standalone system. Charging NiMH batteries begins when SW1 is closed. Four batteries connected in series supply the astable generator, which was used to imitate traffic light pedestrian crossing - changing the colour lighting of red and green LEDs. For the construction of the astable generator (multivibrator) timer 555 was used. Astable generator is powered when the switch SW2 is closed. The system allows to charge the battery without turn on the astable generator. It also allows to simultaneous charge the battery and the astable generator.

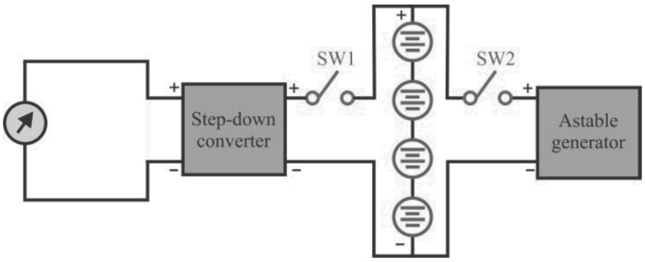

Fig. 6. Simplified electrical diagram of the photovoltaic system

2. Selection of component for PV system

2.1. Selection of photovoltaic module

In order to determine the basic electrical properties of monocrystalline silicon photovoltaic cells (Solartec Company in the Czech Republic) their current - voltage characteristics were measured. Measurements were made for 36 photovoltaic cells with dimensions 29.4 mm x 12.3 mm. In order to obtain the photovoltaic module with a value of voltage as much as possible, from the 36 solar cells, 31 were selected with the highest short-circuit current (Fig. 7) because solar cell with the smallest current determines the current flow through the PV module in series connection [14,15].

In Fig. 8 the determined current - voltage characteristics of the photovoltaic module is shown. Solar module at maximum power point generates a voltage 12.93 V and a current equal 84 mA [14].

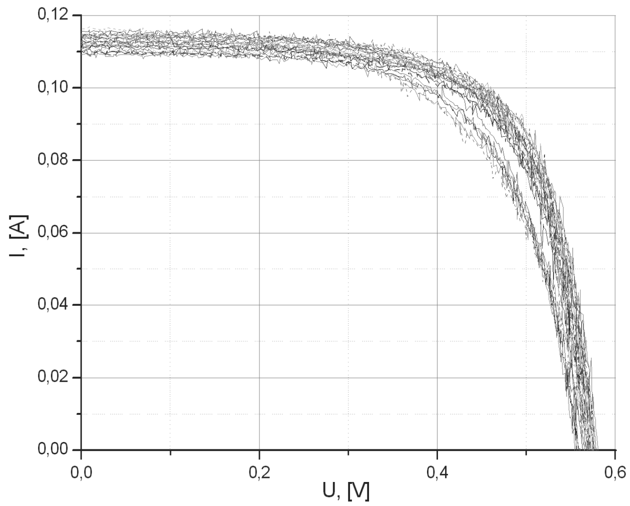

Fig. 7. Current-voltage characteristics of chosen solar cells

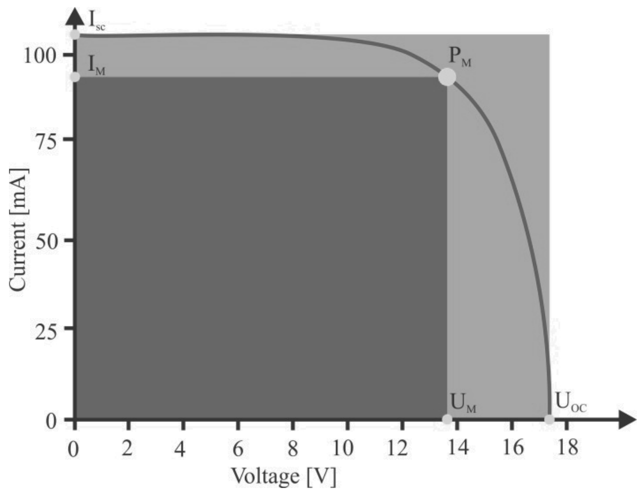

Fig. 8. The determinate current - voltage characteristics of the PV module [14,15]

2.2. Selection of step-down converter

The switching inverter in conjunction with external components specified in the technical documentation [16] was designed to be incorporated in step-down, step-up and voltage-inverting. In order to adjust the voltage of the photovoltaic module (17,56V) the battery voltage (6V) step-down converter was used with external component which are: resistors, capacitors and inductor. To step-down converter was also added a Zener diode and two Schottky diodes that ensure proper operation of traffic lights powered by electricity from solar cells.

In order to keep the voltage constant at the specified changes of load and input voltage Zener diode was used with a value of 13 V. The Zener diode is the simplest available tool for voltage stabilization and to prevent malfunctions and early damage to the device. Schottky diodes, despite changing for the worse the overall efficiency of the system, is necessary due to the unstable lighting conditions. Schottky diodes protects the battery against discharging during cloudy weather.

Step-down converter is powered by a photovoltaic module with open-circuit voltage 17.6 V. The maximum power voltage of the solar module is approximately 12.93 V. The system loads the four AA NiMH batteries. The output voltage was set to 6 V minus 0.3 V voltage drop at Schottky output diode.

The output voltage is dependent on the values of the two resistors R1 and R2 (Fig. 9). The value calculated by the formula:

$$U_{out} = 1{,}25 \cdot (1 + \frac{R_2}{R_1}) \tag{1}$$

where:
R_1 - resistance of the resistor *R1*,
R_2 - resistance of the resistor *R2*,
U_{out} - output voltage.

According to formula (1) values of R_1 and R_2 were fitted: R_1=1.2 kΩ and R_2=4.7 kΩ for U=6 V.

Using the data in Table 1, showing the basic properties of the inverter MC34063 and formulas from technical documentation [16] the basic components of the system that reduces the voltage were calculated. Electrical diagram of step-down converter is shown in Fig. 9.

Table 1.
Specifications of pulse converter MC34063 [16]

Parameter	Value
U_{out}	6.15V
I_{out}	500mA
f_{min}	50kHz
$U_{in(min)}$	12.42V
$U_{ripple(p-p)}$	0.03V
U_{sat}, U_F	0.8V

2.3. Selection of components for astable generator

Timer 555 was used as a astable generator, that means the system generates in the output OUT (3) rectangular pulses. The system of timer NE555 consists of the four basic functional blocks (Fig. 10) [17,18]:

- comparator K1
- comparator K2
- flip-flop P,
- discharge transistor T1.

Timer 555 meets the conditions of astable generator operation when three external components are used (Fig. 11):

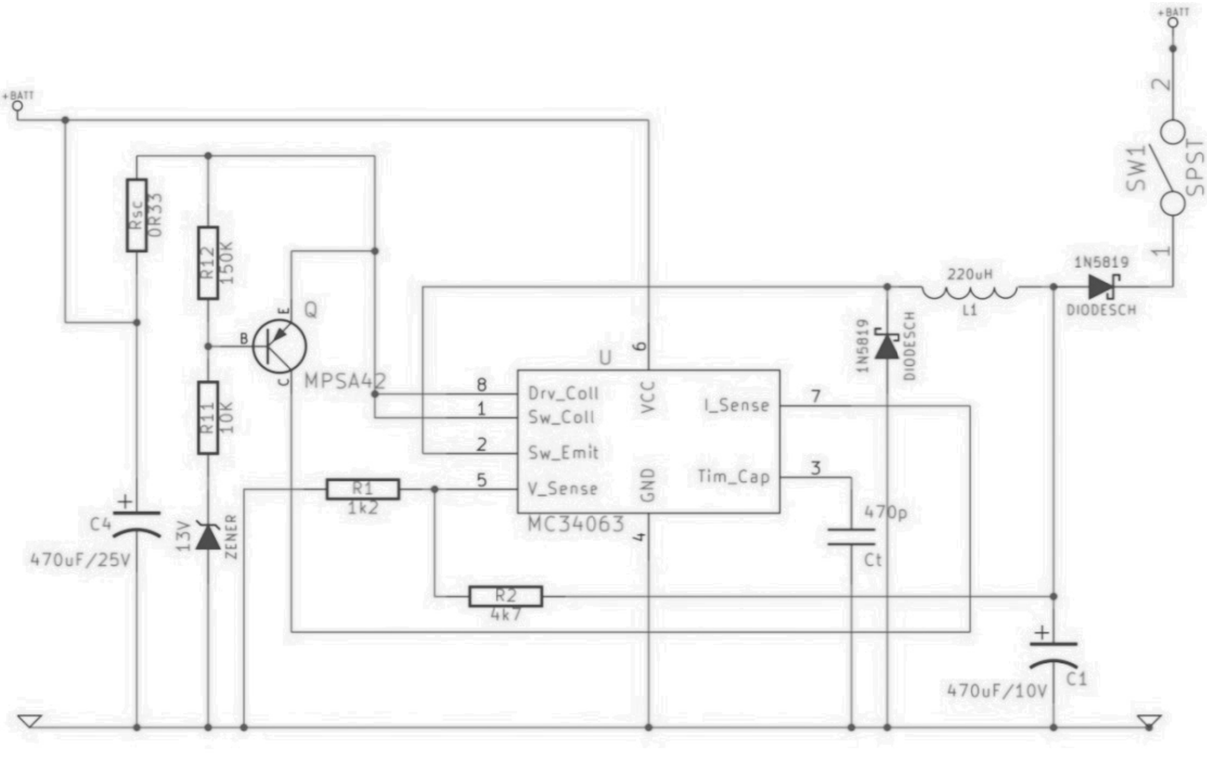

Fig. 9. Electrial diagram of step-down converter

- two resistors (Ra and Rb),
- capacitor (C2).

Electrical diagram of the astable generator, which enables alternating illumination of LED in traffic lights, is shown in Fig. 11. System is powered by 4 AA NiMH batteries connected in series which provide input voltage equal to 4.8 V. Inputs trigger THRESHOLD (THR, 6) and the TRIGGER (TR, 2) are joined together and through the electrolytic capacitor C2 connected to ground. Capacitor C3 is connected to the input CONTROL (CV 5) and acts as a filter. Up to this point the capacitor C2 is discharged, and the voltage at the input TRIGGER is equal zero. Operation of the astable generator starts at the moment of turn of the power. After starting the flip-flop P is switched on and the output OUT (OUT, 3) is set to a high state of tension. Capacitor C2 is charged through the resistors Ra and Rb and trigger turn off after reaching 2/3 voltage. The output is set to low voltage level and the capacitor discharges through the resistor Ra. After the time specified by the capacitance of the capacitor C2 and the resistance of the resistor Ra capacitor voltage drops to one third supply voltage, flip-flop switches on and the whole cycle starts again. System generates a rectangular pulse until the power goes off.

In order to alternate the colour of LED illumination, one part (the red one) is included between the output OUT (3) and the positive end of power, while the second part (the green ones) between the output OUT and ground system . The red diodes are lighted when in the output OUT is low voltage level, whereas the green diodes when in the output OUT is high voltage level. Diodes are connected in parallel, and for each of them is matched the corresponding resistor with resistance set according to the formula:

$$R = \frac{U_{power} - U_{diode}}{I_{diode}} \qquad (2)$$

where:
U_{power} - supply voltage,
U_{diode} - diode voltage,
I_{diode} - diode current.

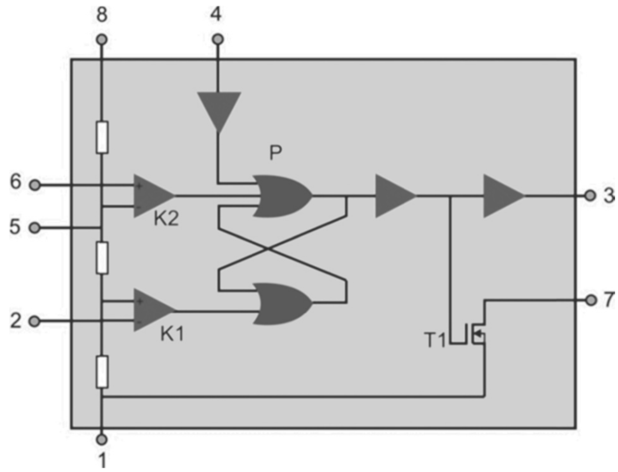

Fig. 10. Simplified inner diagram of the NE555 timer where: 1 - ground, 2 - trigger, 3 - out, 4 - reset, 5 - control, 6 - threshold, 7 - discharge, 8 – V_{cc} [17]

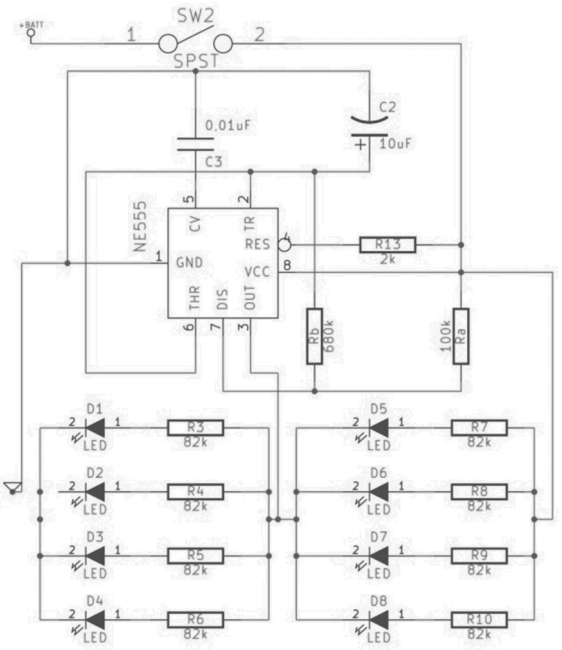

Fig. 11. Electrical diagram of astable generator

Determined by the formula (2) the value of the electrical resistance of resistors R3-R10 is equal to 90 Ω. Given the fact that the resistors are manufactured in accordance with internationally standard rating series, moreover resistance deviation may be ± 10% from the calculated value, resistor with resistance value the nearest 90 Ω, which is 82 Ω, was selected. Electrical diagram of astable generator is shown in Fig. 11.

Operating voltage waveform of astable system for given values of Ra=100 kΩ, Rb=680 kΩ, C2=10 uF is shown in Fig. 12. The first generated pulse is longer than the next, which is due to the fact that the power capacitor C2 is fully discharged, and the first battery is charged from 0 to 2/3 of the power supply. Subsequent cycles of charging and discharging take place in a range from 1/3 to 2/3 of the supply voltage.

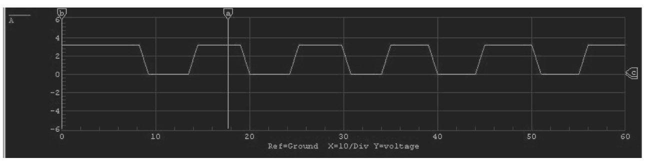

Fig. 12. The output signal of multivibrator

3. Conclusions

Based on the measured current - voltage characteristics of the 36 photovoltaic cells were selected 31 with the largest short-circuit current. Subsequently the solar cells were connected in series and used for the construction of the photovoltaic module with open circuit voltage of 17.58 V and short circuit current of 101 mA.

Solar module was used to build a demonstration photovoltaic system - traffic light pedestrian crossing, which shows the practical use of widely available, renewable energy source which is the Sun.

The applied step-down converter adjust the voltage of photovoltaic module to the voltage of battery protecting them from overcharging, and in the case of unstable light conditions from discharging. Therefore step-down converter protects photovoltaic system against variable input voltage.

Astable generator allows to change the colour of light in every 5 seconds thus imitating the operation of traffic light - pedestrian crossing.

During operation of the photovoltaic system astable generator is powered by NiMH batteries, which can be charged at the same time by using the photovoltaic module. The battery stores energy and ensure its steady supply at night and in low sunlight. It also provides continuous charging of NiMH batteries without turning on the astable generator.

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