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## SCADA SYSTEM SIMULATION FOR A PHOTOVOLTAIC ROOFTOP SYSTEM

SARA ANEVA, MARIJA STERJOVA AND SASO GELEV

**Abstract.** The main goal of this research work is to design and develop an application program for monitoring photovoltaic (PV) systems in real time. In this research, a SCADA (Supervisory Control and Data Acquisition) system in LabVIEW (Laboratory Virtual Instrument Engineering Workbench) was simulated for a solar rooftop system of a household with a total installed power of 3.92 kW. The theoretical foundations for SCADA system and PLC (Programmable Logic Controller) have been laid. The implemented LabVIEW program is an automated computer program that enters temperature, voltage, number of solar panels and radiation and gives performance parameters, power parameters, cost of the PV system, annual energy value, daily energy, generated solar energy, and curves for annual and daily energy generation. The system designed in this way enables control of the solar system and overview of the production from the system. Furthermore, this system can be connected to a microcontroller, Arduino, or PLC, which will collect data from sensors and transmit it to the system. Finally, a conceptual solution is proposed for the introduction of a battery system on the already proposed PV system and the introduction of a PLC to control the charging and discharging of the battery, as well as the transmission of electricity from and to the grid.

### 1. Introduction

Currently, the cheapest and simplest technology for generating electricity from renewable energy sources is photovoltaic technology. This technology involves the production of electricity from solar energy. Combinations of solar panels, inverters, controllers, and batteries are used to install a system of this type that ensure the efficiency of the system. These systems can be stand-alone systems, grid-connected systems, and hybrid systems - systems with multiple energy sources. [10]

Solar energy is converted into DC (Direct Current) mechanical energy in solar cells which is then converted into AC (Alternating Current) electricity that can be used through an inverter. At present, the cost of a solar battery is still expensive. The working methods of the controller evince a great inclination towards the conversion rate of solar energy. Several problems prevail in the solar power system, such as low conversion efficiency, lack of reasonable protection and management of charging and discharging the batteries, short battery life, unstable system operation and so on. [10] Therefore, a new automatic monitoring and control system should be designed for the grid-connected PV systems, that is, a SCADA system through which the operation of the system will be controlled and an insight into the electricity production from the system will be available at any time.

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*Date:* September, 2022.

**Keywords.** SCADA system, LabVIEW, Photovoltaic (PV) system, PLC, battery system

## 2. SCADA and a solar PV real-time monitoring system

In power generation systems, SCADA systems serve as a fundamental means of centralized system process planning, process equipment, and instrumentation. They remain a key goal of automation and data recording when it comes to their utilization for large and small photovoltaic systems. This approach to SCADA systems will ensure operational stability, reliability, efficiency improvement and the overall life cycle of the solar PV system, respectively problem solving and maintaining system accuracy. The implementation of the entire system includes the installation of the equipment (hardware and software) and the operation of the system, as well as testing and maintenance of the system. The main operating functions of SCADA systems include [1]:

1. Data acquisition
2. Network communication with data
3. Data presentation
4. Control

Figure 1 shows several subsystems that enable these functions:

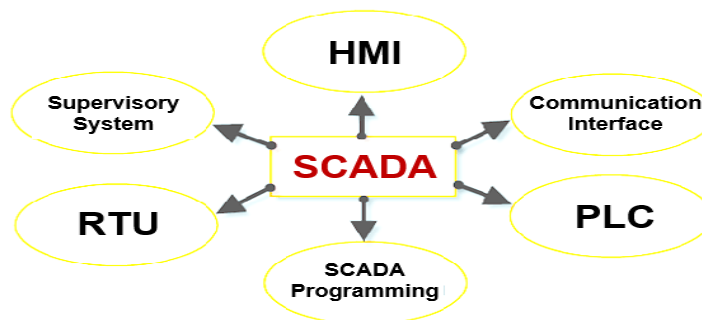


Figure 1. Basics of SCADA

Broadly SCADA consists of the following components described below [1,2] and shown in Figure 1:

- **Human / Machine Interface (HMI)** - It is a device which presents processed data to the human operator. This data assists him in monitoring and controlling the system.
- **Supervisory System** - It is a supervisory computer system which properly coordinates the various processes occurring in the entire system.
- **Remote Terminal Units (RTU)** - These are devices which collect data from various sensors employed in different fields, convert it to digital form and then send it to the supervising system i.e., the master. It is a microprocessor based electronic device.
- **Programmable logic controllers (PLC)** - They are used as field devices in SCADA because of the trademarks they possess. It is a digital computer which is used for automation of electromechanical processes. They are more versatile, economic, flexible and configurable than RTUs.
- **Communications Interface** - This interface is composed of communication protocols that define how data are transmitted along the communication link. The data in SCADA Networks are represented by addressing. The addressing is related to the database of the master station.
- **SCADA Programming** - Used to create maps and diagrams that provide current information in the case of "challenging events" during a process [3].



### 2.1 The architecture and basic sequence of actions of the solar PV monitoring system

A photovoltaic (PV) monitoring system's architecture and functions are critical for its successful and reliable operation. The architecture of a complete real-time monitoring system can be identified in Figure 2. We will begin by presenting and briefly explaining the system, and then focus on the part that is of particular significance to the project.

Figure 2 shows the connection between the field equipment (sensors, switches, etc.) and the PLC (or RTU) over a local network, where the input data are collected and processed. In response to the control logic applied by the PLC (or RTU), the following actions are initiated. The remote monitoring unit receives the information through communication protocols. By the main control unit, data are pre-processed and prepared for human-process interface (HPI) visualization. If necessary, the operator can initiate remote actions on the terminal units based on the data analyzed.

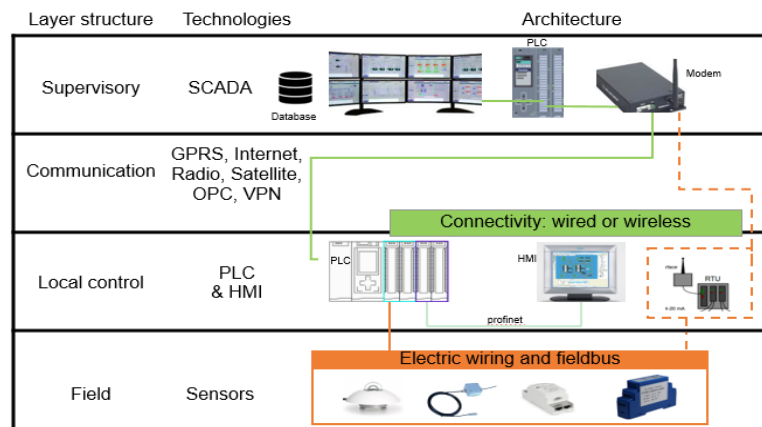


Figure 2. Block diagram of a Solar PV real time monitoring system

## 3. Methodology and model development

Our research was conducted using PV\*SOL premium and LabVIEW software. PV\*SOL premium is a design and simulation software for photovoltaic systems. The program comes with 3D visualization and is intended for detailed analysis of PV systems including their devices [4], while LabVIEW software is a virtual laboratory platform for system design and development environment for the visual programming language [5]. Using these concepts, a real-time monitoring solution for solar PV systems can be provided.

### 3.1 Design of a 3.92 kW rooftop system in PV\*SOL premium working environment

A solar PV system's design starts with selecting a location and identifying an appropriate area, since location information helps to improve performance and efficiency. The proposed place is the roof area of a household in Shtip, with a prefabricated area and the installation of a solar PV system directly connected to the electricity grid. Some of the characteristic parameters appropriate for the selected location are shown in Table 1.

Table 1. Data and parameters for the solar PV system

Data and parameters	
Coordinates	41° 44' 15.01" N, 22° 11' 36.81" E
Altitude [m]	300
Electrical Network	230 V, 3ph, $\cos \phi = 1$
Module Area	22.7
Global Horizontal Irradiance (GHI) [kWh/m <sup>2</sup> ]	1,554.1
GHI for Optimal Angle ( $\angle 34^\circ$ ) [kWh/m <sup>2</sup> ]	1,804.3
Daily GHI for Optimal Angle [kWh/m <sup>2</sup> ]	4.943

The selected PV system design module includes the features shown in Table 2. Electrical parameters are given under standard test conditions (STC) AM 1.5,  $G = 1000\text{W/m}^2$ ,  $T = 25^\circ\text{C}$ .

Table 2. Characteristics and electrical parameters of the module

Electrical Characteristics	
STC (radiation: $G = 1000\text{W/m}^2$ , module temperature: $T = 25^\circ\text{C}$ , air mass: AM 1.5)	
Manufacturer	BISOL BMU-280 PREMIUM
Solar Cells	60 multi-crystal silicon in series
Cost per Module	195 €
Rated Power ( $P_{rated}$ )	280 W
Short Circuit Current ( $I_{sc}$ )	9.30 A
Open Circuit Voltage ( $V_{oc}$ )	40.0 V
Current at Maximum Power Point ( $I_{mpp}$ )	8.60 A
Voltage at Maximum Power Point ( $V_{mpp}$ )	32.6 V

Using these modules with 0.28 kW of power per panel, an installed power of 3.92 kW requires 14 modules. There will be two arrays of seven panels each. The installed area is  $22.9\text{ m}^2$ . The terrain and object views of the PV system on the roof surface are shown in Figure 3.

For the total installed power of 3.92 kW, 14 solar panels are needed, each of 280 W, placed on an area of  $22,7\text{ m}^2$ . The household is oriented to the southwest, and the solar system is placed on the southern side of the roof. The total average annual production of electricity from this system can be calculated as follows:

$$\begin{aligned}
 E_{total} &= I_{daily,avg} \cdot P_{PV,total} \cdot 365 \quad [10] \\
 &= 3,6 \cdot 3.92 \cdot 365 = 5150,88\text{kWh/year}
 \end{aligned}
 \tag{3.1.1}$$

Where:

$I_{daily,avg}$  – is the average daily radiation in the city of Shtip

$P_{PV,total}$  – is the total installed power of the PV system

Figure 3 shows the terrain and object view of the PV system obtained from the visualization of the PV system in PV\*SOL premium. [4]

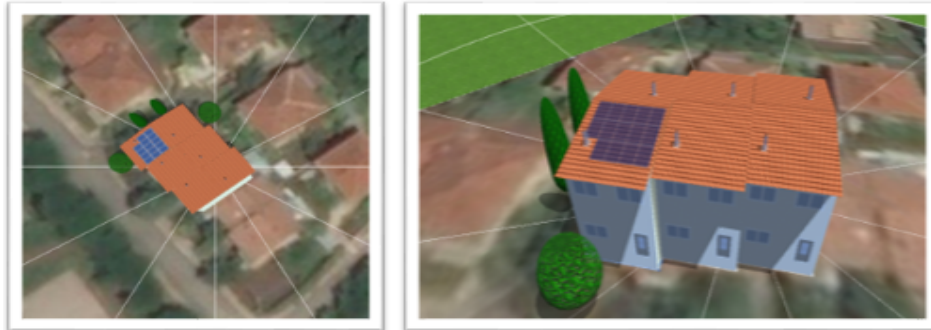


Figure 3. Terrain view and Object view of the solar PV system [4]

### 3.2 Design and implementation of a real-time monitoring of solar PV system in LabVIEW working environment

The PV system introduced and designed in the previous section is now implemented in the LabVIEW graphical programming interface. This system is developed for computer measurement and control of the process of energy production and other parameters. LabVIEW programs are called Virtual Instrument (VI). When creating a new VI project, two panels are used: the Front Panel and the Block Diagram. The front panel window functions as the Graphical User Interface (GUI) of VI and is the gateway for all VI user inputs and outputs, while the graphical source code of the program is contained in the block diagram. The concept of a block diagram is to separate the graphical source code from the user interface in a logical and convenient way. The front panel elements appear as terminals on the block diagram. The terminals of the block diagram reflect the changes made to their corresponding elements on the front panel and vice versa. The elements are essentially controls, indicators, and constants. A block diagram includes terminals, subroutines, functions, constants, structures, and wires that transmit data between other elements.

#### 3.2.1 Mathematics Analysis

To program a system in LABVIEW, it is necessary to make a mathematical analysis of the system, which will then be implemented as a program code in the software.

The maximum power point of the IV characteristics of the PV cell is shown in Figure 4. If  $I_m$  represents the current through the solar cell at maximum power and if  $V_m$  represents the voltage at the resulting maximum power point, then the maximum power of the solar cell can be:

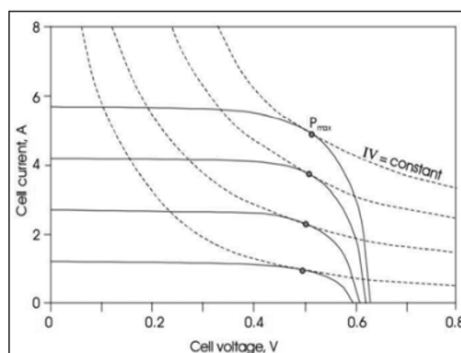


Figure 4. Maximum Power Point [11]

The integral of the energy generated by the solar cell can be called solar energy. Mathematically it can be written as: [11]

$$SolarEnergy = \int(SolarPower) dt \tag{3.2.1.1}$$

where the daily energy value is the average value of the energy used during a full day. [11]

$$DailyEnergy = AverageOf(EnergySignalArray) \tag{3.2.1.2}$$

When the daily energy is multiplied by 365, the annual energy value is obtained: [11]

$$AnnualValue = 365 \cdot (DailyEnergy) \tag{3.2.1.3}$$

The yield (production) to profit ratio can be written as the ratio of annual yield to annual cost. [11]

$$YieldTo Profit = (AnnualYield)/Cost \tag{3.2.1.4}$$

The ambient temperature can be linearly represented by the formula given below. [11]

$$T_c = T_A + [(NOCT - 20)/0.8] \cdot G \tag{3.2.1.5}$$

The fill factor (*FF*) is a unit of measurement with a value less than 1 related to the amount of maximum power generated. The duty factor can be defined as the ratio of the maximum power to the product of the open circuit voltage and the short circuit current. Mathematically, it can be defined as: [11]

$$FF = (J_{mp} \cdot V_{mp}) / (J_{sc} \cdot V_{oc}) \tag{3.2.1.6}$$

The equations (3.2.1.1) – (3.2.1.6) are used for the graphical programming of the PLC on which the system behavior is based. Figure 5 shows the front panel of the application. In this case it is for a solar PV system with installed power of 3,92 kW and values of parameters according to the selected module type and its configuration (from the section for PVSOL). Figure 6 shows part of the source code of the block diagram.

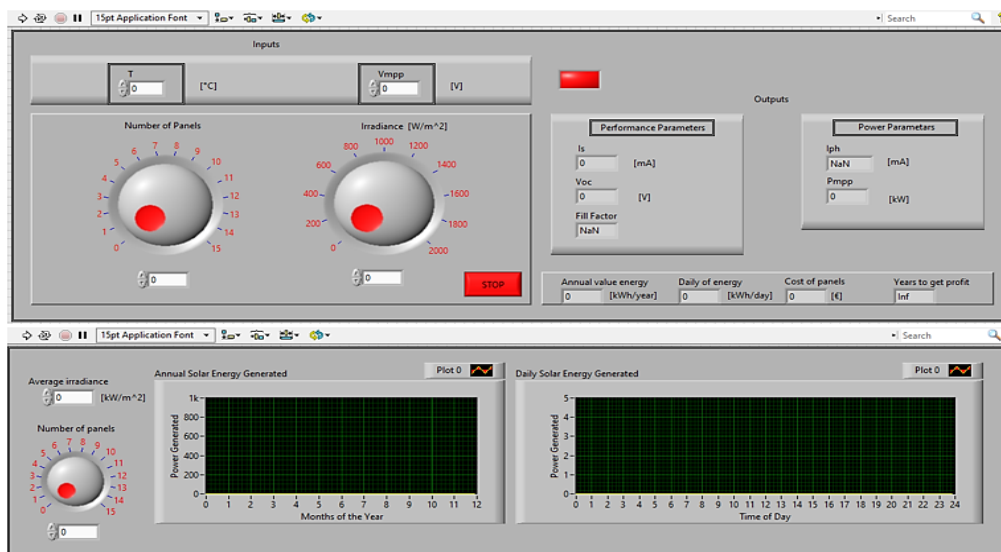


Figure 5. Front Panel solar PV system monitoring [5]

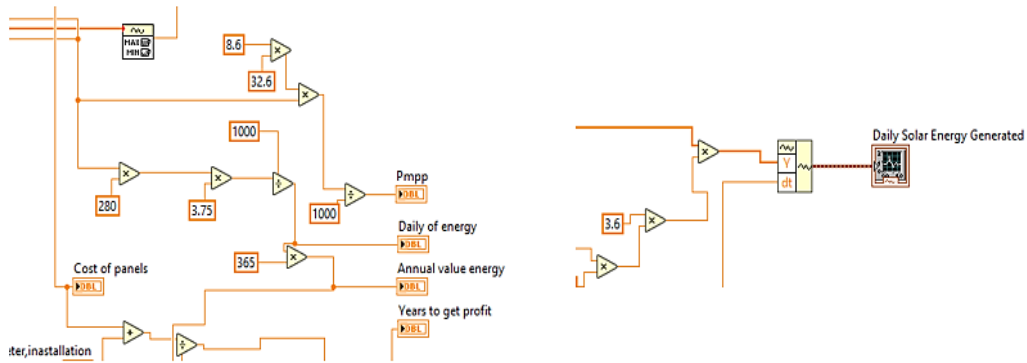


Figure 6. Part of the Block diagram of a solar PV monitoring system [5]

In Figure 5, on the front panel we notice that we have an LED button that is activated or turned on when it has a TRUE value, i.e., when there is no power generation.

This simulation requires input parameters, which must be entered manually to enable control, data processing and to obtain the output results. As input parameters we note that these are: **weather parameters** - temperature  $T$  ( $^{\circ}C$ ) and solar irradiance ( $kW/m^2$ ); **voltage** -  $V_{mpp}$  (V) and Number of solar panels. For this project, as we have already mentioned, the technology of solar radiation and temperature sensors can be used as a conceptual solution:

- **pyranometer** (gives the change of radiation at a given moment) and
- **temperature sensor** (gives the change of temperature).

Also,

- a **current sensor** that is connected between the solar panel and the load - which also gives a signal in case of overvoltage or under voltage for the supply voltage of the modules.

To obtain output results, there must be values of input parameters to process the program and obtain the necessary data. The first part of the front panel as we see from Figure 5 shows the output values on the right, while the values as we can see - annual solar PV power generation and daily solar PV power generation are displayed in the front panel with graphic views. These results are based on the average solar radiation for the selected location, which can be found in [9].

#### 4. Results and discussion

The model that was set up in the LabVIEW working environment in the previous section is tested and analyzed in this section. In our case, the analysis was performed under STC.

For program startup and data visualization, we have the following values: input, power, and energy parameters, listed in Table 3.

Table 3. Input, performance, and power parameters for application

Input Parameters	
Ambient Temperature	25°C
Voltage at Maximum Power Point	32.6 V
Solar Irradiation	1000 W/m <sup>2</sup>
Number of Modules	14
Performance Parameters	
Short Circuit Current	$I_s = 9.30 \text{ A}$
Open Circuit Voltage	$V_{oc} = 40.0 \text{ V}$
Fill Factor	$FF = 0.7388$
Power Parameters	
Photogenerated Current	$I_{ph} = -9.3 \text{ [A]A}$
Maximum Power	3.92 kW

When the Run button is pressed, that generates the results presented in Figure 7 on the front panel.

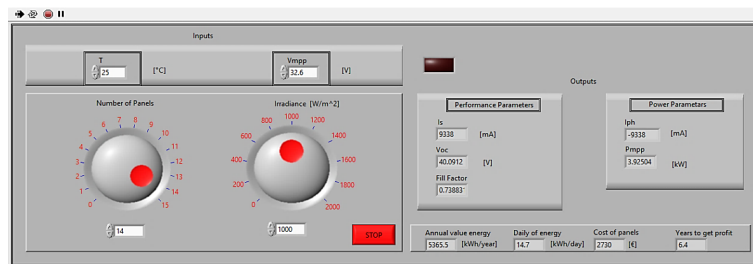


Figure 7. Simulation results on the Front Panel of Solar PV real-time monitoring system [5]

From Figure 7, we can notice that we have simulated parameters. The obtained results refer to the annual value of the produced energy as well as the daily energy production with values of: 5,365.5 [kWh/year] and 14.7 [kWh/day], respectively. The cost price of the modules, in relation to the installed power and type, is: 2,730 € (195 € per module), while the years of return on investment are 6.4 years. This value includes the full cost of installing the system to the grid (5,430 €) in relation to the annual energy production (5365.5 [kWh/year]) at the feed-in tariff (in this case it is 0.16 €).

The program also simulates graph charts for generated energy on an annual and daily basis. These results are obtained using the average radiation value of 3,6 [kW/m<sup>2</sup>] for both graph charts (Figure 8), versus the number of modules.

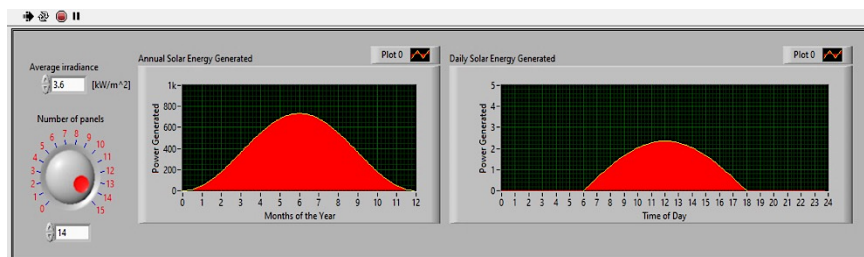


Figure 8. Simulation results on the Front Panel for generated annual production and daily electricity production [5]

From the first chart in Figure 8, we can see that for the month of July the generated electricity is the highest and is around 773,326 kWh/month, while it is the lowest for the months of December and January with a value of about 169.65 kWh/month. In the second chart we can see that the average electricity generation from solar energy starts at 6:00 a.m. and lasts until 6:00 p.m. The maximum production is somewhere in the period from 11:00 a.m. to 2:00 p.m. with maximum generated energy with a value of about 2 kW at 12:00 p.m.

This system can be further adapted to similar PV systems with different installed power by changing the inputs.

According to the theoretical foundations and simulations proposed in this project, we can conclude that the SCADA systems applied to the PV systems provide an overview of the system production, control, and manipulation of system components. Implementing systems such as the SCADA system proposed in this project can significantly improve the efficiency of PV systems, features, and electricity generation.

A photovoltaic system configured in this way can be upgraded by adding a battery system. The authors' next research would be to upgrade the already proposed PV system for monitoring and control, by adding a battery whose charge and discharge will be regulated by a PLC.

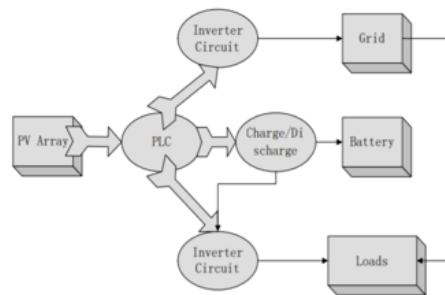


Figure 9. Structure chart of PV grid-connected system with battery regulation

A grid-connected PV system, which is shown in Figure 9, consists of solar panels, batteries, a PLC controller, an inverter, and a load. Photovoltaic arrays through maximum power point tracking (MPPT) intelligently charge the battery, so that the battery, as a stand-alone power source, offers AC power to the loads through an independent inverter. If the storage battery is full, the remaining solar energy produced is fed into the grid via an inverter. If the energy loads need more than the amount of electricity produced by the system and the battery, the power grid will automatically supply the loads with electricity. This solution includes regulation of charging and discharging of the battery and regulation of energy movement from and to the grid.

## 5. Conclusion

The aim of this paper was to realize automation of a solar PV system for conversion of solar energy into electricity. The model developed in the software programs PVSOL and LabVIEW and the concept as a conceptual solution can be used to design a real system. Real-time system monitoring ensures maximum use of energy sources by controlling the production and energy consumption of a typical household.

With the help of this application the user gets access to the data on the current state of the behavior of the system, equipment, and archived data in the form of graph charts that present the generated electricity in relation to time. Depending on the needs, there is always the possibility for future

development and modification of the system. Additionally, obtaining the data will enable performance and cost optimization for these types of systems.

The sophistication of the SCADA system is vital to achieving proper, reliable, and safe operation of the solar PV system and reducing energy losses. The model implemented in this research work can be used for further analysis, data acquisition and development of more complex systems as it is shown in Figure 9.

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