

**Marija Čuljak**

University of Zagreb  
Faculty of Electrical Engineering and Computing  
Unska 3, 10 000 Zagreb, Croatia  
[Marija.culjak@fer.hr](mailto:Marija.culjak@fer.hr)

**Mateo Beus**

University of Zagreb  
Faculty of Electrical Engineering and Computing  
Unska 3, 10 000 Zagreb, Croatia

**Hrvoje Pandzic**

University of Zagreb  
Faculty of Electrical Engineering and Computing  
Unska 3, 10 000 Zagreb, Croatia  
[hrvoje.pandzic@fer.hr](mailto:hrvoje.pandzic@fer.hr)

# Development of a LabVIEW - Based Data Logging and Monitoring Application for a Photovoltaic Power Plant at FER

## SUMMARY

The purpose of this paper is to implement an application in LabVIEW programming language which logs the measurements from photovoltaic (PV) inverters. The application's communication module is connected to the inverters of the PVs via the Modbus TCP/IP protocol and collects the measurements of appropriate process quantities, such as the active power, the total electricity produced, the panel temperature, the insolation, the air temperature, etc. Furthermore, all the collected measurements are saved on a 15-minute basis in separate csv files for each day. Additionally, a graphical user interface (GUI) is developed, where the collected measurements from the PV are displayed. The PV for which the application is developed is located on the roof of the building B of the University of Zagreb Faculty of Electrical Engineering and Computing (FER).

## KEY WORDS

photovoltaic inverter, SCADA systems, Modbus TCP/IP protocol, LabVIEW, measurements logging, user interface

## 1. INTRODUCTION

Technical and scientific challenges of the twenty-first century lay in providing energy to humanity in a safe, sustainable, and clean way [1]. According to this goal, photovoltaic (PV) sources are currently one of the most relevant renewable energy resources (RES), e.g. [2]. PV systems are attractive for electricity generation due to no carbon emissions during operation and easy maintenance, as compared to the other RES. The available solar radiation needed to meet the world's energy requirements is more than sufficient. For these reasons, in the last decade, the PV systems market has experienced a remarkable growth, primarily due to reduced production costs and increased electricity prices [1]. As compared to the above-mentioned benefits, PV also have some limitations, such as dependencies of geographical longitude and latitude, weather forecasting, and limitations in production energy only during the sunny days [3]. Consequently, the supervisory control and monitoring of these systems is especially significant for the optimization of their effectiveness.

This paper presents a detail characterization of performance and dyna-

mic behavior of a PV system using a real-time application developed in LabVIEW. LabVIEW is a graphic programming language that has found its application in many scientific fields and technical engineering. In this paper, the development of an application for collecting, processing, and monitoring the measurements from a PV system is described. The proposed method is a cheaper solution than many commercial SCADA (Supervisory Control and Data Acquisition) systems, which provides reliability and safety by creating a database used for a detailed analysis of the PV system. The developed application and collected measurements are according to the implemented advanced measurement system proposed in [4]. Many applications developed in the LabVIEW for tracking PV systems are shown in the following literature [1], [3], [5], [6], [7].

The remainder of the paper is structured as follows. The second section describes technical characteristics of PV located at the University of Zagreb Faculty of Electrical Engineering and Computing (UNIZG-FER), where the measurements are acquired. In the third section, the Modbus TCP/IP protocol is presented, which is used for the establishing a communication between the PV inverters and the server. A detailed description of the

functionality of the developed application is provided in the fourth chapter, along with a graphical representation of the collected measurements.

## 2. PV SYSTEM

The intensity of solar radiation in Croatia is among the highest in Europe. For example, the annual sum of global radiation is 1300 kWh/m<sup>2</sup> in the northern parts of Croatia and increases up to 1850 kWh/m<sup>2</sup> in the southern parts of Croatia [8]. Possible annual electricity production in 1 kWp (PV system capacity; the maximum electrical capacity that a PV cell can give in ideal circumstances: a solar collector facing the sun in a cloudless sky) system ranges from 975 kWh/kW in the northern Croatia up to 1375 kWh/kW in the southern Croatia [8]. The reference electric power that a PV panel produces is defined for an average cell temperature of 25 °C and solar radiation intensity of 1000 W/m<sup>2</sup>. Under these conditions, the PV cell generates maximum power. This value is relevant for producers, but in operating conditions terms, the power of a PV cell depends on the temperature changes and the level of solar irradiation [9].

PV inverter is the main element of any PV system, as it converts direct current of PV modules into alternative current compatible with the network. It simultaneously controls and monitors the entire power plant. The inverter measures voltage, current, frequency and impedance of the network, and is switched off if any of these values deviates from its default value range. This ensures, on the one hand, that the PV modules always operate at maximum power, depending on the irradiation and the temperature. On the other hand, it continuously monitors the electrical network, and is responsible for compliance to various security criteria. In the PV plant at UNIZG-FER, two types of PV inverters are used: Sunny Tripower 10000TL-20, manufactured by SMA [10], and Fronius Symo 12.5-3-M manufactured by Schrack industry [11].

### 2.1 Sunny Tripower 10000TL-20

Sunny Tripower 10000TL-20 is a three-phase inverter without a transformer, nominal power of 10 kW and maximum efficiency of 97,6 %. At its input A, there is a Maximum Power Point (MPP) tracker related to the west orientation and has twenty-one modules, while at the input B there is an MPP tracker related to the east orientation and also has twenty-one modules, as shown in Figure 1. In addition to the above, the inverter is equipped with an overcurrent protection of strings, a monitoring system for the network operation, a device for automatic synchronization to the network voltage, a monitoring system for the waveform of the network voltage and protective devices. The expected annual yields obtained by the simulation for the Sunny Tripower 10000TL-20 inverter are around 1065 kWh per installed kilowatt of PV field power [12].

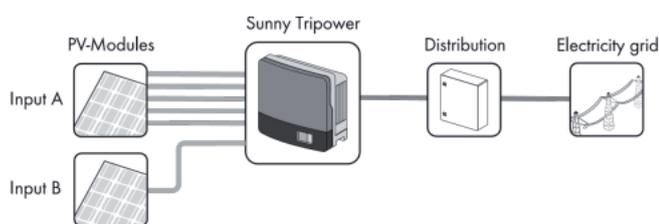


Figure 1. Connecting Sunny Tripower inverter with a PV system [12]

The technical parameters and specification of Sunny Tripower 10000TL-20 are shown in Table 1.

Table 1 Technical parameters of Sunny Tripower 10000TL-20 inverter [12]

Parameter	Value
Max. input (DC) power	13.500 Wp
Max. input (DC) power	1000 V
Input voltage operating range	320 – 800 V
Max. output (AC) power	10000 W
Num. of MPPT units	2
Nominal output voltage (AC)	230 V/400 V
Max. output current	14,5 A
Network frequency	50 Hz
Dimension (W/H/L)	470 mm/730 mm/240 mm
Weight	kg

### 2.2 Fronius Symo 12.5-3-M

Fronius Symo is a three-phase inverter without a transformer, with a nominal power of 12.5 kW and a maximum efficiency of 97,6 %, adapted to any system size.

Thanks to the possibilities provided by SuperFlex Design, Fronius Symo is optimal for curved roofs or roofs that are differently oriented. Standard internet connection via WLAN or Ethernet, as well as easy integration of the components from other manufacturers, make Fronius Symo one of the most adaptable inverters on the market in terms of communications. The module interface, moreover, allows a dynamic power management and a clear view of the local consumption. Furthermore, the inverter is equipped with protective devices that include DC insulation, DC disconnecter, over-load protection by shifting operating point or power limitation, and pole reversal protection [11].

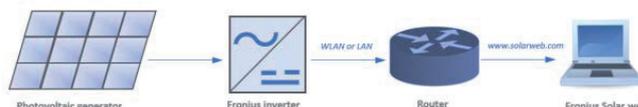


Figure 2. Connection of Fronius Symo inverter with PV and communication system [11]

The technical parameters and specification of Fronius Symo 12.5-3-M are shown in Table 2.

Table 2 Technical parameters of Fronius Symo 12.5-3-M inverter [11]

Parameter	Value
Max. input (DC) power	18.800 Wp
Max. input (DC) power	1.000 V
Input voltage operating range	370 – 800 V
Max. output (AC) power	12.500 W
Num. of MPPT units	2
Nominal output voltage (AC)	230 V/400 V
Max. output current	18 A
Network frequency	50 Hz
Dimension (W/H/L)	510 mm/725 mm/225 mm
Weight	34,8 kg

## 3. MODBUS TCP/IP

Modbus is an application layer messaging protocol, positioned at the seventh level of the Open Systems Interconnection (OSI) model, which enables Client/Server communication between devices connected to different buses or networks. Modbus is standard, open-source and the most commonly used network protocol in an industrial production environment [13]. It is a request and response protocol, implemented by Master/Slave or Client/Server relationship. In a Master/Slave relationship, the communication happens in the pair – one device must initiate the request and then wait for the response. The master is responsible for initiating each interaction. The Human Machine Interface (HMI) or SCADA system is commonly master, while the slave is commonly Programmable Logic Controller (PLC) or sensor. The contents of these requests and responses, and the network layers through which they are sent, are defined by different protocol layers. The Modbus message consists of a protocol data unit (PDU) which is independent of communication layers [34]. Modbus PDU format is defined like the function code followed by the associated data set. The PDU specification defines the basic concepts for data access and manipulation.

Data collected via Modbus are stored in address ranges or in one of four memory blocks: coils, discrete inputs, holding registers and input registers. Depending on the industry specifications or application, names of blocks may vary. With the specified memory blocks, data types and master-slave access rights are also defined. Slave devices have a direct access to data that is locally saved on the devices. In contrast, the master must require access to this data via various function codes. In addition to the Modbus protocol functionality defined in the PDU, multiple network protocols can be used. The most common protocols are serial and TCP / IP (Transmission Control Protocol / Internet Protocol), but others such as UDP (Unit Data Protocol) can be used. To transfer data across layers, Modbus includes an ADU (Application Data Unit) which is adapted to each network protocol. Modbus requires certain data to provide reliable communication. Unit ID or addresses are used in each ADU format to provide application layer routing information. Each ADU comes with a full PDU, which includes function code and associated data for the default request. For reliability, each me-

ssage includes the information error checking. Finally, all ADUs allow determining the beginning and end of the request frame. The three standard ADU formats are: TCP, RTU, and ASCII. RTU and ASCII are ADUs that are used over a serial line, while TCP is used over TCP/IP or UDP/IP networks. TCP/IP determines the rules of data exchange via the Internet by providing end-to-end communication that identifies the rules, e.g. how to divide data into packets, and how to address, transmit, direct or receive data at the destination. The protocol is designed to make networks dependable, with the ability to automatically recover from a failure of any device on networks. TCP defines how applications can create communication channels in a network. It also manages the way a message is compiled into smaller packets before being transmitted over the Internet and reassembled in the correct order at the destination address. IP defines how to address and route each packet to the right destination. Each computer connected to the network checks the IP address to determine where to forward the message. Considering adaptable and ubiquitous physical network (Ethernet) with universal network standard (TCP/IP) and independent presentation data by the manufacturer, Modbus provides an open and available data exchange network. It is easy to implement for any device that supports TCP/IP ports. The Modbus TCP ADU consists of a 7-byte header (MBAP) and N-byte data units (PDUs). The MBAP header includes Unit ID used to communicate via devices such as routers and gateways using a single IP address to support multiple and independent Modbus endpoints. The MBAP is also contained of a ProtocolID, which is commonly equal to zero, TransactionID used in the networks where more requests send at the same time, and Length. The inverters, Sunny Tripower 10000TL and Fronius Symo 12,5-3-M, have integrated Modbus TCP servers and they are supported for communication using the MODBUS TCP / IP communication protocol.

## 4. DEVELOPED APPLICATION FOR DATA LOGGING AND MONITORING

In this paper, the main aim is to collect measurements of relevant process quantities from the PV inverters such as current active power, total electricity produced, panel temperature, irradiation, ambient temperature, etc. The mentioned measurements are needed to save them to csv files in order to be available for further analysis and forecasting. Therefore, a communication between the PV inverters and the central computer needs to be established. The PV power plant consists of seven inverters and one data manager, which is used to collect temperature and irradiation data. Furthermore, it is necessary to design a graphical user interface (GUI), where the collected measurements from the PV power plant will be displayed. The graphical interface should consist of a main screen, on which it will be possible to select measurements from an individual inverter or total measurements for the entire PV power plant.

The State Machine structure used to develop the application in LabVIEW consists of three mains while loops: the loop to read data from the inverters, the loop to process and store data in a file and the loop to display data in the User Interface. The design pattern on which the application is based is Producer/Consumer. The Producer/Consumer design pattern is purposed at enhancing the data sharing between multiple loops running at different rates. It is used to separate the State Machine loops. one loop “produces” data, while the other loops “consume” them at different rates. The Producer/Consumer pattern is the most suitable for an application which acquires data while processing them in the order in which they are received. Consequently, collecting this data is much faster than their processing. If the producer and the consumers were in the same loop, the speed of collection data would be slowed down to match the data processing speed. That is why it is useful to separate the code into a data collection part and a data processing part.

Communication between the producer and consumer loops is done by using queues. The queues in the Producer/Consumer form are based on the FIFO (First In First Out) theory. In the Producer/Consumer form, queues can be applied using LabVIEW synchronization functions. The following advantages are derived using queues in the Producer/Consumer form:

- both loops are synchronized -- the consumer loop is executed only when the data is available in the queue;
- efficient code is created using queues;
- eliminating the possibility of losing data in the queue while adding new data.

The producer loop is commonly simpler than the consumer loop. The task of the producer loop is to read and collect measurements from the PV inverters, check the time and to forward the collected measurements to the consumer loop. The purpose of the consumer loop is to create folders in which the data will be stored in a csv file and use data for monitoring.

Therefore, the program creates a new file every day in which the measurements for that day are saved. Also, for each new month or year, a new map will be created for better data visibility.

The queue should be initialized outside the producer loop using the “Obtain Queue” function and associate it with an appropriate data type. To add data to the queue within the producer loop, the “Enqueue Element” function is used. The consumer loop retrieves data from the queue created in the producer loop, and then removes the data from the queue using the “Dequeue Element” function. The first data inserted in the queue is also the first data to be removed from the queue. Moreover, before executing the program, the inverter initialization must be done. The required initialization data contains 3 elements: “Inverter Name”, “IP address” and “UnitID”. “Inverter Name” is the name of the inverter, “IP address” is the address over which measurements are sent from an individual inverter and “UnitID” is the identification number of each inverter. “UnitID” for SMA inverters can be freely configured within the range of 3 to 123, and the default value is 3. With Fronius Symo inverters, “UnitID” is equal to the number of inverter, and it can be configured using the control panel on the inverter.

### 4.1 User Interface

The front panel of this application is in fact a graphical user interface that is characterized by simplicity and clarity. The interface displays measurements that give users an insight into the current situation, but also the possibility of their further processing and analysis. The interface consists of nine tabs:

- Data Manager
- Sunny Tripower 1
- Sunny Tripower 2
- Sunny Tripower 3
- Fronius Symo1
- Fronius Symo 2
- Fronius Symo 3
- Froius Symo 4
- Data list

In Figure 3, the initial “Data Manager” tab shows data read from the device of the same name, radiation, temperature of PV modules and ambient temperature. Also, the total measured active power for the PV power plant in the period of the last hour is shown. At the top of the interface, there is an indicator that turns red if a communication error occurs.

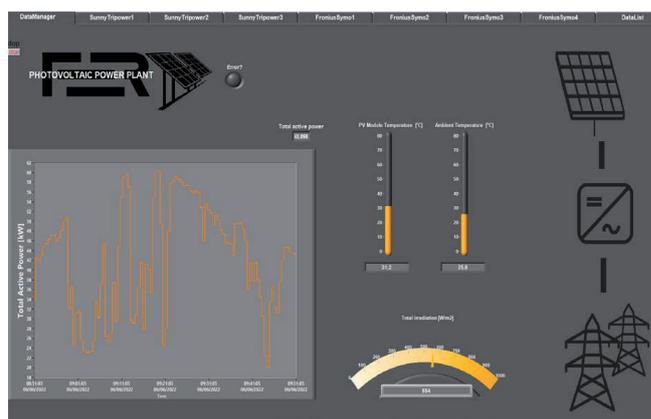


Figure 3. User Interface - Data Manager Tab

On the next seven tabs with inverter names, the interface is the same, except the measurements are adjusted for the corresponding inverter. The tabs are intended for instant display of all measured quantities. Displaying the measured quantities in real-time is a great advantage because the current state of the system can be obtained. Also, the current display gives an insight into whether the device is working properly. The measured quantities are displayed in two ways: numerically and graphically, as shown in Figure 4 for Fronius Symo 1 inverter. Possible causes of data deviations may be inverter malfunction, communication error or short-term atmospheric disturbances that may affect the sudden change of physical quantities. All measured quantities are read from inverters installed in SmartGrid Laboratory at UNIZG-FER [14].

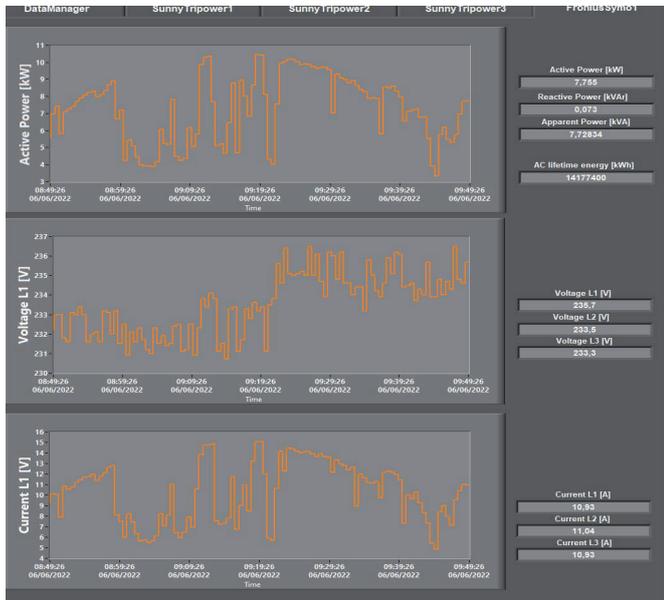


Figure 4. User Interface - Fronius Symo 1

The last tab “Data List” shows a list of the last 200 collected measurements. In this way, a better visibility of historical data to the user is ensured. At the bottom of this tab, there is also a file path through which the user accesses the csv file where can find all collected measurements of the current day.

## 4.2 Display of collected measurements

The graphs show the measurements of the active power of the inverters [kW], the radiation [W/m<sup>2</sup>] and the temperature of the PV modules [°C] and the ambient temperature [°C] for June 6th, 2022 (Figures 5-8). An increase in the temperature of solar cells is always accompanied by an increase in the intensity of the solar cells radiation and the output power of the photovoltaic module depends linearly on the temperature of the PV modules [15].

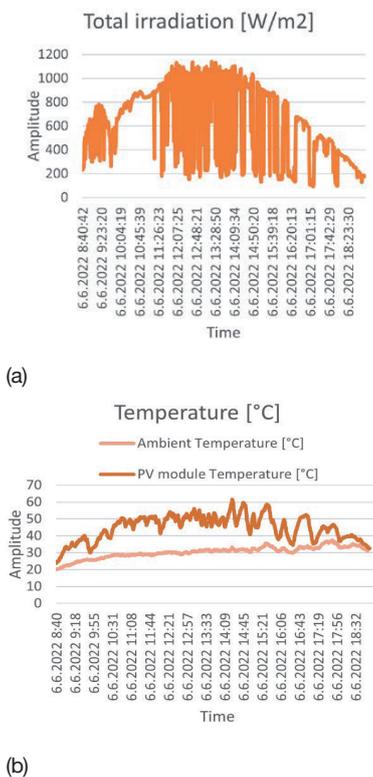


Figure 5. Graphical representation of measurements on June 6th, 2022: (a) Total irradiation [W/m<sup>2</sup>]; (b) PV module and ambient temperature [°C]

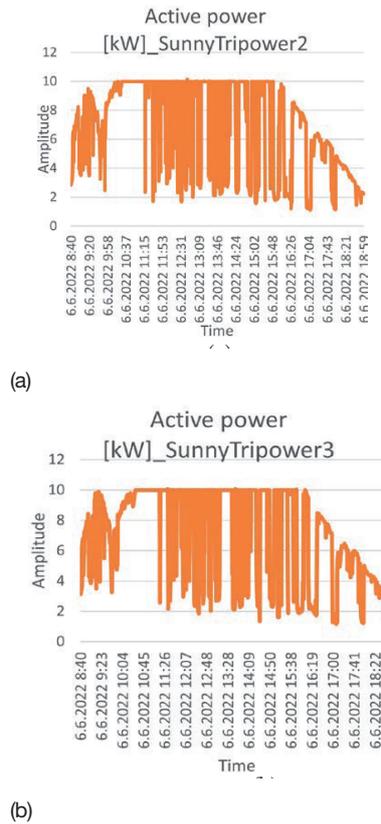


Figure 6. Graphical representation of measurements on June 6th, 2022: (a) Active Power of Sunny Tripower 2 [kW]; (b) Active Power of Sunny Tripower 3 [kW]

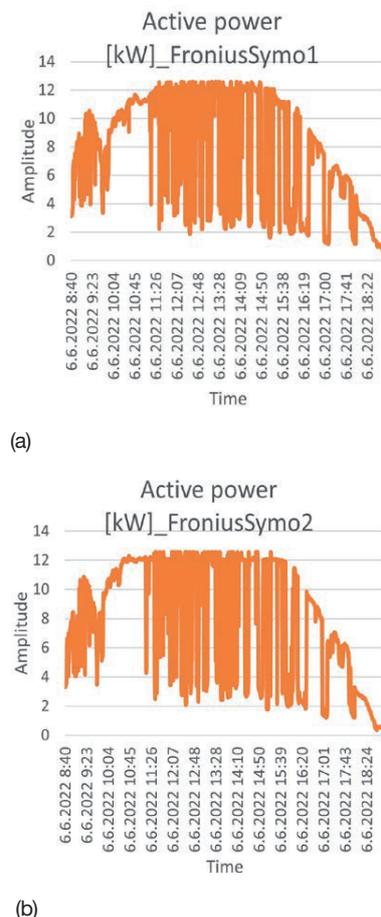
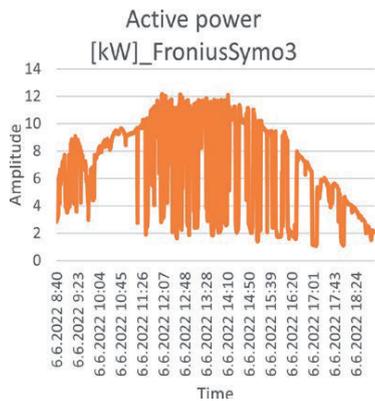
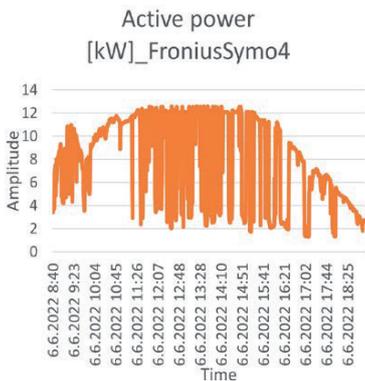


Figure 7. Graphical representation of measurements on June 6th, 2022: (a) Active Power of Fronius Symo 1 [kW]; (b) Active Power of Fronius Symo 2 [kW]



(a)



(b)

Figure 8. Graphical representation of measurements on June 6th, 2022: (a) Active Power of Fronius Symo 3 [kW]; (b) Active Power of Fronius Symo 4 [kW]

## CONCLUSION

In this paper, an application is presented for logging and visualization of measurements from a PV power plant located at the University of Zagreb Faculty of Electrical Engineering and Computing. The main aim of this paper is to increase the visibility of the PV power plant by implementing a system for monitoring and collecting measurements in a real-time. The technical characteristics of PV inverters Sunny Tripower 10000TL-20 and Fronius Symo 12,5-3-M are described in detail. The communication between the inverters and the central computer is achieved by the Modbus TCP/IP protocol that enables an open and accessible network for the exchange of process data in a simple and reliable way. The graphical language LabVIEW is used to create the application that allows analysis, processing and display of data in an intuitive way. LabVIEW uses the Producer/Consumer format to improve program performance to a certain level and enable easy multi-process operations performed at different speeds. The collected measurements are displayed on the developed User Interface which shows the current condition. The created csv files contain accurate 15-minute measurements and provide detailed insight into the operation of the PV power plant.

Therefore, this application achieved efficient and synchronized measurements, collecting and processing data in one place, as well as real-time communication, whereby the reliability of the electric power system is increased. This system with minor upgrades can be easily used to collect data and monitor large PV modules and systems or for industrial purposes.

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