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DESIGN OF A SCADA SYSTEM FOR A SOLAR PHOTOVOLTAIC POWER PLANT

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A B S T R A C T

This paper presents the design and implementation of a solar panel data monitoring system using a SCADA (Supervisory Control and Data Acquisition) system. The system is built via the Siemens S7-1200 Programmable Logic Controller (PLC) and programmed using TIA (Totally Integrated Automation) Portal V17 software. The system includes various sensors and instrumentation for monitoring solar panel performance, such as temperature sensors, current and voltage sensors, and irradiance sensors. The PLC collects data from these sensors and transmits it to the SCADA software, which displays real-time data on the graphical user interface (GUI). The system also includes features such as alarms and notifications for abnormal conditions, data logging for historical analysis, and remote access for monitoring and control from a central location. The system's reliability and efficiency are enhanced through the use of the S7-1200 PLC and TIA Portal V17 software, which provide advanced programming and automation capabilities. Therefore, this solar panel data monitoring system provides a comprehensive solution for monitoring and optimizing the performance of solar panel systems, helping to increase efficiency, reduce downtime, and improve overall system performance.

1. Introduction

SCADA is a technology used in various industries to monitor and control processes. In the renewable energy sector, SCADA systems are essential for managing and optimizing the performance of solar panels [1]. The use of solar energy has become increasingly popular due to its environmental benefits and cost-effectiveness. However, ensuring the efficient functioning of solar panels requires real-time monitoring of various parameters such as temperature, irradiance, and voltage [2]. This is where a SCADA solar panel data monitoring system comes in. The SCADA solar panel data monitoring system is designed to gather real-time data from solar panels and transmit it to a central control room [3]. The system consists of several components, including sensors, a PLC, a communication network, and a human-machine interface (HMI) [4]. The S7-1200 PLC is a popular choice for solar panel data monitoring systems due to its reliability, compact size, and ease of programming [5]. The S7-1200 PLC is responsible for collecting data from various sensors installed on the solar panels, including temperature sensors, irradiance sensors, and voltage sensors [6]. The PLC then processes the data and transmits it to the central control room via a communication network [7]. The HMI provides operators with a user-friendly interface for monitoring the performance of the solar panels in real-time [8]. The data collected by the SCADA solar panel data monitoring system can be used to identify any performance issues and take corrective actions to ensure optimal efficiency [9]. Therefore, the SCADA solar panel data monitoring system using the S7-1200 PLC is an essential tool for ensuring the reliable and efficient operation of solar panels. By providing real-time data on the performance of the solar panels, operators can make informed decisions and take proactive measures to optimize the performance of the system [10].

Several studies have used Arduino and Raspberry Pi technology for monitoring PV system performance [11-15]. Although these solutions are low-cost, open-source, and extensible, they should not be considered a replacement for PLC technology. The PLCs are designed for industrial applications; they have the required approvals and environmental specifications; and they are robust, scalable, and extensible [16-20]. So, PLC technology can be considered a better choice for monitoring the PV system. Therefore, this work tries to use a Siemens S7-1200 PLC to monitor a solar panel system, as it is able to receive data from various sensors that measure various parameters such as solar panel terminal voltage, load current, temperature, irradiance intensity, etc.

2. Literature Survey

The survey of related works encompasses several studies that focus on monitoring and controlling photovoltaic (PV) systems using various technologies for SCADA system.

One study [21] emphasizes the authors propose the creation of an open-source SCADA system using the Python programming platform. The SCADA system is designed to communicate with various control devices such as PLCs (Programmable Logic Controllers) and PACs (Programmable Automation Controllers) through an open-source OPC-UA (OPC Unified Architecture) server. This enables data exchange and control capabilities within the manufacturing environment. The system incorporates an Active Fault Tolerant Control (AFTC) architecture, enhancing its fault tolerance capabilities. The architecture is designed with three layers of interaction according to the CIM model, facilitating communication and control between different components. The proposed SCADA system is tested in a laboratory setup, and experimental results showcase its effectiveness in practical applications.

Another study [22] presents. The authors emphasize the importance of using automation systems to enhance energy efficiency, reliability, and economic as well as environmental considerations in managing microgrids. They introduce a comprehensive microgrid testbed named "LAMBDA MG" established at Sapienza University of Rome, Italy. The microgrid comprises various sources like Photovoltaic (PV) panels, a Battery Energy Storage System (BESS), and an Emergency Generator Set, along with loads such as lighting, HVAC, and plugs. The control strategy involves two distinct subnets. The first subnet utilizes a distributed Home and Building Electronic System (HBES) for supervisory and control purposes, targeting energy and comfort objectives. The second subnet centres around a central Programmable Logic Controller (PLC) responsible for managing different sources during grid-connected and island modes. Both subnets are integrated into a common SCADA system, facilitating real-time monitoring, alarm handling, human-machine interaction, and event/data management.

In [23] The research article focuses on the implementation of a Nearly Zero-Energy Microgrid (MG) testbed laboratory with a centralized control strategy based on a Supervisory Control and Data Acquisition (SCADA) system. The authors highlight the importance of microgrids, which incorporate renewable energy sources (RESs), as a solution for managing the complexity and productivity issues faced by traditional distribution networks. They emphasize the role of power electronic interfaces and communication infrastructures in advancing SCADA systems and controlling microgrids. The development and success of microgrids are closely tied to advancements in power electronic interfaces and SCADA systems. The authors present the "LAMBDA MG" testbed laboratory implemented at Sapienza University of Rome as a real case study for microgrid control and management. They introduce the concept of a centralized energy management system (CEMS) within the microgrid context.The SCADA system is described as a means of achieving proper energy balance and minimizing power exchange between the microgrid and the main grid.

In a related study [24] The research paper introduces a novel approach for modeling and simulating hybrid power systems (HPS) using Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems for Hardware in the Loop (HIL) testing. The authors focus on analyzing the dynamics of renewable energy-based HPS and propose a method that combines real-time control and simulation capabilities on commercial off-the-shelf (COTS) hardware and software. The authors highlight the need for real-time Energy Management Units (EMUs) to ensure optimal utilization of primary energy sources and enhance supply reliability.

3. Proposed SCADA monitoring system

This work was to create a SCADA system to monitor and display data from solar panels. The SCADA system collects data from the solar panels, such as voltage, current, and temperature, and displays this information in a user-friendly way. This allows operators to monitor the performance of the solar panels and identify any issues or anomalies. Additionally, the data collected by the SCADA system can be used for analysis and optimization of the solar panel system, such as identifying areas for improvement or predicting future energy output. The proposed circuit diagram of the PV panel monitoring system is shown in Fig. 1.

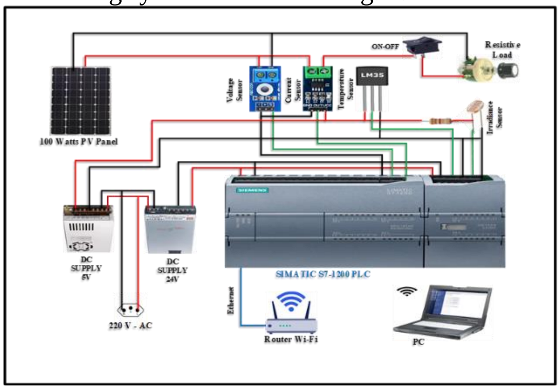

Fig. 1. Circuit diagram of the proposed PV monitoring system

Four measurement sensors are used to collect the data from the PV panel (A 100-watt polycrystalline solar panel type) and its environment and transmit it to the PLC unit (S7–1200).

3.1 PV Panel

A solar panel, also known as a photovoltaic (PV) panel, is a device that converts solar radiation into electrical energy. In this work, a 100-watt polycrystalline solar panel was used, and its specifications (under standard test conditions) are shown in Table 1 (It is taken from the nameplate of the used PV panel).

Table 1. Specifications of the utilized PV panel.

TYPE	M-100W
Maximum Power (Pmax)	100 Watt
Open Circuit Voltage (Voc)	21.5 Volt
Short Circuit Current (Isc)	6.4 Amp.
Maximum Power Voltage (Vmp)	17.8 Volt
Maximum Power Current (Imp)	5.71 Amp.
Maximum System Voltage	1000 Volt
Power Tolerance	±3 %
Dimension (mm)	1200*540*30

3.2 Voltage sensor

A voltage divider was used with the PLC as a PV voltage sensor. It consists of two resistors (30 kΩ and 7.5 kΩ). It operates between 0 and 25 volts. According to equation (1), its output voltage can be defined.

$$V_{out} = V_{in} * \frac{R_2}{R_1 + R_2} \qquad (1)$$

where Vin is the input voltage, R1 is the resistance of the 30K resistor, and R2 is the resistance of the 7.5K resistor.

3.3 Current sensor

The ACS712 Current Sensor was used because of its high accuracy and simplicity for the load current measurement. It has the ability to measure
both AC and DC current. The "Hall Effect" is the basis for this device's operating concept. This sensor is utilized for normalizing the required hall voltage value from the load current, which is then provided to the PLC. Then the PLC calibrates the hall voltage to the real load current (I) as follows [25]:

$$I = \frac{sensor\ value - 2.5}{scale\ factor} \qquad (2)$$

The scale factor value is dependent on the category of ACS-712 current sensor with consider to its current load capability; for the ACS-712 ELCT-10A used in this work, it is 100 mV per amp.

3.4 Temperature sensor

The low power, low cost, and high precision LM35 temperature sensor was created and manufactured by Texas Instruments. With a scale factor of 10.0 mV/°C, it outputs a voltage that is linearly proportional to the change in temperature.

3.5 Irradiance sensor

An LDR-based method of measuring solar irradiance was employed. For a typical LDR, the resistance RLDR and light intensity (in Lux) have the following relationships [22]:

$$R_{LDR} = \frac{500}{Lux} \qquad (3)$$

Using the voltage divider rule, if the LDR is connected to 5 volts through a 3.3 K ohm resistor, the LDR's output voltage (V out) is

$$V_{out} = \frac{5R_{LDR}}{R_{LDR} + 3.3} \qquad (4)$$

Substituting RLDR from equation (3) into equation (4) to attain the light intensity.

$$Lux = \frac{\frac{2500}{V} - 500}{3.3} \qquad (5)$$

Lux to W/m2 cannot be directly converted; instead, there is a rough conversion for sunlight as shown in equation (6).

$$1\mathrm{Lux} = 0.0079\ \mathrm{W/m^2} \qquad (6)$$

4. Software Implementation

TIA (Totally Integrated Automation) Portal V17 is software tool used for programming Siemens SIMATIC S7-1200 PLCs [26]. The PLC read all sensors' measurement values. It is connected to it through analog input pins, which can be read, monitored, and controlled remotely by computer monitors.

Firstly, for measurement of the terminal voltage of the PV panel; the minimum and maximum of the voltage sensor signal (%IW64) were selected from 0 to 27648, and the value was specified in "NORM_X" It was then scaled to the actual voltage value (0-25) in volts using "SCALE_X" function blocks. During the calibration of the voltage sensor, the error rate was found to be 5%. To avoid this error, a "CALCULATE" block was used to compensate for the error percentage and obtain the correct voltage (see Fig. 2 (a)).

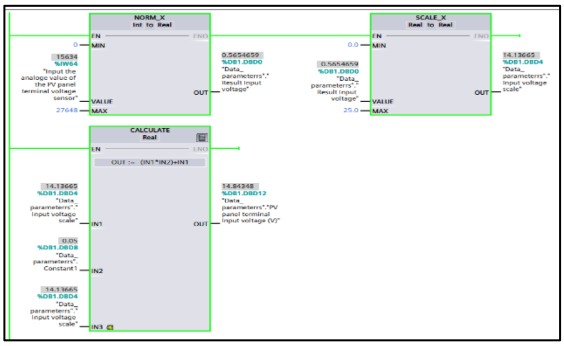

Fig. 2 (a). PV terminal voltage calculation network

For measurement of the load current, the minimum and maximum of the load current sensor signal (IW66%) were normalized from the (0-27468) value using the "NORM_X" block function. Then it scaled with minimum and maximum values of 0-10 amps, which were specified using the "SCALE_X" block. A "CALCULATE" block function was used to implement the required calibration equation of this sensor, equation (2), as shown in Fig. 2 (b).

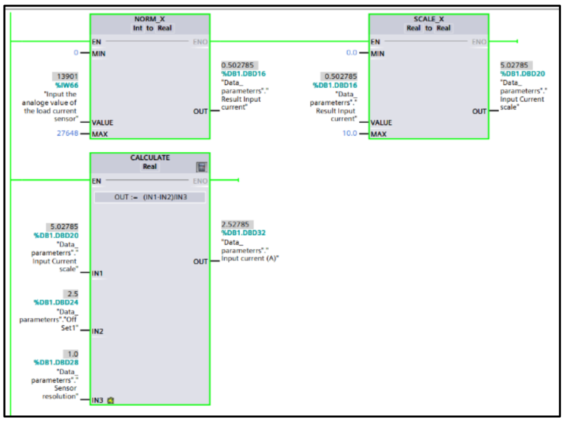

Fig. 2 (b). Load current calculation network

To measure consumption power from the PV panel, the PV terminal voltage value was multiplied by the load current value through the multiplication function block "MUL" to obtain the consumption power value in Watt as shown in Fig. 2 (c). This operation can also be implemented using the "CALCULATE" function block.

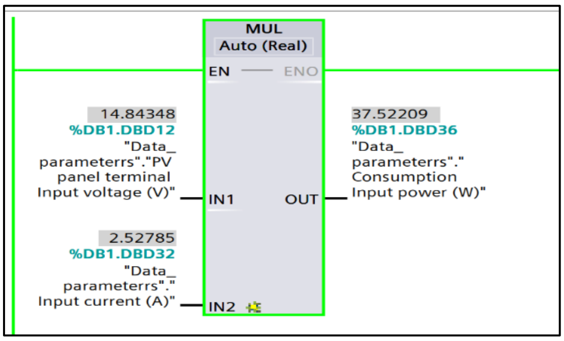

Fig. 2 (c). Consumption power calculation network

For scaling the LM35 temperature sensor signal (%IW100), its parameters are normalized within 0-27648 using the "NORM_X" block function, and the normalized data are scaled with the range of 0–100 °C. During the calibration of the temperature sensor, it was found that the scale factor was: linear + 10.0 mV/°C. So, a "CALCULATE" block was used to multiply this value and obtain the correct current value, see Fig. 2 (d).

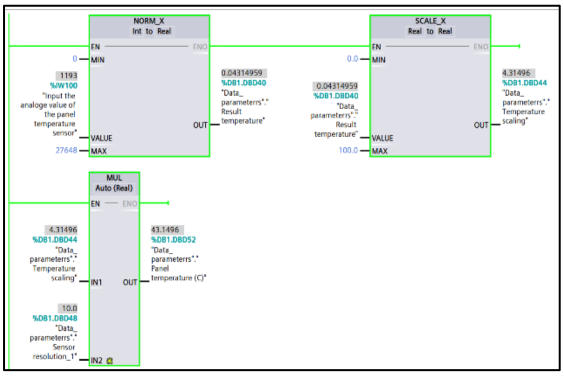

Fig. 2 (d). Temperature calculation network

Finally, to calculate the irradiance of the solar panel, the minimum and maximum of the light sensor signal (%IW102) were normalized with a (0-27468) value using the "NORM_X" function block. A function block named "CALCULATE" was used to calculate the value of the irradiance in "W/m2" unit according to equations (5) and (6) as displayed in Fig. 2 (e).

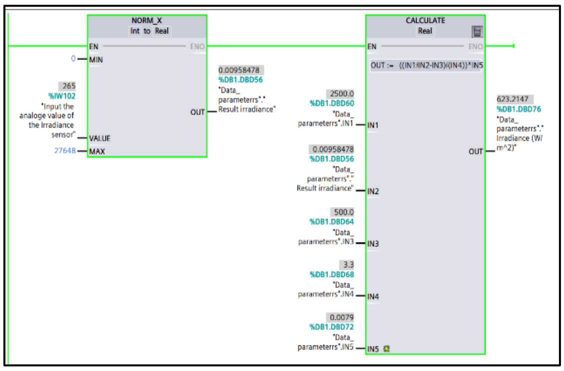

Fig. 2 (e). Irradiance calculation network

5. Proposed SCADA System

The SCADA screen is designed in TIA Portal V17 and configures the communication settings with the S7-1200 PLC and the communication settings for each sensor. The sensors in the project have also been labelled, and appropriate data types have been set for all analog values for voltage, current, power, temperature, and radiation. Screens for the SCADA display were also created using the screen editor in the TIA portal. Graphical elements such as metrics, charts, and tables have been added to display sensor data. alarms and events for each sensor to trigger alerts and warning signs when certain thresholds are exceeded. The project also includes adding trend charts to the SCADA screen to show historical data for sensor values. The S7-1200 PLC reads data for each sensor and sends it to the SCADA system using the communication protocol configured in the TIA Portal project. To define alert and warning signs for each item, thresholds were set up for each parameter based on the normal operating range. When a parameter exceeds these limits, you can trigger an alarm or event to alert the operator of the problem.
The project also includes plotting curve values for voltage, current, power, temperature, and radiation using trend charts on the SCADA screen. Trend charts show historical data for parameter values over time. As the S7-1200 PLC's start and stop can be controlled through the SCADA system, buttons or other graphical elements have been added to the SCADA displays that send signals to the PLC to start or stop it. The PLC is also programmed to respond to these signals accordingly.

6. SCADA Results

In Figure 3, the GUI is displaying several real-time parameters, including voltage, current, power, temperature, and radiation levels, and plotting curve values for these parameters using trend charts on the

SCADA screen. Trend charts show historical data for parameter values over time. It is also showing warning and alert signs in the event of a short circuit or an open circuit in the system. Additionally, the GUI is indicating warning and alert cases if the voltage falls below the allowable limit or the temperature goes beyond certain values. The GUI is also displaying the state of descent in the radiation intensity from the usual limit during the day. Like the LED shape in the GUI of the SCADA system, it is typically displayed in an "exception color" when everything is functioning normally. This could be any color that indicates that the system is operating within acceptable parameters, such as green. However, in the event of an error or warning, the LED shape changes to yellow, indicating that there is an issue that needs to be addressed. Additionally, a warning message may be displayed on the GUI, indicating the specific nature of the error or warning and providing guidance on how to address the issue. This type of visual feedback is a common feature in SCADA systems, as it allows operators to quickly identify issues and take corrective action to prevent downtime or damage to the system. Moreover, the format shows the control of the PLC's operation and discontinuation. This allows the operator to have full control over the system and intervene if necessary to prevent any faults or errors.

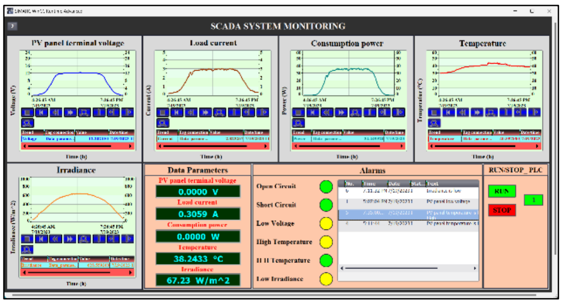

Fig. 3: Visualization on the SCADA system

Also, the SCADA system stores and saves data in various formats, including Excel files. By doing so, the system can track and analyze historical data for future reference, troubleshooting, and optimization purposes. Saving data in Excel files can also help operators and engineers easily analyze and visualize trends and patterns in the system's performance over time. Additionally, Excel files can be easily shared and exported to other software applications for further analysis or reporting purposes. Fig 4. displays the link and barcode pertaining to the data acquired from the photovoltaic system within the proposed framework on July 19, 2023, formatted as an Excel file. (i.e., the same data that is shown in the SCADA system).

https://drive.google.com/file/d/1ynIR-3OoNNNbrKBXmLVk3fgcf26XOBHn/view?usp=sharing

Fig. 4: PV monitoring data in Excel file format (scan the QR-Code)

It appears from the collected data in the Excel file that the data is updated every one minutes, and this time can be reduced to increase the resolution of the results.

Based on the data collected from the SCADA system, the curves for voltage, current, power, heat, and radiation were generated. The data was stored in an Excel file on the Tia portal. These curves were then compared to the ones created using the SCADA system. The analysis revealed that the outcomes are 100%, and the system continuously monitors the solar panel data. Fig (5 (a, b, c, d, e)) displays the curves for voltage, current, power, heat, and radiation in that specific order.

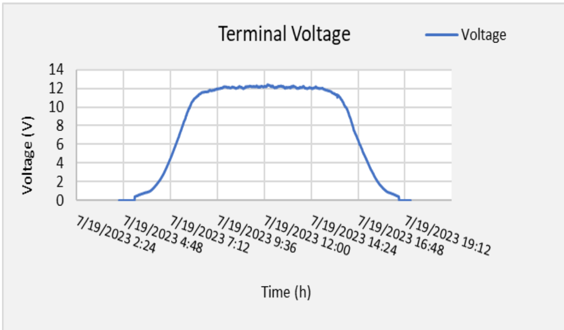

Fig 5 (a) displays the voltage-time curve

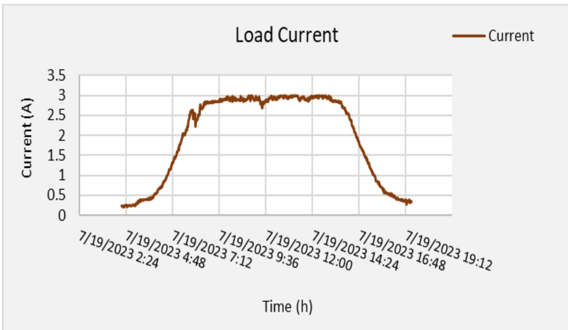

Fig 5 (b) displays the current-time curve

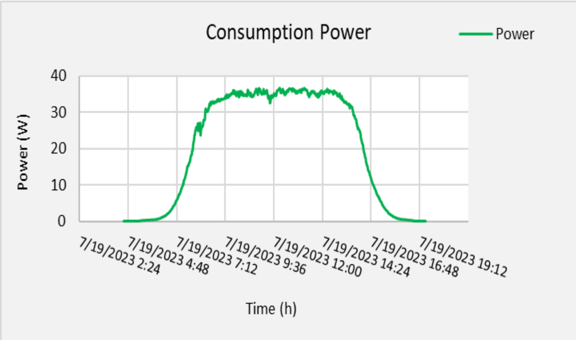

Fig 5 (c) displays the power-time curve

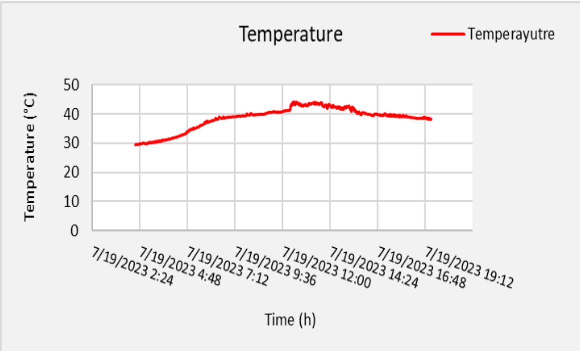

Fig 5 (d) displays the temperature-time curve

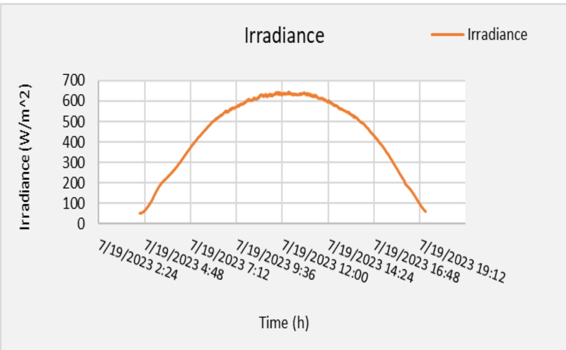

Fig 5 (e) displays the irradiance-time curve

7. Conclusions

- SCADA systems are crucial for any power system to achieve efficiency, process data for smarter decisions, supervisory management, and communicate system issues to help mitigate downtime.
-Based on the results of this research, it can be concluded that the data acquisition system for PV panel parameters via SCADA is an effective and efficient solution for monitoring electrical and meteorological data from PV power plants.
-The system is low-cost and provides precise findings in real-time.
-As for future work, there are several areas for improvement that can be explored.
-One potential improvement is to integrate machine learning algorithms to analyze the collected data and provide predictive analytics to optimize the performance of the PV system.
-Another area for improvement is enhancing the remote-control capabilities of the system, such as by adding more sensors to monitor various parameters and integrating actuators to control different devices remotely.

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