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Design and Practical Implementation of Dual-Axis Solar Tracking System with Smart Monitoring System

***Abstract**. This paper introduces a design and realization of low cost solar tracking system with smart monitoring system for electrical and tracking performance data. Microcontroller Arduino was used as a main controller unit for the proposed system. Two Servo Motors (SMs) have been used to move the solar panel (horizontally and vertically) at maximum light source location sensing by Light Dependent Resistors (LDRs).Thus, the solar panel will take maximum absorption of the light from the sun that necessary to produce the maximum amount of electrical power and obtaining relatively high efficiency compared to the fixed position solar system. Real-time monitoring of the PV panel characteristics (voltage, current and power consumption) was accomplished using only one sensor for current (ACS712 current sensor), and voltage divider circuit. These data in addition to the angles of the two SMs are displayed on LCD. A Bluetooth module HC-05 is used to transmit the measuring data from Arduino to the mobile device. Proteus software program was used as a Simulink environment for simulation the system before practical implementation. The performance of the proposed system has been tested at different time periods, and it shows the efficiency of the dual tracking system is more than efficiency in fixed system solar panel (at optimum angle that pre-calculated).*

Streszczenie.** W artykule zaprezentowano prosty I tani system śledzenia słońca. Dwa serwomechanzmy przemieszczają panel słoneczny tak aby otrzymał maksimum światła. Dane mogą być przesyłane do urządzenia mobilnego. **Projekt i wykonanie dwuosiowego systemu śledzenia światła io sterowania penelami fotowoltaicznymi.

Keywords: Solar Panel, Arduino, LDR, Dual-Axis, and Servo Motor.
Słowa kluczowe: system fotowoltaiczny, śledzenie światła słonecznego

Introduction

Solar energy is one in all the foremost promising renewable energy within the globe. On the opposite, the effectiveness of the commercially offered solar cells is in the close between 10 and 20% [1, 2]. This means that there lies a scope for perfection as its efficiency relatively small. In general there are two methods can be employed for rising the efficiency of the solar panels, that is: (i) Use Maximum Power Point Tracking (MPPT) techniques, and (ii) Use of a Solar Tracking System (STS). MPPT is the procedure of capitalize the generated power from the PV panel; conversely this technique cannot increase the generated power when the sun isn't directly aligned with the PV system.

The generation capability of solar cell respects the intensity of the sunlight. The place of the sun with regard to any position of the world change s in acyclic track through the course of a calendar year. Tracking the position of the sun in order to expose a PV panel to maximum radiation at any given time and any position is the target of a computerized STS [3].

There are two forms of STSs; single-axis STS and dual-axes STS. Single-axis STS typically permit motion from morning to evening. It is appropriate for places along the equator where the sun locations do not fluctuate greatly through summer and winter. The benefit of the single-axis is it only needs a one motor which is easier mechanism and has less mass. Yet, it necessitates an appropriate installation that allows the mechanism to track sun travels. Instead, dual-axes STS with two motors are more flexible as its capability to track the sun in any directions regardless of the angle of the initial position of the PV [1]. Thus dual-axis trackers require to be developed. Controlling of Dual-axis STS can be performed using different controller such as programmable integrated circuit (PIC) Microcontroller [4], Field Programmable Gate Array (FPGA) [5, 6], and Programmable Logic Controller (PLC) [3, 7].

Microcontroller and FPGA controllers when used for solar tracing system, it required an analog-to-digital conversion (ADC) external card as it doesn't has it. So Arduino card it preferred as it has built in ADC in addition to it cheaper than other options, ease of usage and it is widely used now, therefore; it employed in this research work for dual-axis STS.

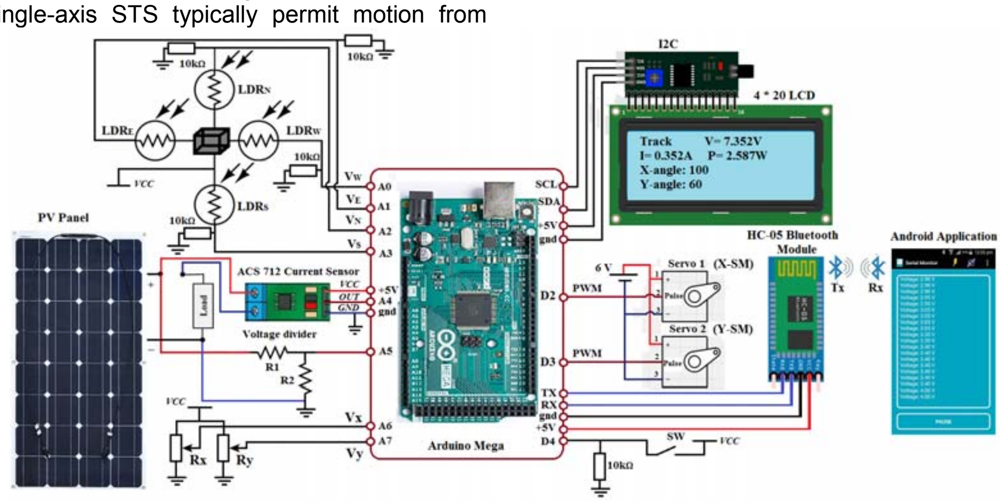


Fig.1. Block diagram of the proposed solar system

Proposed Solar Tracking System

Circuit diagram of the proposed solar system based on Arduino is shown in figure 1. Four LDRs fixed above the solar panel were used to sense the sun light; then gives its signal to Arduino. Arduino card compare between each two signals and then send the order for two SMs. One used for moving the system horizontally and the other for vertically to keep the PV panel orthogonal to the sun and continuously for the duration of the day. Basically the system consists of two subsystems: dual-axis STS and monitoring system. The dual-axis STS depend on four LDR sensors and two motors: X-axis SM (X-SM) and Y-axis SM (Y-SM). Monitoring system depend on two measuring sensors, 4*20 Character LCD, and HC-05 Bluetooth Module.

Arduino Mega 2560

The embedded board used in this work is Arduino Mega 2560, in which the ATMega328 microcontroller is integrated. It has 54 digital I/Ps and O/Ps pins (of which 15 can be used as Pulse Width Modulation PWM O/Ps), 16 analog I/Ps, 4 UARTs ("Hardware Serial Ports"), build-in crystal oscillator with frequency 16 MHz, 10-bit Analog - Digital Converter (ADC). It encloses every part needed to support the microcontroller; it easily programmed by the Arduino IDE software via USB connection.

Light Dependent Resistor

Photoresistor or LDR can be considering as a "passive electronic component", as its resistance decreases with increasing light intensity. The resistor of an LDR is very high, sometimes as high as 1 Mega ohms. The light resistances will drop much when illuminated [8].

The commonly method when using dual-axis STS; is adding four LDR sensors at four ends of the solar panel. However, this process is not ideal as the sun would be lighting all four LDRs perpendicularly at all times with little to no difference in LDR readings to enable the panel to move. Alternative technique employs the formation of shadows by change in place of sun to predict its present position. In general, four LDR sensors are positioned closed together separated by solid black box or can entitle as "opaque partitions", with one LDR sensor in each partition. This way is further ideal because the dark partitions reason a shadowing effect on parts not showing to the sun and thus enable the LDRs to perfectly detect the position of the sun (i.e. improving the sensitivity of these sensors under various position of the sun) as displayed in the following figure.

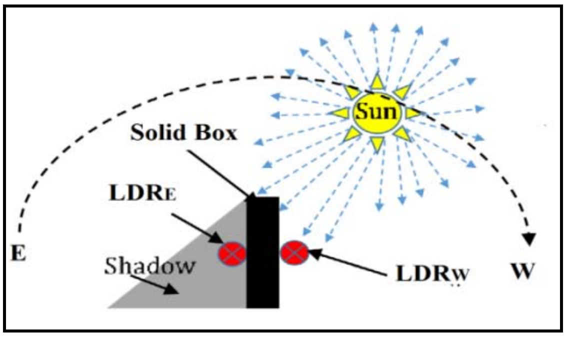


Fig. 2. Solar tracking under various positions of sun

Four LDR were used in the work as light intensity sensor attached on the surface of the solar panel as mention lately: two for East-West orient (LDRE and LDRW) and the other two for North-South orient (LDRN, and LDRS). When the sun moves, then the intensity of the light falling on the four LDRs will varies. This varies is calibrated into voltage and as following; Light intensity was measured by using a resistor in series (equal to 10 KΩ) (see figure 3) with each LDR making a voltage dividing circuit (resistive of LDR and 10 KΩ). When the intensity of light on LDR changes, its resistance and hence the output voltage are changed; change in intensity is transformed into a change in voltage which represents the analog signals (V_N, V_S, V_E, and V_W) for each LDR sensor. Arduino will receive these analog voltage signals then convert it to digital (0–1023) via its internal 10 bits ADC.

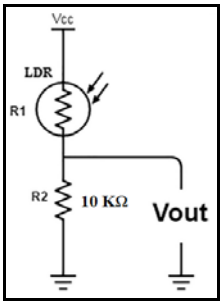


Fig. 3. Light intensity measuring circuit

Servo Motors (SMs)

SMs are a precise kind of electric motors; where motor shaft can position at a specific position (angle) in both directions using PWM control signal. It cans usually only turn 90°in either direction (clockwise & counter clockwise direction) for a total of 180° movement. The SM shaft will hold at this position as long as the control signal not changed [5]. So it is very suitable for our work for solar tracing system.

SM is a three-wire DC motor. Among those wires, two wires deliver power supply to the motor and one is used to guide the motor via PWM control signal. The period of this signal must be 20 msec then the Duty Cycle (K) "encodes" the position of the SM. If the K is 1 msec, the SM is positioned at 0°. If the K is 2 msec, the SM is positioned at the maximum possible angle (180°) as shown in figure 4 [9].

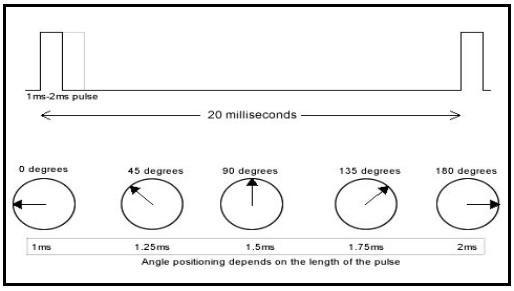


Fig. 4. Servo motor PWM timing diagram

Architecture of the Proposed Tracking System

Switch (Sw) was used as a selector switch for replacing the automatically dual-axis STS based on LDR sensors to Fixed system as shown in flowchart of proposed solar system in figure 5 (i.e. in Fixed system means manually tracking solar system by varying the angles of motors via two variable resistance Rx for varying and adjusting the X-angle, and Ry for varying and adjusting the Y-angle). When Sw is ON state, Arduino card receives these four analog signals via four analog inputs port (A0 to A3); Each time the comparison between each adjacent analog signals (V_N compared with V_S, and V_E compared with V_W) was done, the comparison results decide the operation the two SMs (i.e. solar tracking direction) via two PWM signals from Arduino as the following situations:

- If intensity of light on LDRW is greater than intensity on LDRE, the resistance of LDRW will be lower than the resistance of LDRE lead to in $V_W > V_E$; if $(V_W - V_E) > 0.25$ V (tolerance level) then X-SM move the solar panel toward the west and vice-versa.

- If $(V_S – V_N) > 0.25$ V; then Y-SM move the solar panel toward the south and vice-versa.
- If light intensity on both LDR is same ($V_W = V_E$ or $V_S = V_N$); solar tracker will maintain its present position.

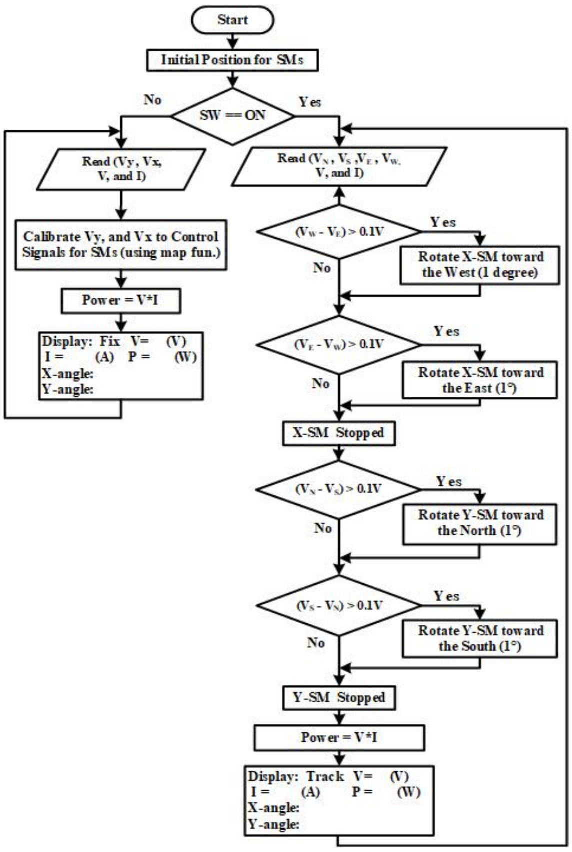


Fig. 5. Flow-chart of the proposed system

Monitoring System

Arduino Voltage Sensor Module was used for normalizing the PV voltage to the Arduino analog voltage range to be measured. In fact this module is a voltage divider circuit, which produce an output voltage less than the input original voltage by five times. Because the Arduino chip have 10 bit ADC, so the resolution of this module simulation is 4.89 mV (5 V/1023).

The ACS712 Current Sensor was used for the load current measurement as it has good accuracy and simplicity. The principle operating of this device is based on the Hall Effect [10]. Rendering to this principle, when current carrying conductor is placed in magnetic field, voltage is induced which is called "hall voltage". The sensor is used to normalizing the required hall voltage level from the load current which is further supplied to the Arduino [11]. The Arduino then calibrate the hall voltage to the actual load current as following equation:

$$(1) \quad Load\ current(A) = \frac{(sensor\ value - 512) * 5 / 1024}{Sensitivity\ value}$$

The sensitivity value is depend on the type of the ACS712current sensor regard to its current load capability ; there are three type of current sensor each one used for specific range of current measurement, the sensitivity value for ACS-712 ELCTR-5A-T which measure until 5A equal to 66mV/A, it used in this work. The DC power combustion it's easy to be calculated by multiplying the measured PV panel voltage by the load current. The PV panel voltage, load current, DC power combustion, and the angles of the two SMs (X-SM, and Y-SM) used for dual tracking system are displayed on 4*20 character LCD in addition to these data can be monitoring via PC using serial print on serial monitor.

HC-05 Bluetooth Module utilized for interfacing between two Arduino cards, or between Arduino cards with any unit has Bluetooth functionality (as a mobile or computer); so this module was used in this work to transfer the data from the Arduino (the same data which displayed on the LCD) to the mobile device. The android application developed for this project was named as “Bluetooth Serial Monitor for Arduino app”; this app works just like the Arduino IDE's Serial Monitor but in mobile way.

Simulation of the Proposed System

The circuit is designed in Proteus, simulation software. The advantage of using such software is that, the code can be simulated there before burning into the microcontroller. The simulation circuit diagram is as follows:

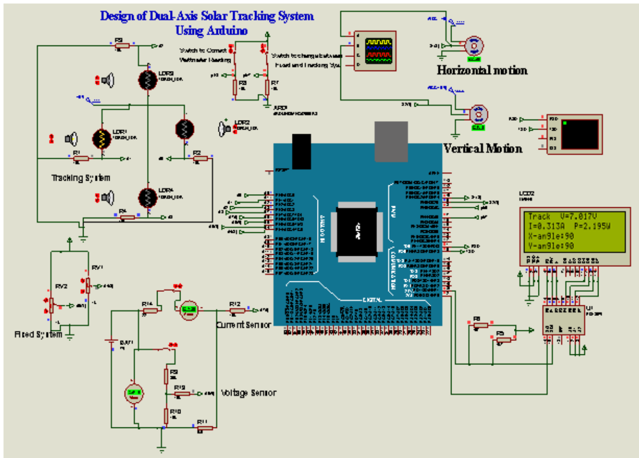


Fig. 6. Proteus simulation circuit of the proposed solar system

Fig. 7. Experimental setup of the proposed system

Experimental Results:

After practical implementation the proposed solar tracking system was tested at different times of a day in presence of varying orientation of sun; figure 8 show the variation of power with the variation of time for both fixed system and dual-tracking system.

The percentage energy gain of the dual-STS with respect to the fixed system can be presented by the following formula:

$$(2) \quad Energy\ Gain = \frac{P_{dual\ STS} - P_{fix\ system}}{P_{fix\ system}} * 100\%$$

where; $P_{dual\ STS}$ is the power consumption of dual STS in Watt, and $P_{fix\ system}$ is the power consumption of fixed system in Watt. Thus, according to the measured power consumption from 9 am to 5 pm for fix and dual-axis STS shown in figure 8, the energy gain is equal to 20.38%. In other word, the dual axis sun tracker can collect 20.38% more energy than fixed angles panel. The efficiency can be increased by take a measurements data for longer time (from 6 am to 6 pm for example). The maximum angle that can be obtained (180°) of SM made limitation for taken data for longer time.
Figure 9 shows the change in rotation angles (in degree) on both the X-axis and Y-axis with the time variation (in Hour).

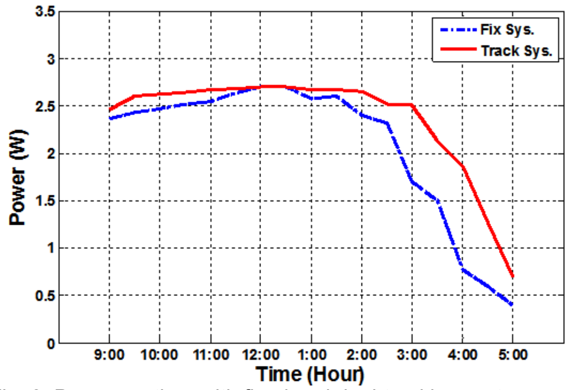


Fig. 8. Power vs. time with fixed and dual-tracking system

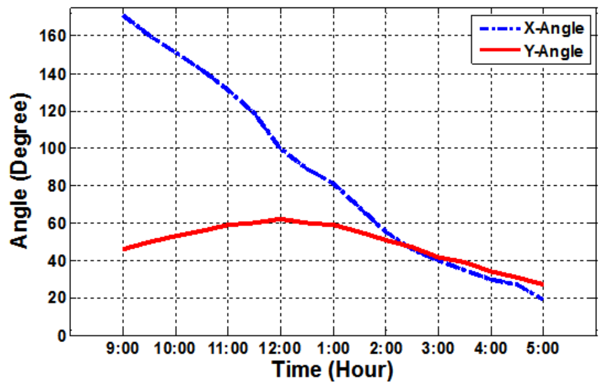
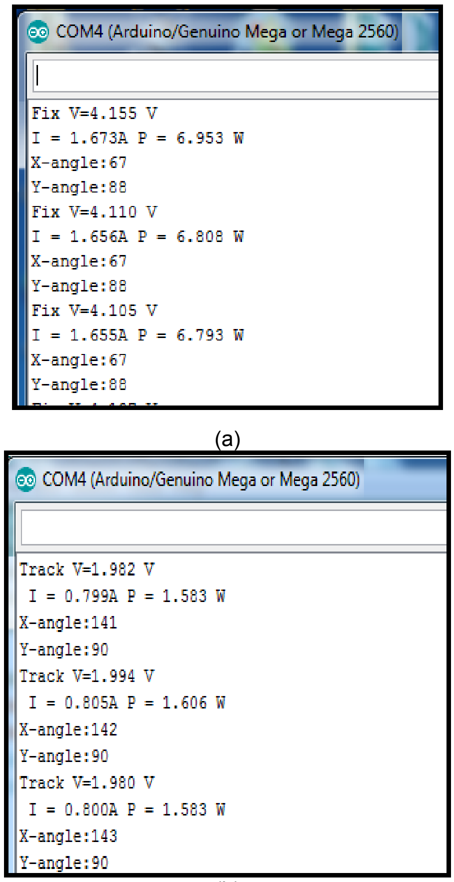


Fig. 9. Vertical and horizontal angles vs. time of SMs

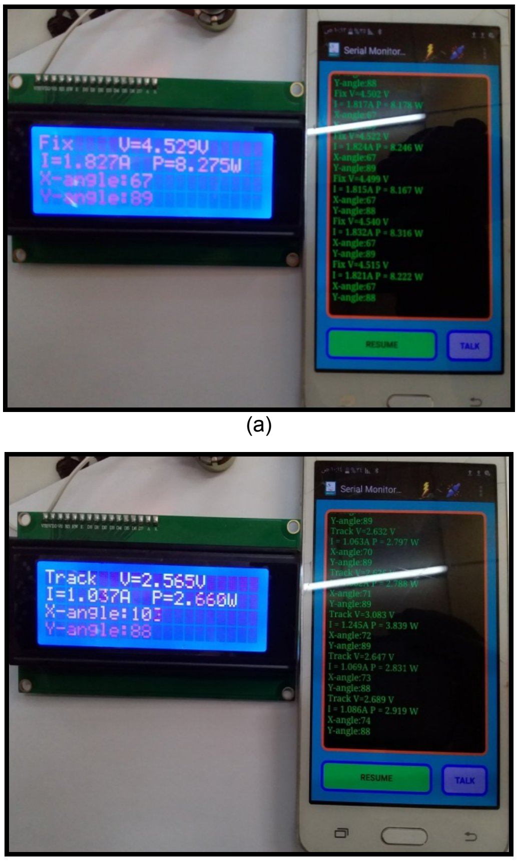
The solar panel moves on the X-axis from 9 am to 5 pm at a rate of approximately 10 degrees per half hour (from east to west). On the other hand, the solar panel moves on the Y-axis from 9 am to 12 noon (bottom to top) and then moves down from 12 noon to 5 pm (top to bottom) at a rate of approximately 4 degrees per half hour. Thus, the vertical axis (or Y-axis angle) curve is symmetric about midday time. While the horizontal axis curve (or X-axis angle curve) is negative symmetric about midday time. These curves enable us to detect the best panel angles of both x & y-axis at any time of the day (in respect to previous defined angle of selected time).

The data of the solar system (Tracking or Fixed system, voltage of PV panel, load current, power consumption, and angles of the motors (X-angle, and Y-angle)) are displayed on the Serial print in the PC via USB cable as shown in figure 10. Also these data are displayed directly on 4*20 LCD, Bluetooth module was used for sending these data to be displayed on the android app. as shown in figure 11; this property adds the flexibility for monitoring the system.



(b)

Fig. 10: Solar system data displayed on serial print

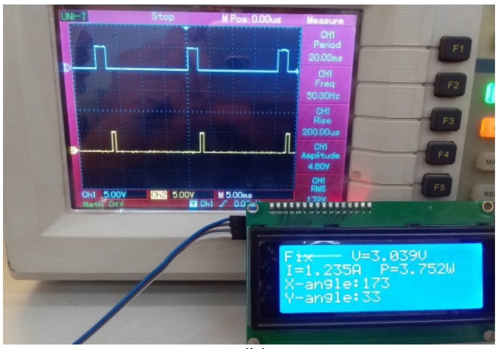


(b)

Fig. 11. Solar system data displayed on LCD, and on an android app. for: (a) Fixed system, and (b) Dual tracking system

Figure 12 shows the waveform of the PWM signals for both X-axis and Y-axis SMs; fig. 12-a shows the PWM of the x-axis SM at angle equal to 20°, and PWM of the y-axis SM at angle equal to 31°. While fig. 12-b shows the PWM of the x-axis and y-axis SMs at angles equal to 173° and 42° respectively.

(a)



(b)

Fig. 12. Waveform of the PWM signal for SMs

The ON time of the first signal for the X-axis SM is approximately equal to 1.1 msec when the angle equal to 20°, while its ON time equal to 1.96 msec when the X-axis angle 173°.

Conclusions:

The proposed STS based on Microcontroller Arduino has high degree of flexibility since it moves in two axis (dual), high response to the light of sun, it is very easy to program and modify, in addition to the simplicity and low cost of the system. The system provides easy monitoring of process data on the smartphone; as it is extremely difficult to collect data at different time intervals of the day under the sun's radiation. The proposed system consider more expensive compared with single-axis STS. While the efficiency of the proposed system was incensed 20% compared with the fixed solar panel. In north Iraq regains, where our solar system prototype was installed and tested, the obtained results of the angles curves are very important to predict the optimum angles for the fixed solar system at any time. The x and y-axis angle can be adjusted manually using two variable resistor (Rx, and Ry); although this method is consider an open loop method (without using sensors) but it offer a precision angles for the SMs. In future work, Battery charging system based on MPPT technique with DC-DC converter can be developed; especially the voltage and current of the system was measured (digitally processed) using Arduino.

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