Development of Maximum Power Point Tracker for PV Panels Using SEPIC Converter

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***Abstract* - "Photovoltaic Panel Maximum Power Point Tracker". As the name implied, it is a photovoltaic system that uses the photovoltaic array as a source of electrical power supply and since every photovoltaic (PV) array has an optimum operating point, called the maximum power point, which varies depending on cell temperature, the insolation level and array voltage. A maximum power point tracker (MPPT) is needed to operate the PV array at its maximum power point. The objective of this paper is to build MPPT to charge a 12-volts lead acid battery by using a (TBP 1275) 74 - watts PV panel. A technique for efficiency extracting the maximum output power from a solar panel under varying meteorological conditions is presented. The methodology is based on connecting a pulse width modulated dc/dc SEPIC converter, which is controlled by a micro controller based unit. The main difference between the method used in the proposed MPPT systems and other technique used in the past is that PV array output power is used to directly control the dc/dc converter thus reducing the complexity of the system. The resulting system has high efficiency, low cost and can be easily modified. This approach ensured maximum power transfer under all conditions by using micro controller for calculation. The tracking capability of the proposed technique has been verified experimentally with a 74 W solar panel at different insolation levels.**

Index Terms DC–DC Converter, PWM, maximum-power point tracking, photovoltaic.

I. INTRODUCTION

As we know that the natural resources, which has been using for power generation are dwindling fast and energy became very expensive. So the entire world is looking for another option to generate electrical energy. The best option is Photovoltaic energy to generate electrical power.

Solar panel is the fundamental energy conversion component of photovoltaic (PV) systems. Its conversion efficiency depends on many extrinsic factors, such as insolation levels, temperature, and load condition. There are three major approaches for maximizing power extraction in medium- and large-scale systems. They are sun tracking, maximum power point (MPP) tracking or both. MPP tracking is popular for the small-scale systems based on economical reasons.

The algorithms that are most commonly used are the perturbation and observation method, dynamic approach method and the incremental conductance algorithm.

Perturbation and Observation Method [2]

Perturbation and Observation (P&O) method has a simple feedback structure and fewer measured parameters. It operates by periodically perturbing (i.e. incrementing or decreasing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the perturbation leads to an increase (decrease) in array power, the subsequent perturbation is made in the same (opposite) direction. In this manner, the peak power tracker continuously seeks the peak power condition.

Dynamic Approach Method [9]

This method employs the ripple at the array output to maximize the array power by dynamically extrapolate the characteristic of the PV array. The instantaneous behavior of array voltage V, current I and power P can be grouped into three cases: current below that for the optimum power, current near the optimum and current above the optimum. The array performance is reflected in both shapes and phase relationships. The product of the derivative p and v is negative if the current is below that for optimum power and positive if the current is above the optimum and zero when the maximum power point is being tracked. Since p v is a chain rule derivative, it is actually equal to dp/dv. This implies that by driving dp/dv to zero, power will be effectively maximized.

Incremental Conductance Algorithm (ICT) [2]

This method uses the source incremental conductance method as its MPP search algorithm. It is more efficient than Perturb and Observe method and independent on device physics. The output voltage and current from the source are monitored upon which the MPPT controller relies to calculate the conductance and incremental conductance, and to make its decision (to increase or decrease duty ratio output).

Concluding the above discussions, one of the most desirable approaches of implementing a MPP tracker is to use the ICT without requiring more mathematical manipulations. Moreover, the realization should be of low-cost and high accuracy and control capability. In this paper, a technique for efficiently maximizing the output power of a solar panel supplying to a load or battery bus under varying meteorological conditions is presented. The power conversion stage, which is connected between a solar panel and a load or battery bus, is a pulse width-modulated (PWM) dc/dc SEPIC converter operating in continuous current mode (CCM). The

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tracking capability of the proposed technique has been verified experimentally with a 74 W solar panel at different insolation levels.
This paper is organized as follows: the **PV** module and SEPIC converter characteristics are analyzed in section **II** and **III**, respectively; the proposed system design and experimental results are given in section **IV**

II. PV MODULE CHARACTERISTICS

The equivalent circuit of a PV module is shown in fig 1, while typical output characteristics are shown in fig 2 and 3. The characteristic equation for this PV model is given below

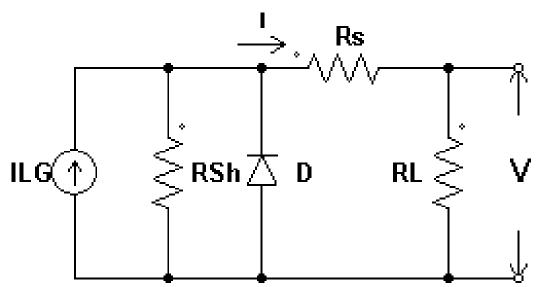

Fig 1. Equivalent circuit of a PV module

$$I = I_{LG} - I_{OS}\left\{\exp\left[\frac{q}{AkT}(V + IR_s)\right] - 1\right\}\frac{V + IR_s}{R_{sh}} \text{ --1}$$

where

$$I_{os} = I_{Or}\left[\frac{T}{Tr}\right]^3\left\{\exp\left[\frac{qE_{GO}}{Bk}\left(\frac{1}{Tr} - \frac{1}{T}\right)\right]\right\}$$

$$I_{LG} = [I_{SCR} + K_I(T - 25)]\lambda / 100 \text{ ----------------------2}$$

and

I and V	cell output current and voltage
I_{oz}	cell reverse saturation current
T	cell temperature in ^0C
k	Boltzman constant
q	electronic charge
K_I =0.0017	short circuit current temp coefficient at I_{SCR}
λ	Solar irradiation in W/m^2
I_{SCR}	short circuit current at 25 ^0C
I_{LG}	light generated current
E_{GO}	band gap for silicon
B=A= 1.92	ideality factors
T_r = 301.18 ^0K	reference temperature
I_{or}	cell saturation current at T_r
R_{sh}	shunt resistance
R_s	series resistance

The variation of the output I-V characteristics of a commercial PV module as function of temperature and irradiation is shown in fig 2. It is seen that the temperature changes affect mainly the PV output voltage, while the irradiation changes affect mainly the PV output current. The intersection of the load line with the PV module I-V characteristic, for a given temperature and irradiation, determines the operating point. The maximum power production is based on the load- line adjustment under varying atmospheric conditions

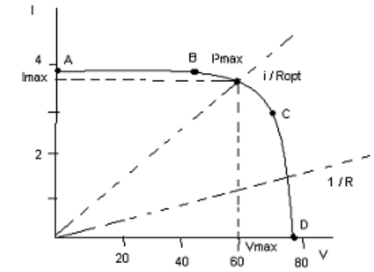

Fig 2. PV current - voltage characteristics

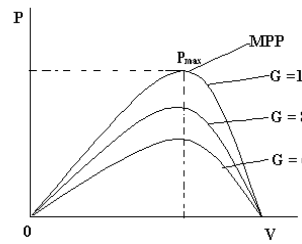

Fig 3. PV power - voltage characteristics at different irradiation

Incremental Conductance Algorithm

This method uses the source incremental conductance method as its MPP search algorithm. It is more efficient than Perturb and Observe method and independent on device physics. The output voltage and current from the source are monitored upon which the MPPT controller relies to calculate the conductance and incremental conductance, and to make its decision (to increase or decrease duty ratio output). Mathematical of the Incremental Conductance algorithm is discussed below.
The output power from the source can be expressed as
P = V*I--- (3)
The fact that P = V *I and the chain rule for the derivative of products yields
dP/dV = d (V I) / dV
= I dV / dV + V dI / dV
= I + V dI / dV
(1/V) dP/dV = (I/V) + dI/dV------------------- (4)
Let's define the source conductance:
G = I/V --- (5)
And the source incremental conductance:
ΔG = dI/dV -------------------------------------- (6)
In general output voltage from a source is positive. Equation (4) explains that the operating voltage is below the voltage at the maximum power point if the conductance is larger than the incremental conductance, and vice versa. The job of this algorithm is therefore to search the voltage operating point at which the conductance is equal to the incremental conductance. These ideas are expressed by equation (7), (8),
(9), and graphically shown in Figure4.
dP/dV > 0, if $G \tilde{>} G$ --------------------------(7)
dP/dV = 0, if $G \tilde{=} G$ --------------------------(8)
dP/dV > 0, if $G \tilde{>} G$ --------------------------(9)

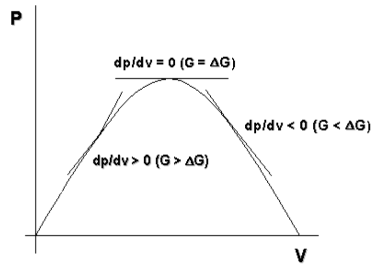

Fig.4. PV cell Power-voltage characteristics

III. SEPIC CONVERTER ANALYSIS [1]

SEPIC (Single ended Primary Inductor Converter): Much attention has been given to the S E P I C topology recently because output voltage may be either higher or lower than input voltage .The output is also not inverted as is the case in a fly back or Cuk topology. Voltage conversion is accomplished with isolation transformer, instead of using inductors to transfer energy. The input and output voltages are DC isolated by a coupling capacitor and the converter works with constant frequency PWM.

SEPIC principle of operation:

The fig 5 shows basic topology of SEPIC converter .The analysis of the converter is performed under the following assumptions

1.The components of the converter are ideal

2.The capacitances C1 and Co are large enough so that the voltages across them are constant. And the efficiency of the structure is considered equal to 100%.

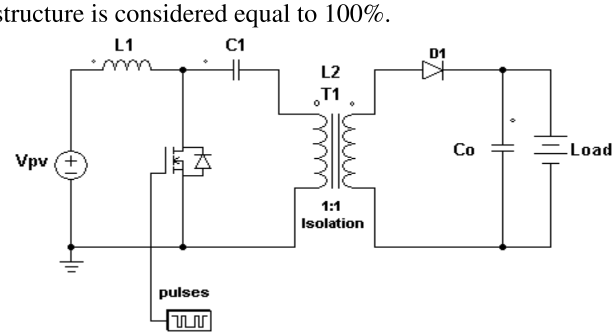

Fig 5. Proposed SEPIC Converter topology

The SEPIC converter can be operated in continuous conduction mode and discontinuous conduction mode. Working in continuous conduction mode (CCM) presents two operating modes.

Where

V_{in} = input voltage for converter

I_{l1} = current through inductor L1

I_{l2}= current through inductor L2

Vo= out put voltage

Mode 1:(0<t<DT) fig 6 shows at moment t=0, switch S is turned on. The energy from the source V_{in} is stored in the inductance L_1 and the capacitor C_1 transfer its energy to the $L_2(T_2)$. The capacitor C_1 voltage is considered constant and equal to V_{in} . The currents I_{l1} and I_{l2} increases linearly. During this stage diode D_1 is kept blocked and the capacitor C_o supplies energy to the load.

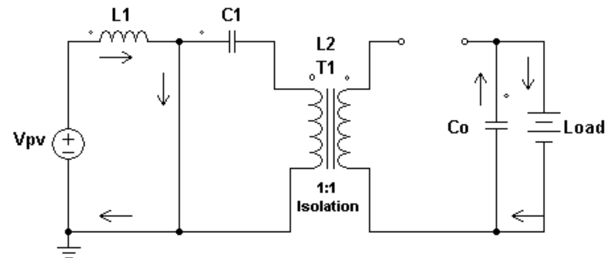

Fig 6. SEPIC Converter when Switch (MOSFET) is on

Mode2: (DT<t<T) fig 7 shows at moment t=DT, switch S is turned off and the diode D_1 is turned on, transferring the inductor storage energy to the load. The currents I_{l1} and I_{l2} decreases linearly. The voltage across switch the switch $(V_{in}+V_o)$.

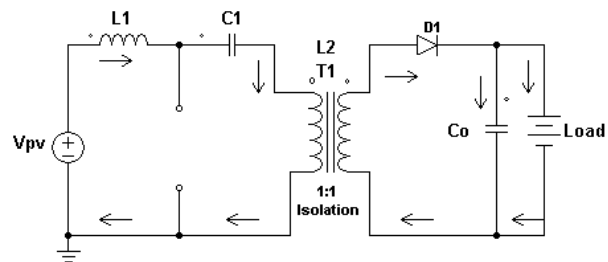

Fig. 7. SEPIC Converter when Switch (MOSFET) is off

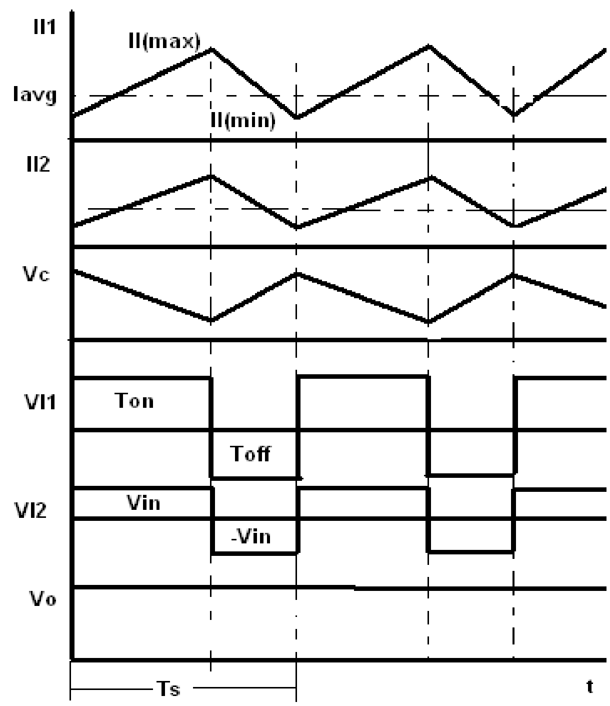

Fig 8. Wave forms of SEPIC in CCM

From mode 1 and mode 2 the average voltage across inductor in one cycle is zero

$V_{in}DT - V_o(1-D)T = 0$ ………..1

$V_{in}DT = V_o(1-D)T$ ……………..2

$$\frac{V_0}{V_{in}} = \frac{D}{(1-D)}$$ ……………………3

From (2) it is concluded that the SEPIC converter can operate as step –up / step - down converter.

$$I_{in} = \frac{V_{in} * DT}{\Delta I_{L1} * L_1 * 2}$$ ……………….4

from this we can find L1 value the current across C_1 is $I_{L2} = I_0$

$$ic = C_1 \frac{\Delta v}{DT}$$ ………………..…5

ic=io then
and

$$C2 = \frac{io * DT}{\Delta Vin}$$ ………………..…..6

IV EXPERIMENTAL SETUP AND RESULTS

To verify the proposed PV energy conversion system a prototype MPPT system has been developed using the above-described method and tested in the laboratory, the following parameters are selected for simulation and experiment

PV Array Specifications (at irradiation 1kw/m^2)

Open –circuit Voltage	21.6V
Short-circuit Current	4.75A
Maximum Power Current	4.4A
Maximum power	74W

Converter Specifications

Input Voltage	= 12V to 18V DC
Output Voltage	= 14V DC
Out put Current	=5A
Out Put power	=74W
Switching Frequency	=50Khz

For above specifications the inductor and capacitor values are calculated by using the formulae and are

L1 = 500e-6 H
L2 = 500e-6 H
C1 = 1500e-6 F
Co = 2200e-6 F
Switching frequency = 50 KHz

L2 is Isolation Transformer with 1:1 turns ratio with 500e-6 H and it wound with ferrite core to decrease losses and to avoid saturation. Toroidal core is taken for L1.

Experimental Setup of MPPT

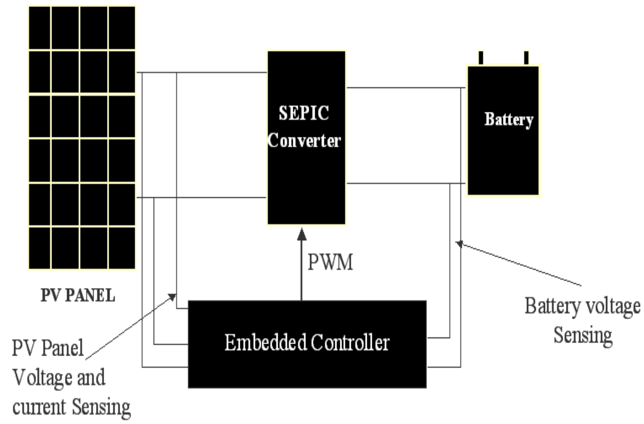

Fig.9.Block diagram of proposed MPP Tracker

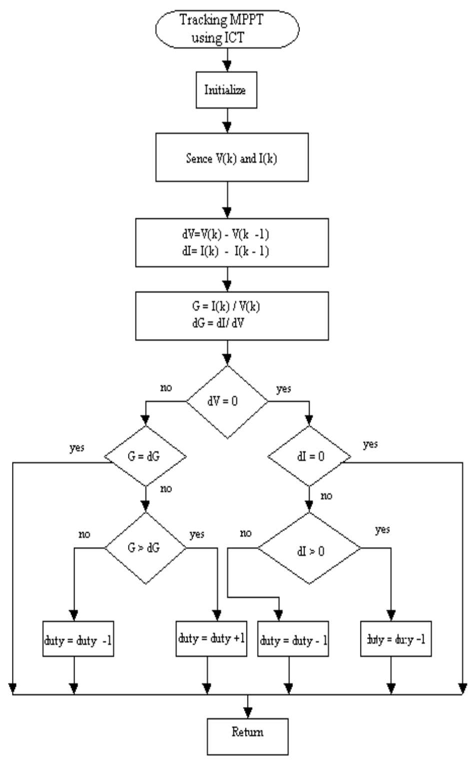

Fig.10.Program flowchart

The Incremental Conductance method is chosen as a tracking algorithm for the MPPT.
The program flow chart is shown in Figure.10. The program starts by initializing the A/D module and the D/A (PWM) module and sets the duty ratio at 50%, since it is likely that the MPP can be found. The PWM module is turned off at this stage and the program runs A/D conversion to measure the battery voltage. The measured voltage is then compared to the predefined values to determine the state of charge of the battery. If the battery voltage is greater than the 13.8V the

program goes to sleep for 1 second and then goes back to measure the battery voltage again. If the battery voltage is less than 13.8V the program goes to the high current charging mode. In this mode, the Incremental Conductance algorithm is employed.

First, the program is running the Incremental conductance algorithm on the PV array. The program flow chart for this algorithm is shown in Figure. The operating output current (I(k)) and voltage (V(k)) are measured by using A/D .The incremental changes dV and dI are approximated by comparing the most recent measured values for (V(k)) and (I(k)) with those measured in the previous cycle (V(k - 1)) and (I(k - 1)). Then G and ΔG are computed. From section II equation (8), if dP/dV = 0 (i.e G = ΔG) is true, then the system operates at the MPP and no change in operating voltage is necessary, thus the adjustment step is bypassed (no adjustment for the duty ratio) and the current cycle ends. The program then runs the Incremental Conductance algorithm on S2. If equation (8) is false, equation (7) and (9) are used to determine whether the system is operating at a voltage greater or less than the MPP and hence to increase or decrease the duty ratio by 1 accordingly.

If the system was operating at the MPP during the previous cycle, the incremental change of the operating voltage will be zero (dV = 0). This would lead to a division by zero i..e G = dI ÷ dV = dI ÷ 0, this is impossible for calculation. To avoid this, the condition (dV = 0) is checked first and leads to another branch if true in the algorithm with further tests on possible changes of the panel's operating conditions. Since the voltage (dV = 0) that means it has not changed, now the only useful information about possible changes can be found from the current measurement. If dI is equal to zero, the operating conditions have not changed and therefore the adjustment of the system voltage is bypassed.

If dI > 0, the duty ratio is increased by 1. If dI < 0, the duty ratio is decreased by 1. The program then returns and starts tracking again until the MPP is reached. The tracking process duration is 1 minute. After 1 minute the program goes back to measure the battery voltage again to determine the state of charge of the battery. The tracking process using Incremental Conductance algorithm is then repeated.

Testing

A control experiment has been performed using a solar panel of TBP1275. The setup is shown in fig 9 and the component values of the SEPIC converter are shown. The 12V VRLA battery is taken as load and the switching frequency are set at 50khz and duty cycle is initialized at 50%. The output of the SEPIC converter was observed at different insolation levl and it was observed that the PWM of micro controller was varying with input changes. Detailed experimental waveforms of the gate signal, the converter output and converter terminal voltage are shown in figure 11.1, 11.2, 11.3, 11.4,.

Thus the proposed MPP tracker is better than the buck-boost/Cuk by giving positive output voltage and the results are all in close agreement with the theoretical ones.

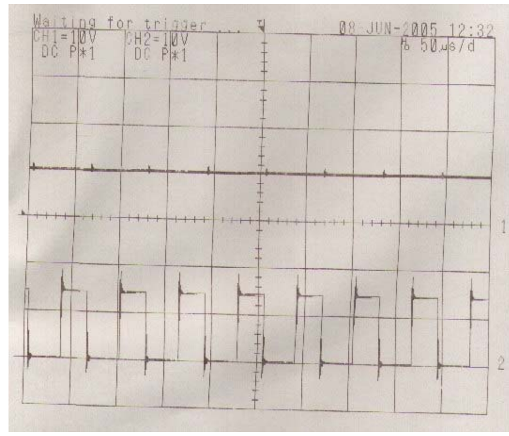

Fig.11.1At Duty cycle is 50 %. 10VCh1. Output voltage Ch2. Gate Pulses

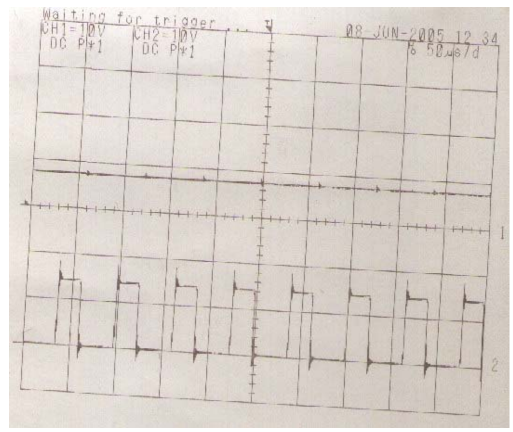

Fig.11.2. At Duty cycle is 40 %

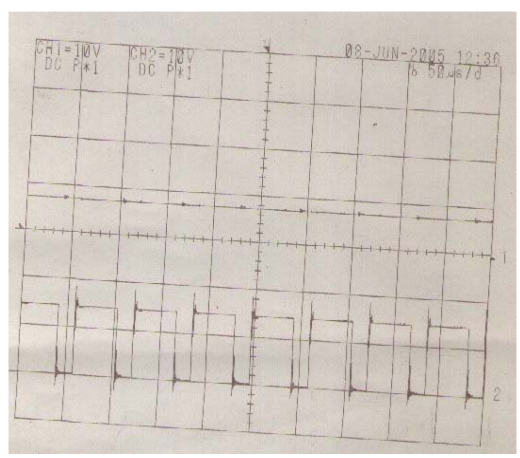

Fig.11.3.At Duty cycle is 60 %

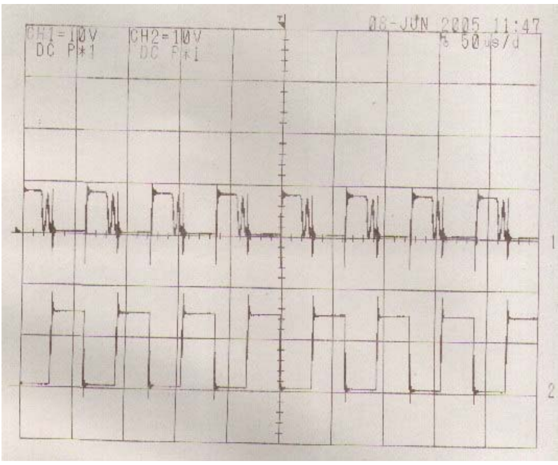

Fig.11.4. Inductor Voltage with respect to Gate pulses

From the above observations the MPP Tracker is able track maximum power from solar panels irrespective of load and atmospheric conditions.

V. Conclusion

When the PV array is used as a source of power supply to charge a 12V lead acid battery, it is necessary to use the MPPT to get the maximum power point from the PV array. The MPPT is implemented by using a SEPIC-Converter, which is designed to operate under continuous conduction mode and a micro controller to control the PWM signals to the SEPIC-Converter and also to monitoring the state of charge of the battery. The Incremental Conduction Algorithm is used as the control algorithm for the MPPT. Experimental results have shown that the MMPT has the conversion efficiency of 91.32% and tracking accuracy of 97.6%.

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