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A Novel MPPT Method for a standalone PV System

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ABSTRACT

Maximizing the efficiency of Photovoltaic (PV) systems to convert sunlight into electricity is crucial for enhancing the performance of standalone solar power installations, especially in remote areas where grid connection is not feasible. This paper introduces a novel Maximum Power Point Tracking (MPPT) method designed to optimize the energy harvest from standalone PV systems regardless of environmental conditions. The proposed method employs an advanced algorithm that dynamically adjusts the operating point of the PV system to ensure it operates at its maximum power point, even under rapidly changing weather conditions. The MPPT algorithm's effectiveness and efficiency are validated through simulations conducted in the MATLAB/Simulink environment, highlighting its superiority over traditional MPPT techniques in terms of convergence speed and power output stability. This novel MPPT method promises to significantly improve the autonomy and reliability of standalone PV systems, making solar energy a more viable option for powering remote and off-grid applications.

KEYWORDS: Photovoltaic System, Maximum Power Point Tracking, Standalone PV System, MATLAB/Simulink, Renewable Energy, Solar Power Optimization.

1. INTRODUCTION

The proposed strategy is to push the framework to execute remarkable systems to expand the productivity of the solar power generation tracking system has been designed. PV framework can't appear as a steady DC source since its output control is moved relying on nature, temperature, and light intensity. Maximum Power Point Tracking is utilized to track the most exceptional power in the photovoltaic structure. The feasibility of solar energy relies on control frameworks and the MPPT circuit. The MPPT control incremental conductance procedure is connected to the DC-DC converter, which is utilized as the MPPT circuit. In this proposed work unveils a possible approach managed out how to enhance the capacity of solar power generation in various structures by the use of reflected mirrors, auto-tidy cleaning and customized cooling framework and this structure is produced utilizing locally available raw materials to influence it to financially efficient one. Incremental conductance structure is utilized to track the MPP under low irradiance.

2. MAXIMUM POWER POINT TRACKING METHODS:

Maximum Power Point Tracking (MPPT) is a technique used to achieve maximum power from photovoltaic devices. MPPT works based on various algorithms. The ability of this algorithm to detect the maximum power output is the most important factor to be considered in choosing proper MPPT technique Esram *et al.* (2007). At different points on the solar panels irradiance levels may vary. Due to this variation in one system, there may be multiple local maximum power points. There are several publications that deals with MPPT, but each technique has its own limitations.

It is always desirable to extract maximum possible power from the Solar Panel. An MPPT controller enables extraction of maximum power from the PV array even at varying load and weather conditions. The MPPT controller is a semiconductor device which is connected between the PV array and the battery or inverter. Its working is based on an algorithm developed to extract maximum power. This controller consists of two important devices (PV System & DC-DC converter). A regulated DC-DC buck-boost converter uses the MPPT technique to extract the maximum power from the PV array thereby required power is supplied to the load as shown in Figure 3.6.

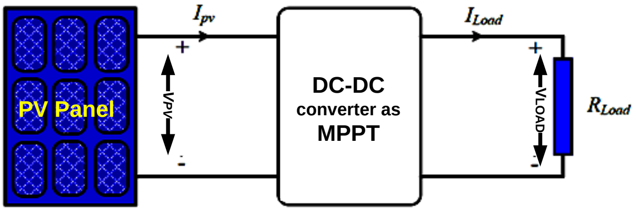

Figure Regulated DC-DC converter as MPPT Controller

Multiple algorithms exist to find the optimal operating point. Algorithms can be classified into two general categories:

1. Indirect Control (Quasi Seeking): These methods rely on a database of the solar-PV unit's parameters. The extensiveness of the database varies and can include items such as the unit's power-voltage (P-V) curve or empirical data. Thus a drawback to these techniques is longer time to program and update the database as the unit ages.

2. Direct Control (True Seeking): These methods share the commonality of relying solely on voltage and current measurements and therefore require minimal time as specific unit parameters are not required.

2. 1 Incremental Conductance (IC) Method (Direct Control):

The IC method seeks to reach the peak of the P-V curve by satisfying

$$\frac{dP}{dV} = \frac{d(V*I)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = 0 \qquad (3.7)$$

where P, V , and I are the measured DC power, voltage, and current, respectively. Multiplying (3.7) by1/V yields:

$$\frac{1}{V}\frac{dP}{dV} = \frac{I}{V} + \frac{dI}{dV} = G + dG \qquad (3.8)$$

where *G* is conductance and *dG* is incremental conductance.

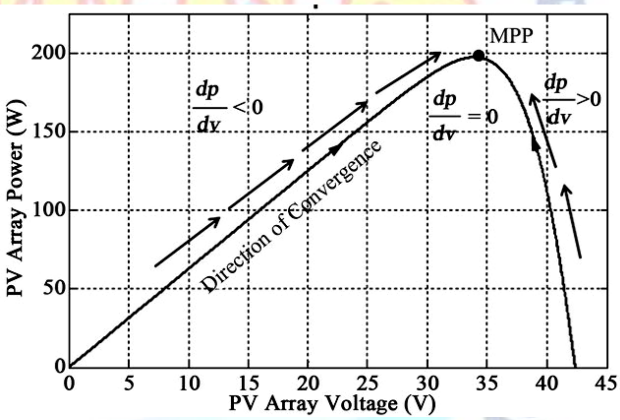

Figure 3.9: P-V Curve for Explanation of Incremental Conductance Method

Equation (3.8) establishes if the current operating point is above or below V_{MPP} and the resulting voltage reference is determined from this. For example, if $dP/dV > 0$, then $G + dG > 0$ and the current operating point is on the left-hand-side of maximum power point (MPP). Alternatively, if $dP/dV < 0$, then $G + dG < 0$ and the current operating point is on the right-hand-side of MPP as shown in Figure 3.9.

3. PROPOSED MODIFIED INCREMENTAL CONDUCTANCE MPPT

To extract the maximum power from solar PV systems MPPT technique is used. Between PV module and load a DC-DC converter is connected and duty cycle of the DC-DC converter always regulated to operate the PV system at maximum power point (MPP). Figure 3.10 shows the conventional INC method algorithm, which operates with high efficiency under steady irradiance. In this method the slope of the P-V curve is used to vary the duty cycle of converter to get the voltage corresponding to maximum power point, V_{mpp}.

MPP is reached when $\frac{dP}{dV} = 0$

$$\frac{dI}{dV} = -\frac{I}{V} \qquad (3.9)$$

$$\frac{dP}{dV} > 0\text{, then } V_{pv} < V_{mpp} \qquad (3.10)$$

$$\frac{dP}{dV} = 0\text{, then } V_{pv} = V_{mpp} \qquad (3.11)$$

$$\frac{dP}{dV} < 0\text{, then } V_{pv} > V_{mpp} \qquad (3.12)$$

To determine the V_{mpp}, knowledge of the relation between *dI*/*dV* and –*I*/*V*. If the slope $\frac{dP}{dV}$ is negative, then MPP must be moved to the left by decreasing the module voltage. If the slope is positive, the operating point must be moved to the right by increasing the module voltage. This process is repeated till slope is zero. Finally, when the slope is null, the operating point is at the MPP and the algorithm stops the voltage adjustment.

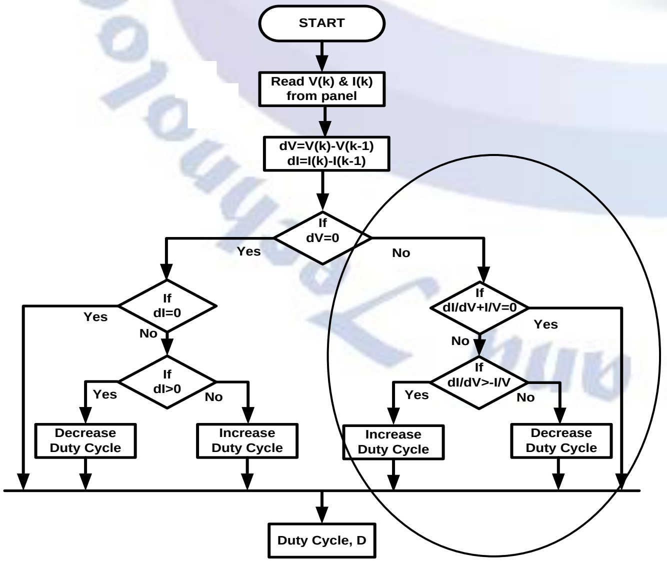

Figure 3.10: Incremental Conductance MPPT Algorithm

For varying irradiance the response of fixed step size is slow. So, variable step size is proposed which decreases the step size and convergence of MPP is slow when it reaches to near the peak of P-V curve. A modified INC algorithm is proposed to increase the converging speed with fast varying irradiance. Proposed block diagram is shown in Fig3.11.

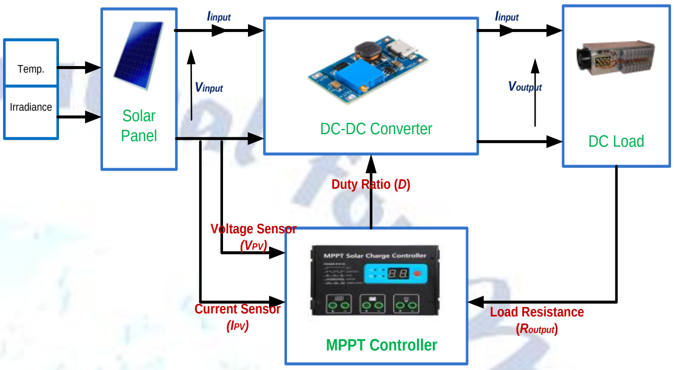

Figure 3.11: Block diagram of proposed DC/DC converter with modified INC Algorithm

Fig3.12 shows the *I-V* curve of the PV module under different levels of solar irradianceand also the MPPs which can be connected approximately by a straight line (MPP line). A load line is generated and it can be imposed on the *I–V* curve when the PV module supplies power to the load. The power generated by the PV module is the product of the voltage and current of PV module at the intersection point between the load line and the *I–V* curve. Therefore, the output power of PV module varies according to the solar irradiation (*I–V* curve) and the resistance of the load (load line).

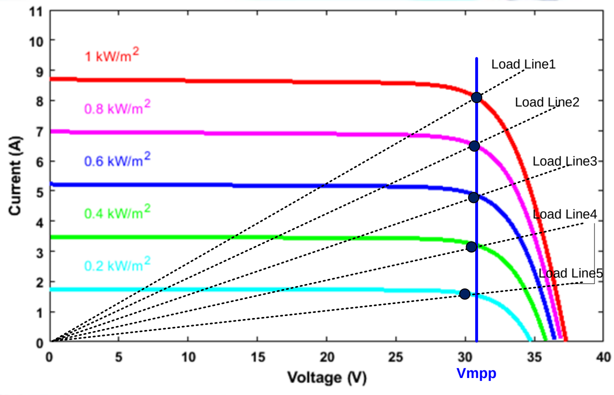

Figure 3.12: I-V Curves at different irradiances with load line and MPP line.

The relation between the input output voltage and currents for a DC-DC converter is represented by

$$V_{input} = \frac{1-D}{D} V_{output} \qquad (3.13)$$

$$I_{input} = \frac{D}{1-D} I_{output} \qquad (3.14)$$

Divide eq.(3.13) with eq.(3.14) we get

$$R_{input} = \frac{(1-D)^2}{D^2} R_{output} \qquad (3.15)$$

where D is the duty cycle or duty ratio, V_{input} is the input voltage of the converter or the voltage of the PV module V_{pv}, I_{input} is the input current of the converter or the current of the PV module I_{pv}, R_{input} is the input resistance of the converter or the resistance seen by the PV module, and R_{output} is the output resistance of the converter or load resistance R_{load}.

From eq.(3.15) it is noticed that duty cycle can be regulated to force the input resistance of the converter to be varied until the load line cuts the *I-V* curve at MPP.

Equation (3.15) can be written as

$$\frac{D^2}{(1-D)^2} = \frac{R_{output}}{R_{input}} \qquad (3.16)$$

Load resistance can be calculated at any operating MPP by substituting the duty cycle, PV voltage and PV current in (3.16)

$$D = \frac{\sqrt{\dfrac{I_{input}}{V_{input}} R_{load}}}{1 + \sqrt{\dfrac{I_{input}}{V_{input}} R_{load}}} \qquad (3.17)$$

In incremental conductance method the slope of power vs voltage ($\frac{dP}{dV}$) of solar panel is zero at the MPP. Getting zero slope in practical systems requires several iterations. It is reasonably accurate to allow an acceptable error while finding the MPP. An attempt has been made in this thesis to modify this condition of zero slope to find MPP, with a small permitted error. In proposed method, permitted error of 0.06 as shown in eq.(3.18) is used to eliminate the steady-state oscillation in the system after the MPP is reached. The permitted error is chosen to be more than MPPT step size of 0.05.

$$\frac{dI}{dV} + \frac{I}{V} < 0.06 \qquad (3.18)$$

Fig 3.13 shows the flow chart for the proposed algorithm

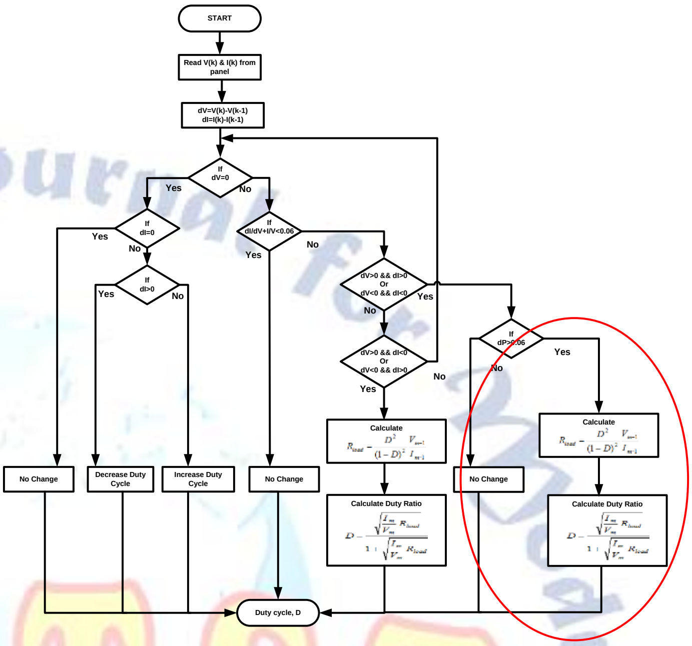

Figure 3.13: Proposed modified INC MPPT method under fast varying irradiance

3.1 Working Procedure for decrease in Solar Irradiance Level

Figure 3.14 shoes the load lines on the *I-V* curves for solar irradiance level at 0.4 and 1.0 kW/m². When the PV module is operating at 1000 W/m², the MPP operates at the point A (V_{MPP1}, I_{MPP1})of the load line 1 as shown in Fig 3.14. Then, if the solar irradiance is decreased from 1000W/m² to 400 W/m², then the MPP immediately comes to point B (V_B, I_B) along the load line 1, which is far away from the MPP of 400 W/m², point C, because the duty cycle of the DC-DC converter remains unaltered. In order to track the new V_{MPP} and I_{MPP} of the PV module equation (3.17) is used. But these two values are unknown and their approximated values are submitted in (3.17) to track the new MPP. As shown in Fig 3.14, the current at point B, I_B is very close to the short circuit current of 400 W/m² and the I_{MPP} is approximately equals to 0.8 times of the short circuit current (0.8*I_{SC}). Then 0.8*I_{SC} is approximated as new I_{MPP}. The V_{MPP} at all the solar irradiance levels is almost equal hence the previous V_{MPP} is approximated as a new V_{MPP}. So, substituting I_{MPP}

$\approx I_B$ and $I_B = I_{PV}$, $V_B = V_{MPP} = V_{PV}$ in (3.17) to track the new MPP to the load line 2, point C which is very near to new MPP.

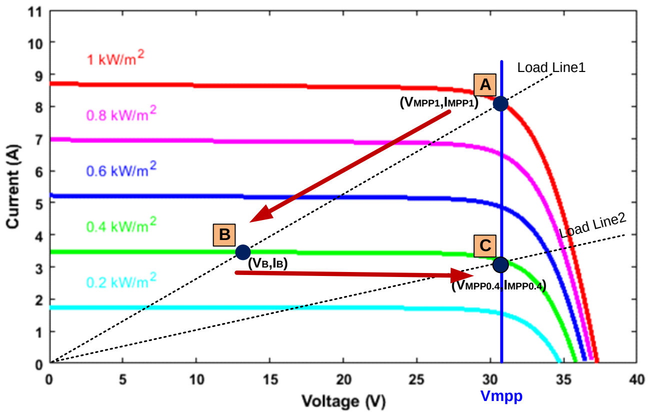

Figure 3.14:MPP on *I* –*V* curves for decrease of solar irradiation level from 1.0 to 0.4 kW/m²

4. SIMULATION RESULTS

In present work STH-250WH panel is considered and, as shown in Table 3.1, the specifications of photovoltaic panels offer only a few parameters. Consequently, several mandatory parameters for the modeling of the photovoltaic panel are omitted in the manufacturer's specifications, namely the diode saturation current, the current generated by the light, the ideality factor of the diode and the series and shunt resistors.

Table 3.1. Specifications of Soltech 1STH-250 WH PV panel at Standard Testing Conditions (STC) of 1000 W/m² and 25⁰ C

Characteristics	Value
Maximum Power	250 W
Voltage at Pmax, Vmp	30.7 V
Current at Pmax, Imp	8.15 A
Short-circuit current, Isc	8.66 A
Open-circuit voltage, Vco	37.3 V
Temperature coefficient of open-circuit voltage Voc, kV	-369.0 mV/⁰C
Temperature coefficient of short-circuit current Isc, Ki	86.9 mA/⁰C
The number of cells	60

Simulation for conventional incremental conductance algorithm and proposed algorithm are carried out for constant, variable irradiance and the results are compared. Sampling time for the MPPT controller is 0.05s. Simulation is carried out for 1 sec for constant irradiance and time is 4 sec for solar irradiation level which varies from low (0.4kW/m²) to high (1.0kW/m²) and then reduced to low again in order to investigate the performance of the system under fast-varying solar irradiation level.

4.1 Simulation results with variable solar irradiance

In this test condition solar irradiance is varied from 500W/m² to 1000W/m² at time period of 1 sec and then it is decreased from 1000W/m² to 800W/m² at 2 sec time period. Again it is decreased from 800W/m² to 600W/m² at 3 sec time period.

4.1.1 with INC MPPT Method

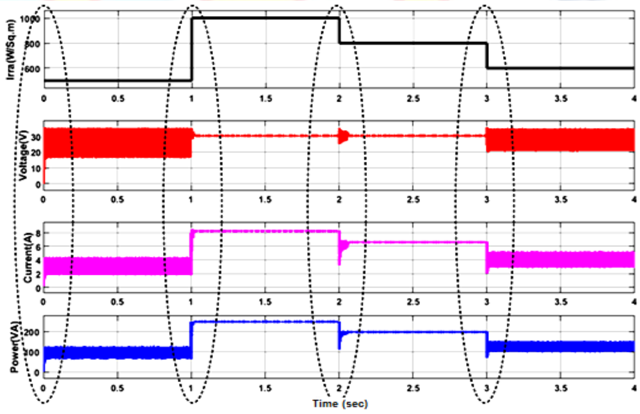

Figure3.20: INC MPPT System Simulation Results with variable irradiance of 1000 W/m²; (i) Irradiance; (ii) PV Voltage; (iii) PV Current; (iv) PV Power

From simulation analyses for INC method, it fails to track MPP for sudden variation at different irradiance level at low intensity and tracks better MPP at high intensity. Steady state analysis and dynamic performance is shown in Table 3.3. System reaches steady state condition in 20 ms at maximum irradiance and dynamic performance is also good.

Table 3.3 Voltage and Current Values at different irradiance conditions with INC Method

Time Period(in sec)	Irradiance (in W/m²)	V (volts)	I (amps)	Reaches to Steady state(in sec)	Dynamic Performance
0 – 1	500	17-34 V	2-4 A	Never Reaches	Good
1 – 2	1000	30.7 V	8.15 A	0.02	Good
2 – 3	800	32 V	6-7 A	0.05	Good
3 – 4	600	20-32 V	3-5 A	Never Reaches	Good

4.1.2 with Proposed MPPT Method

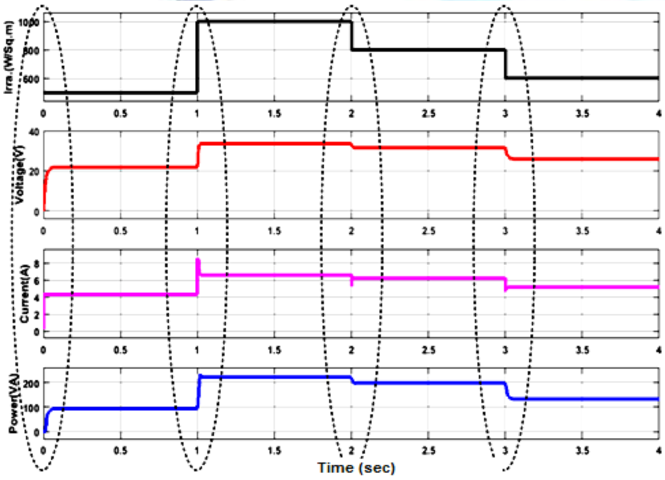

Figure3.21: Proposed MPPT System Simulation Results with variable irradiance of 1000 W/m²; (i) Irradiance; (ii) PV Voltage; (iii) PV Current; (iv) PV Power

In proposed MPPT controller initially duty cycle is generated according to the characteristics of the I-V curve and DC-DC converter and regulates the duty cycle by using a small step size. This small step size can improves the efficiency by ensuring that the operating point is on the MPP.

Voltage, current values and performance of PV system with proposed MPPT is shown in Table 3.4. From the simulation result analysis it is observed proposed MPPT tracks MPP with in milliseconds at low and high intensity. The system will also reaches to steady state with on 30 ms and dynamic performance of the system is very good.

Table 3.4 Voltage and Current Values at different irradiance conditions with proposed Method

Time Period(in sec)	Irradiance (in W/m²)	V (volts)	I (amps)	Reaches to Steady state(in sec)	Dynamic Performance
0 – 1	500	24 V	4 A	0.0055	Very Good
1 – 2	1000	30.7 V	8 A	0.03	Very Good
2 – 3	800	32 V	6 A	0.03	Very Good
3 – 4	600	33 V	5A	0.03	Very Good

Table3.5. Comparison of proposed MPPT with other techniques for variation in solar irradiance

Parameter	P&O Method	INC method	Proposed Method
Efficiency (%)	83.47	91.51	94.25
Tracking Power Loss (%)	24.60	17.05	5.76
Tracking Time (s)	1.42	1.16	0.28
Steady State Oscillations	Large	Small	Negligible

It is found that, under the variation of solar irradiance, the tracking speed of proposed technique is 5.6 times and 3.8 times faster than the P&O and INC methods. The power loss during the tracking is also less when compared with other techniques. The steady state oscillations of P&O, INC methods are large due to the oscillations in the duty cycle, where as it is negligible for proposed method.

5 CONCLUSION

In the proposed work a novel and fast acting MPPT for fast varying solar irradiance is implemented. Since the proposed MPPT is not an iterative method, directly it tracks the MPP when there is a sudden change in irradiance or in load. Simulation of proposed MPPT method is implemented for various irradiance levels and compared with P&O, INC algorithms. In the conventional method by trial and error the peak power point is reached. Time taken to track MPP is more. So the power loss in those methods will be more. These methods continuously track the voltage and/or current, without using empirical data. The main advantage of such methods is that they do not require prior knowledge of the PV array characteristics. The drawbacks of the conventional algorithms are slow tracking speed, and steady-state oscillation at the transient stages. To overcome this draw back a novel and fast acting modified INC algorithm is proposed to increase the converging speed under fast varying irradiance. In incremental conductance method the slope of power vs voltage characteristic ($\frac{dP}{dV} = 0$) of solar panel is zero at the MPP. But it can never be met practically; so, a permitted error of 0.06 is acceptable to detect MPP. The proposed method directly calculates the required duty cycle to obtain the new MPP by considering the load line. This reduces the normal iterative process and reaches the required MPP point in a fast way. The results show that the overall tracking speed of the proposed MPPT is 5.6 times, 3.8 times faster than P&O method and INC method respectively. During the variation of irradiance the power loss is reduced by 18.84% and 11.29% in comparison with P&O and INC method. The proposed method also minimizes the steady state oscillations.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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