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Mathematical models for resolving the nonlinear formula for solar cell

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ABSTRACT

Accurate representation of a photovoltaic solar cell requires a comprehensive assessment of modeling factors that are unique to the individual device being studied. In the context of the single diode model, it is necessary to ascertain five distinct parameters, namely Rs, Rsh, Iph, Io, and n. In general, analytical or numerical methods may be used to calculate these values. In this paper, two alternative iterative approaches to solving nonlinear problems in solar cells without temperature are described and analyzed. The new iterative approach has several instances that have been quantitatively tested. This novel approach can be seen as a potential option for solving nonlinear equations. Additionally, a comparison between the suggested method, classic chord formula (CCM), and predictor-corrector type reveals that it is better and has the lowest evaluation. This is supported by an examination of accuracy and efficiency (as evaluated by function evaluations) false position method (FPM).

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1. INTRODUCTION

Many iterative methods have been employed to solve nonlinear equations, and many researchers have utilized and improved them. Newton's method is widely used in the fields of chemistry as a standard method for solving nonlinear equations, engineering, and physics. Many researchers [1]-[10] suggested many experiments and iterative methods are used to solve a solar cell's nonlinear equation depending on Kirchhoff's current law for the equivalent circuit of a photovoltaic (PV) cell. Several iterative methods for the first order derivative of a function have been suggested and explained. Several researchers utilized the umerical techniques for solving solar cell parameters problems, such as: the single-diode model used by Yin and Babu [11] to study the solar cell parameters were compared in terms of the number of unknown parameters, accuracy, and calculation time to support the advantages and disadvantages of each model. In accordance with the requirements of the optimization, Louzazni *et al*. [12] presented the solar cell parameters for a single diode circuit based on the larange multiplier approach. To demonstrate the effectiveness of the suggested optimization strategy, computer simulations are used to show a realistic numerical example for several technologies. According to Wang *et al*. [13], given an unknown set of circuit model parameters, a PV cell's behavior may be inferred from its current-voltage characteristics.

Since nonlinear, multivariable, and multimodal aspects have been examined, it is important to precisely and effectively extract the parameters of the PV model. Among them, Kalliojärvi-Viljakaine *et al.* [14] potential monitoring techniques for PV systems include the single-diode model and measured current-voltage curves from PV modules. Module aging and deterioration may be shown by changes in model parameters. However, each parameter's values are affected by the operating temperature and irradiance, thus those values must also be noted. Xu and Qiu [9] have conducted research on the effective estimation of the unidentified model parameters for both the single diode model and the double diode model of solar cells and PV modules [15] suggest a modified stochastic fractal search technique. According to Calasan *et al*. [16], the current-voltage characteristics of the double diode and triple diode models of solar cells exhibit significant nonlinearity, rendering them devoid of any analytical solution. Hence, irrespective of the selected methodology (such as metaheuristic and hybrid), it is necessary to use an iterative approach in order to calculate the present value in relation to voltage. This is essential for accurately determining the parameters of these models. Depending on load resistance (R) ranges between 1 and 5, the study introduces two numerical iterative algorithms, double false position method (DFPM) and classic chord method (CCM) procedures. The alternative approach DFPM requires seven function evaluations every iteration, while the proposed technique only needs five. The process for the present work is shown by the stages: sections two address the mathematical technique and zeros cause analysis for the DFPM and CCM strategies whereas; the mathematical experiments, the discussion, and the conclusion are included in sections three and four.

2. METHOD

2.1. Photovoltaic module

Kirchhoff's process is applicable to the photovoltaic cell-single-diode electrical arrangement [17]–[29]:

$$I = I_{ph} - I_D$$

where: $I = I_{ph} - I_0\left(e^{-V_{pv}/mV_T} - 1\right)$, $I_D = I_0\left(e^{-V_{pv}/nV_T} - 1\right)$, and $V_T = {KT}/{q} = 27.5$ mV, $k = 1.38 \times 10^{-23} J/K$= the Boltzmann constant, I_0 =diode's reverse saturation current=10^{-12}A, I_{ph} =generated current, m=1 to 2 imply the factor involved in recombination., T =the junction's temperature, $q = 1.6 \times 10^{-19}$ C.

$$I_{ph} = I_{source}\ ,\ I_D = I_s * \left(e^{\frac{V_D}{nV_T}} - 1\right) \tag{1}$$

$$I_{pv} = \frac{V_{pv}}{R};\ P_{pv} = I_{pv} \times V_{pv} \tag{2}$$

where: I_{pv}, V_{pv}, P_{pv} = the cell's current, voltage, and power, respectively. Put the appropriate value for I, and obtain:

$$(I_{source}) - 10^{-12}\left(e^{-V/1.2*0.026} - 1\right) = V\ /\ R \tag{3}$$

2.2. Classic chord method

To compare the various numerical iteration algorithms, methods 1 FPM and 2 classic chord algorithm were utilized CCM. The following steps have been presented the CCM, by combining the Newton's technique [25]–[28]. The following equation $x = g(v) \equiv v - b(v).f(v)$ defining the iterative procedure based on the function $b(v)$.

$b(v) = m = \text{constant} \neq 0$. Chord algorithm defines the chord algorithm for which the iteration is:

- Let v_0,
- Calculate v_{n+1} which is the approximate solution.

$$v_{n+1} = v_n - mf(v_n) \tag{4}$$

- $0 < m\acute{f}(v_n) < 2$; the chord method 1st order algorithm), calculate m at each iteration leads to the order of convergence.

$$v_{n+1} = v_n - m_n f(v_n) \tag{5}$$

- The inverse of the slope for the straight line named (m_n) which is defined by (6):

$$v_{n+1} = v_n - \frac{v_n - v_{n-1}}{f(v_n) - f(v_{n-1})} f(v_n) \tag{6}$$

- CCM model focus if $f'(a) \neq 0$ and in the neighbourhood of a, $f'(v)$ is continuous. The tolerance $\varepsilon = 10^{-9}$ and for the purpose of estimating the rootss, the following criteria are used

$$\sigma = |v_{n+1} - v_n| < \varepsilon, \tag{7}$$

2.3. Regula Falsi method (FPM or DRFM)

For the purpose of solving nonlinear equations of the form $y = f(v_n) = 0$, Regula Falsi technique can be used [29]–[33]. For problems that are more difficult DFPM can be used, such that $f(v) = av + b$, if $f(v_1) = b_1, f(v_2) = b_2$. It is mathematically equivalent to linear interpolation. Using a pair of test inputs v_0, v_1, as shown in:

$$v = \frac{b_1 v_2 - b_2 v_1}{(b_1 - b_2)} \tag{8}$$

thus, $f(v) = av + c$ (linear function)

3. RESULTS AND DISCUSSION

In this study, a nonlinear equation solver (5) is utilized to compare the CCM with DFPM method with a guess value of $v_0 = 1$ (6). Every calculation is completed with the level of accuracy given by the quantity of function evaluations and calculations in the Figure 1 and Table 1, the R value in the numerical test, which represent the circuit's load resistance Figure equal to 1. Regarding the numerical examples and answers generated by these two approaches for solving (3), five different experiments are conducted. The DFPM approach only requires five iterations, but the CCM method requires seven, as seen in the Tables and Figures. This demonstrates how much quicker the DFPM approach is than the CCM method.

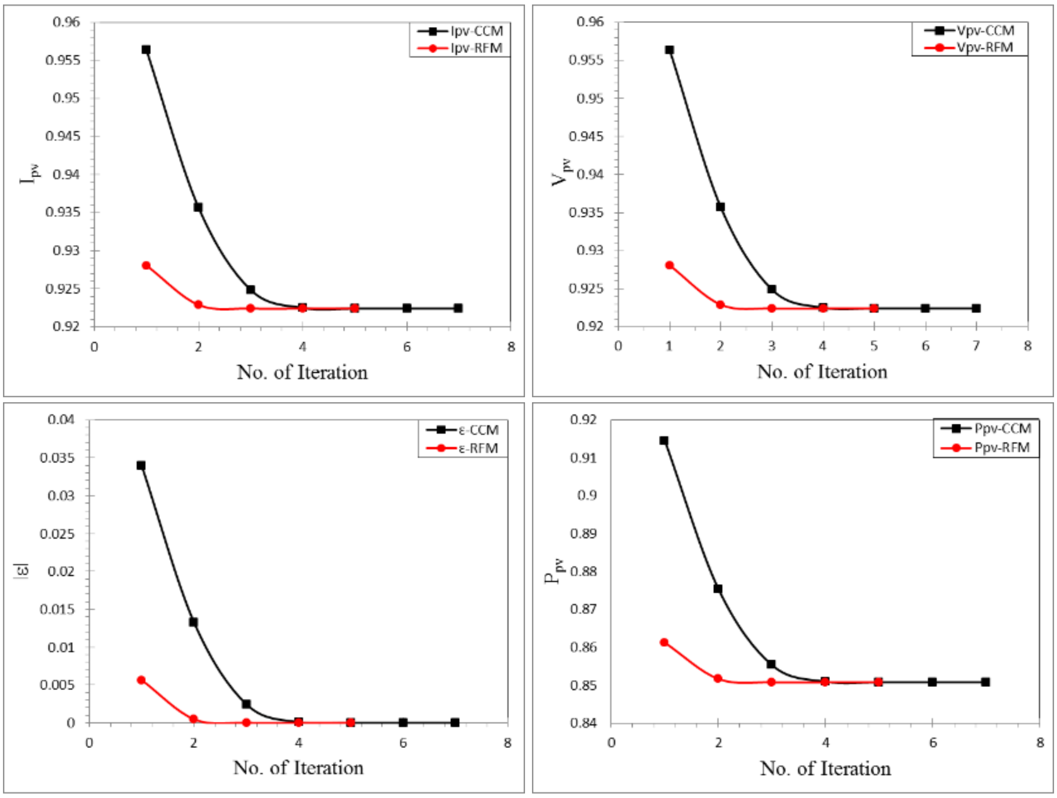

Figure 1. Results of according to (3)'s comparison based on (3), (5), and (6)

Table 1. Solutions to (3) that are predicted using the absolute error values ε

V_{pv}-CCM	I_{pv}- CCM	P_{pv}- CCM	V_{pv}- DFPM	I_{pv}- DFPM	P_{pv}- DFPM	ε- CCM	ε- DFPM
0.956342897	0.956342897	0.914591738	0.928076971	0.928076971	0.861326864	0.033919763	0.005653836
0.935676402	0.935676402	0.875490329	0.922905033	0.922905033	0.8517537	0.013253267	0.000481898
0.924881651	0.924881651	0.855406068	0.922426829	0.922426829	0.850871255	0.002458516	3.6943E-06
0.922517679	0.922517679	0.851038869	0.922423135	0.922423135	0.85086444	9.45447E-05	2.18964E-10
0.922423278	0.922423278	0.850864704	0.922423135	0.922423135	0.850864439	1.43773E-07	0
0.922423135	0.922423135	0.850864439				3.33178E-13	
0.922423135	0.922423135	0.850864439				0	

Every calculation is completed with the level of accuracy given by the quantity of function evaluations and calculations in the Figure 2 and Table 2. The R value in the numerical test equal to 2. Every calculation is completed with the level of accuracy given by the quantity of function evaluations and calculations in the Table 3 and Figure 3. The R value in the numerical test equal to 3.

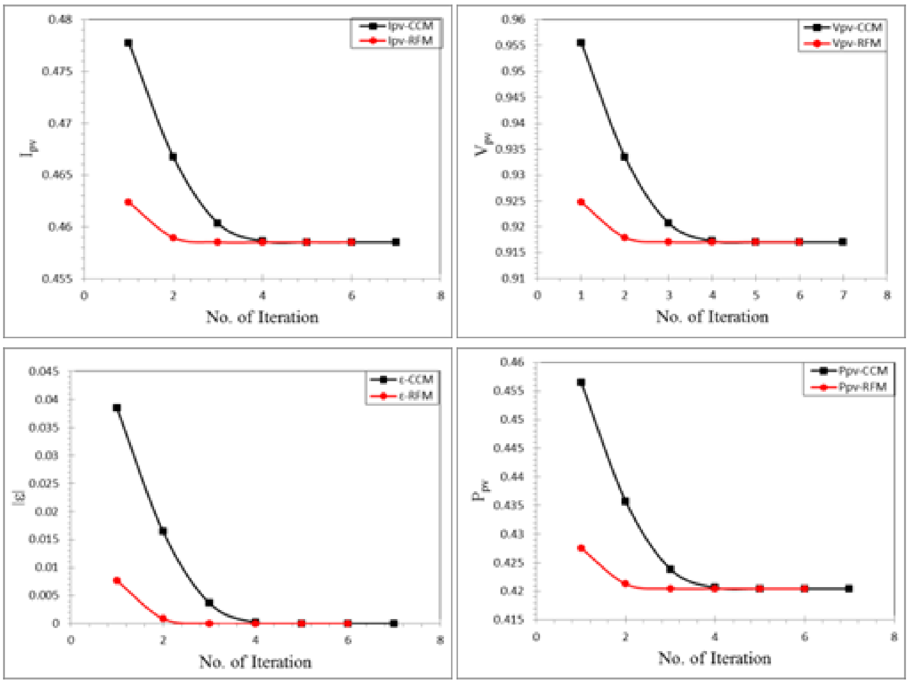

Figure 2. Results of Results of according to (3)'s comparison based on (3), (5), and (6)

Table 2. Solutions to (3) that are predicted using the absolute error values ε.

V_{pv}-CCM	I_{pv}- CCM	P_{pv}- CCM	V_{pv}- DFPM	I_{pv}- DFPM	P_{pv}- DFPM	ε- CCM	ε- DFPM
0.955509809	0.477754904	0.456499497	0.92471291	0.462356455	0.427546983	0.038474426	0.007677528
0.933452268	0.466726134	0.435666569	0.917911499	0.45895575	0.42128076	0.016416886	0.000876117
0.920708719	0.46035436	0.423852273	0.917047635	0.458523817	0.420488182	0.003673337	1.22522E-05
0.917245199	0.4586226	0.420669378	0.917035385	0.458517692	0.420476949	0.000209817	2.42601E-09
0.917036095	0.458518047	0.4204776	0.917035382	0.458517691	0.420476946	7.12519E-07	2.22045E-16
0.917035382	0.458517691	0.420476946	0.917035382	0.458517691	0.420476946	8.24774E-12	0
0.917035382	0.458517691	0.420476946				0	

Table 3. Solutions to (3) that are predicted using the absolute error values ε

V_{pv}-CCM	I_{pv}- CCM	P_{pv}- CCM	V_{pv}- DFPM	I_{pv}- DFPM	P_{pv}- DFPM	ε- CCM	ε- DFPM
0.954668501	0.318222834	0.303797316	0.921077731	0.30702591	0.282794729	0.044265127	0.010674357
0.931130761	0.31037692	0.289001498	0.912060122	0.304020041	0.277284556	0.020727387	0.001656748
0.916050375	0.305350125	0.279716096	0.910447324	0.303482441	0.276304776	0.005647001	4.39496E-05
0.91089377	0.303631257	0.27657582	0.910403406	0.303467802	0.27627812	0.000490396	3.15643E-08
0.910407299	0.3034691	0.276280483	0.910403374	0.303467791	0.276278101	3.92473E-06	1.64313E-14
0.910403374	0.303467791	0.276278101	0.910403374	0.303467791	0.276278101	2.53289E-10	0
0.910403374	0.303467791	0.276278101				0	

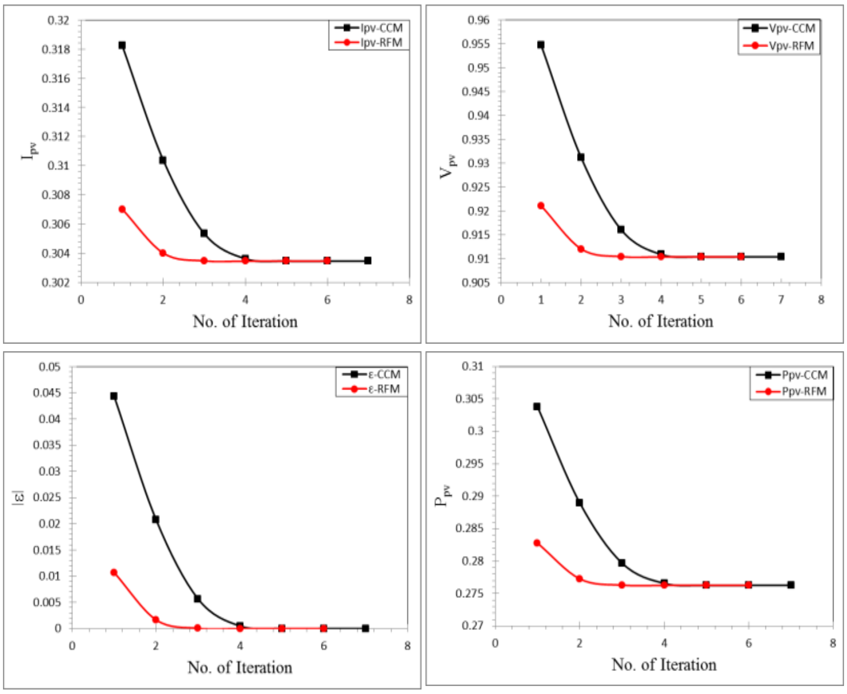

Figure 3. Results of according to (3)'s comparison based on (3), (5), and (6)

Every calculation is completed with the level of accuracy given by the quantity of function evaluations and calculations in the Figure 4 and Table 4, the R value in the numerical test equal to 4. Every calculation is completed with the level of accuracy given by the quantity of function evaluations and calculations in the Table 5 and Figure 5, the R value in the numerical test equal to 5. The findings of the analysis show that the CCM technique is capable of competing favorably with the DM strategy. Because the recommended method DFPM requires less function evaluations than the alternative method (A2), the amount of time spent computing has been reduced, and the efficiency of the method (DM) has been improved.

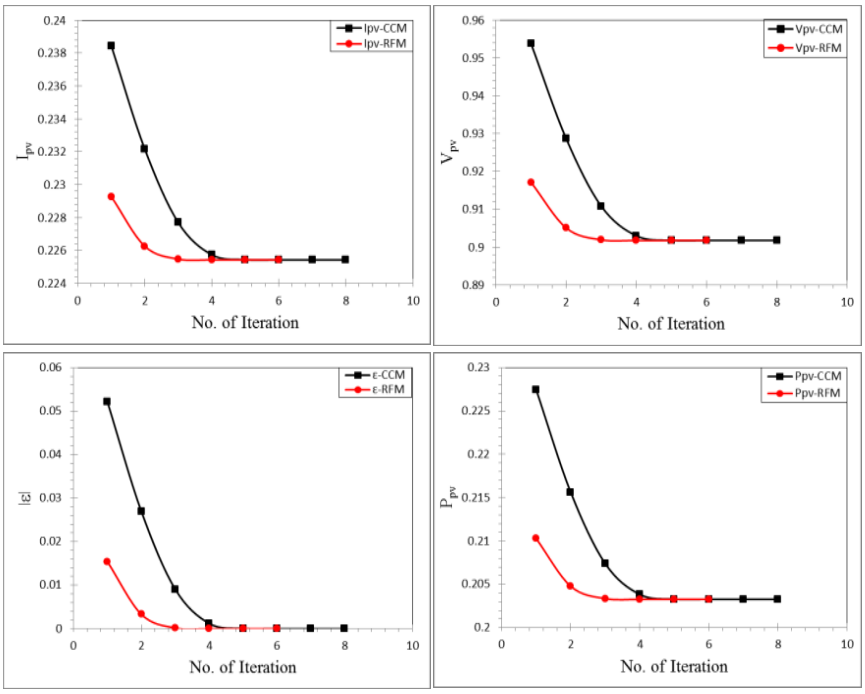

Figure 4. Results of according to (3)'s comparison based on (3), (5), and (6)

Table 4. Solutions to (3) that are predicted using the absolute error values ε

V_{pv}-CCM	I_{pv}- CCM	P_{pv}- CCM	V_{pv}- DFPM	I_{pv}- DFPM	P_{pv}- DFPM	ε- CCM	ε- DFPM
0.953818908	0.238454727	0.227442627	0.917137477	0.229284369	0.210285288	0.052078306	0.015396875
0.928705897	0.232176474	0.215623661	0.905065248	0.226266312	0.204785776	0.026965295	0.003324646
0.910811452	0.227702863	0.207394375	0.901917691	0.225479423	0.20336388	0.00907085	0.000177089
0.902978861	0.225744715	0.203842706	0.901741124	0.225435281	0.203284264	0.001238259	5.22069E-07
0.901765899	0.225441475	0.203295434	0.901740602	0.22543515	0.203284028	2.52971E-05	4.56313E-12
0.901740613	0.225435153	0.203284033	0.901740602	0.22543515	0.203284028	1.07408E-08	0
0.901740602	0.22543515	0.203284028				1.9984E-15	
0.901740602	0.22543515	0.203284028				0	

Table 5. Solutions to (3) that are predicted using the absolute error values ε

V_{pv}-CCM	I_{pv}- CCM	P_{pv}- CCM	V_{pv}- DFPM	I_{pv}- DFPM	P_{pv}- DFPM	ε- CCM	ε- DFPM
0.952960959	0.190592192	0.181626918	0.912852792	0.182570558	0.166660044	0.063868245	0.023760077
0.926171251	0.18523425	0.171558637	0.896503075	0.179300615	0.160743553	0.037078536	0.00741036
0.904871952	0.18097439	0.16375865	0.889962786	0.177992557	0.158406752	0.015779238	0.000870071
0.89266728	0.178533456	0.159370975	0.889105769	0.177821154	0.158101814	0.003574566	1.3054E-05
0.889306005	0.177861201	0.158173034	0.889092718	0.177818544	0.158097172	0.00021329	2.98126E-09
0.889093511	0.177818702	0.158097454	0.889092715	0.177818543	0.158097171	7.96312E-07	3.33067E-16
0.889092715	0.177818543	0.158097171	0.889092715	0.177818543	0.158097171	1.11464E-11	0
0.889092715	0.177818543	0.158097171				0	

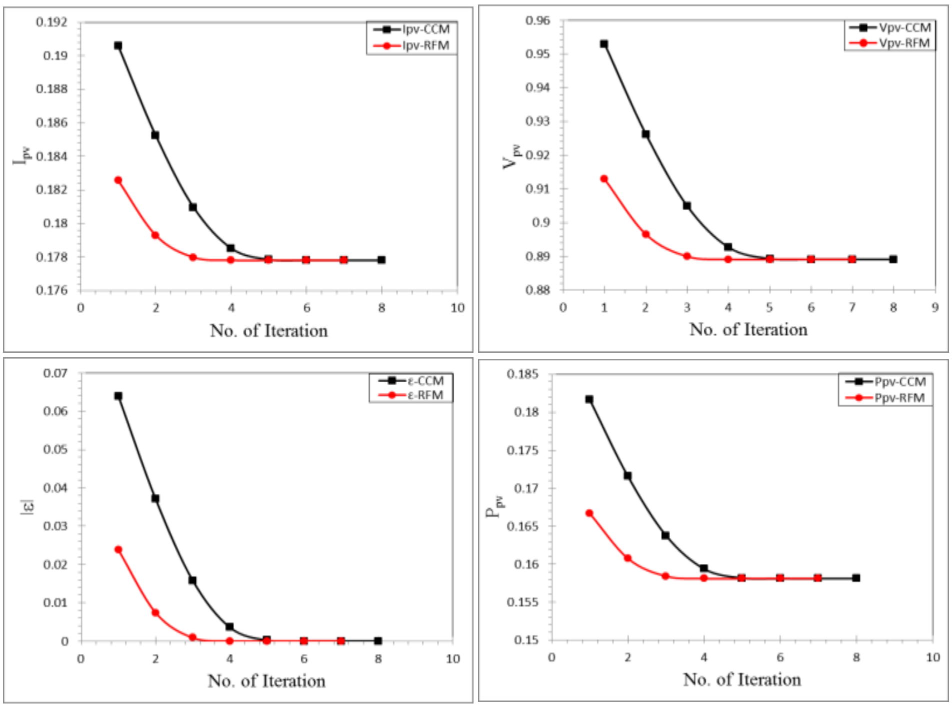

Figure 5. Results of according to (3)'s comparison based on (3), (5), and (6)

4. CONCLUSION

This study presents two numerical methods that have been presented for the purpose of solving non-linear functions in scientific applications, specifically in the context of solar cell devices. These techniques are not dependent on the function's second derivative. Using these methods, a lot of numerical experiments are done, and the results are compared to show that the newly proposed algorithm is better.

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