A Technical Approach to Set Up a Single-Phase Grid-Connected Photovoltaic Power Plant based on Real World Conditions

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Abstract: In this paper, a step-by-step approach of planning, designing and optimization of a single-phase grid-connected photovoltaic power plant based on real world conditions is shown. The location of the real world climate condition chosen from is Bayan Lepas, Pulau Pinang. The content includes the interpretation and tabulation of the power demand and environmental factors to develop proper technical approach to power sizing for generation, choice of control method for the control module which includes implementing the Multiple Power Point Tracking (MPPT) technique through the power converters and also a system with very little power losses as it is delivered to the grid. The design is then proven by simulation using MATLAB/Simulink software.

Keyword: Photovoltaic (PV) modules modelling, PV-Grid connected system, Multiple Power Point Tracking (MPPT) control, Solar Irradiation. Photovoltaic Sizing, Temperature, Sun hours, MATLAB, Simulink

1. INTRODUCTION

The pursuit for renewable energy has been driven by range of factors like fuel price spikes, climate change concerns, public cognizance, and progressions in renewable energy innovations [1] [2]. In this frame of subject, the solar photovoltaic (PV) energy has picked up a stature of quality for its low ecological effect, long working time and quiet operation.

The PV application is expanding exponentially in the renewable energy market. It is also used today as an important piece of technology in various applications pertaining to renewable power generation. Although PV modules generally have low efficiency. The general PV module power losses can be diminished by using high adequacy power conditioners which are expected to obtain the most possible degree of power from the PV module.

In order to set up a proper PV power plant in regards to real world conditions. The selected area of set up for this particular power plant establishment is in Bayan Lepas, Penang. Actual research based environmental data have be retrieved in order to produce the exact system performance based for the particular area. This will ensure the modelled system produces simulation results which will be obtained when it is set up in similar environmental conditions.

This paper explains a step-by-step guideline setting up a single-phase grid-connected photovoltaic power plant based on real world conditions for a power average of 2 kW. The system is explained on the basis of designing and modelling of every segment which includes the selection and implementation of the PV panels, control module that consist of the MPPT technology with the DC-DC boost converter and the AC-DC inverter. The development of the system design is also discussed on the perspective of power production based on selected location. Different location has different solar irradiance. Thus, planning of developing an adequate system based on its location is also discussed.

2. PLANNING OF SYSTEM ACCORDING TO LOCATION

The location of a study must be analysed carefully before developing the design of the system. The chosen location for this study is Bayan Lepas, Pulau Pinang. Environmental

parameters of the environment at the chosen location plays a large role. Parameters such as the solar radiation, ambient temperature and sun hours are very crucial when it comes to planning a system.

Based on the Mean Data for Meteorological and Environmental Data [3], Bayan Lepas has an average daily global solar radiation of $5110 Wh/m^2$. It also has an average daily temperature of 27.8°C. Looking into the Malaysia climate profile [4], the location also has an average 6.75 sun hours every day. Based on the information obtained, the ground work for the planning can be established.

The average solar irradiation and sun hours is $5110 Wh/m^2$ and 6.75 hours respectively. From this, the solar irradiance used in the simulation can be determined;

$$5110 \text{ Wh/m}^2 \div 6.75 \text{ h} = 755.56 \text{ W/m}^2 \quad (1)$$

Thus, the solar irradiance obtained above, 757 W/m^2 is the value at a given point in the study and the temperature will be 27.8°C.

3. POWER SIZING OF THE SYSTEM

Since the power average is set at 2 kW, the design of the system is as such that including the effects of the parameters, the power average must be 2 kW. In order to achieve this, steps of calculation is done;

Desired P_{ave} is 2000W

Total kilowatt-hours for the whole day (24hours) will be:

$$2000 \text{ W} \times 24 \text{ h} = 48 \text{ kWh} \quad (2)$$

Based on the Mean Data for Meteorological and Environmental Data [3], sun hour at Bayan Lepas is 6.75 hours

Generated P_{out} of from the system:

$$48 \text{ kWh} \div 6.75 = 7.1 \text{ kW} \quad (3)$$

Thus, a system that can deliver 7.1 kW of power must be designed to satisfy P_{ave}.

In order to compensate for losses, the system will be designed to produce 6% higher of needed power. The 6% is the ideal losses of an average electrical system [5]

$$7.1 \text{ kW} + 5\% = 7.5 \text{ kW} \quad (4)$$

4. PV CHARACTERISTICS AND SIZING

The PV panel used is the Kyocera KD205GX-LP. The following table 1 shows the parameters of the model.

Table 1: Parameters of KD205GX-LP solar array at 25°C; $1000W/m^2$

Parameters	Value
Referenced solar irradiance, S_{ref},	1000 W/m^2
Referenced cell temperature, T_{ref}	298 K
Cell numbers of a PV module N_p	54
Nominal short-circuit current	8.36 A
Nominal array open-circuit voltage	33.2 V
Array current maximum power point	7.71 A
Array voltage maximum power point	26.6 V
Current / temperature coefficient	0.005016 A/K
Voltage / temperature coefficient	-0.12 V/K
Band-gap energy, E_g	1.237 eV
Cell internal resistance, R_s	0.2273 Ω
Cell shunt resistance, R_{sh}	540.55 Ω
p-n junction ideality factor	0.065

The above model has been implemented using MATALB/Simulink as depicted in the Figure 1 using the parameters Table 1.
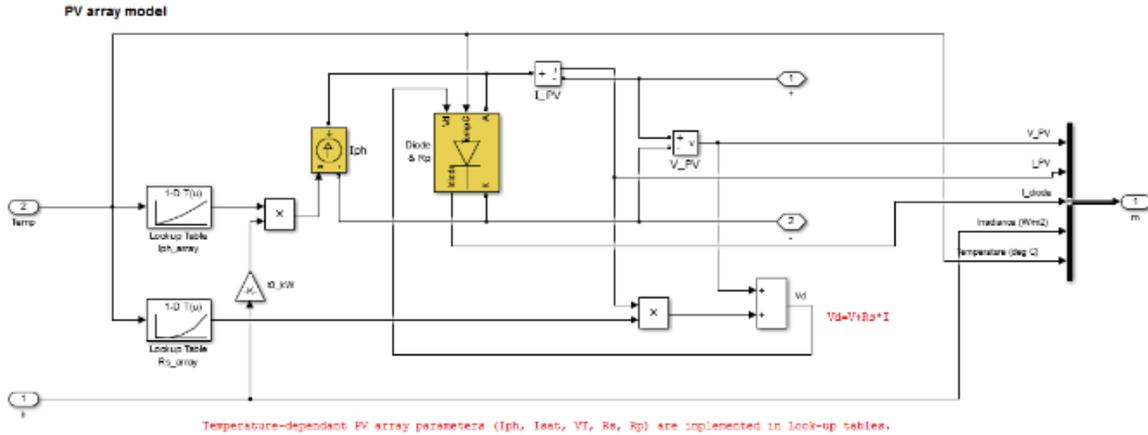

Figure 1: PV array model implemented in MATLAB/Simulink.

According to the climate of our study area, the ambient temperature of 27°C and solar irradiance of 757 W/m². The corresponding PV array characteristic curves is shown below:
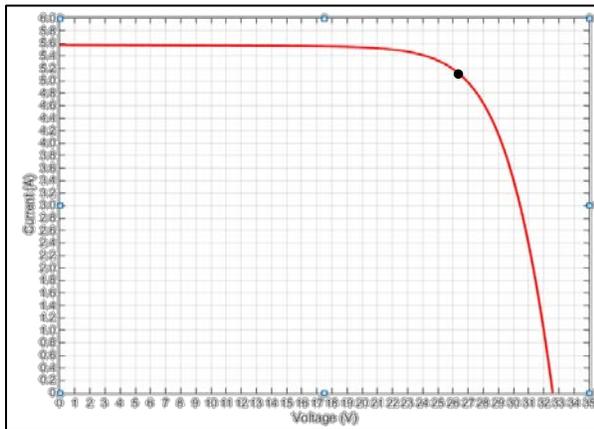

Figure 2: PV array characteristic curve at the ambient temperature of 27°C and solar irradiance of 757 W/m².

Based on the graph above, it can be seen that under the given circumstances, one PV module gives out 26.6 V and 5.09 A at the maximum power point.

PV array in terms of parallel and series connection play an important role. The series-connected module reflect the voltage generated by the array and the parallel-connected module reflects the current produced by the array.

An equation to find the number of series-connected and parallel-connected module can be developed by this equation.

$$(X \times V_{PV}) \times (Y \times I_{PV}) = 7538 \qquad (5)$$
$$(X \times 26.6 \text{ V}) \times (Y \times 5.09 \text{ A}) = 7538$$

Where:

X - Series-connected module
Y - Parallel-connected module
V_{PV} - Maximum voltage at PV
I_{PV} - Maximum current at PV

According to the equation above, an inverse function graph is developed below in order to find the minimal number of module to be used to generate the required power from the PV array.

$$(X \times 26.6) \times (Y \times 5.09) = 7538 \qquad (6)$$
$$Y = 55.67/X$$
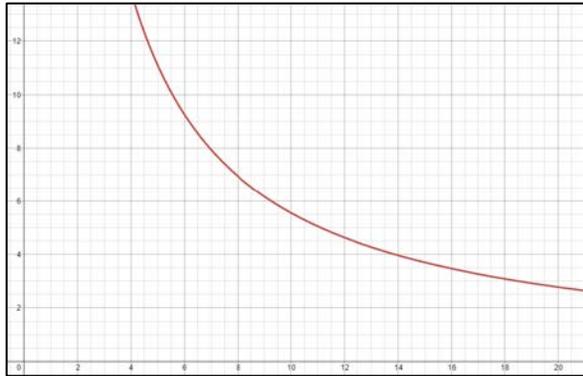
The inverse function graph is shown below;

Figure 3: The inverse function graph for minimal number of PV module.

The voltage at the Grid is $240V_{AC}$ ($339.4V_{RMS}$). The voltage produced by the PV array must be higher than 339.4 V in order for the current generated at the PV array to be sent to the grid. Thus, the number of series-connected module must be;

$$339.4/26.6 = 12.75$$

The number of series connected module must be 13 and above. Based on the inverse function graph above, the number of modules for both series and parallel connected are as follows that satisfy the function is as follows.

Table 2: Number of parallel and series connected modules for every possible combination is needed range.

Layout	Number of parallel connected modules	Number of series connected modules	Total module used
1	13	5	13×5=65
2	14	4	14×4=56
3	15	4	15×4=60
4	16	4	16×4=64
5	17	4	17×4=68

From Table 2, we can deduce that the best combination will be layout 2 and because lesser

modules are used compared to the rest of the layouts. The trend shows that the number of modules increase as we proceed from layout 2 to more. The voltage and current generated by the PV array using layout 2 is:

$$V_{PV} = 26.6 \text{ V} \times 14 = 372.4 \text{ V}$$
$$I_{PV} = 5.09 \text{ A} \times 4 = 20.36 \text{ A}$$

Thus, total power produced is;

$$P_{PV} = V_{PV} \times I_{PV}$$
$$= 372.4 \times 20.36$$
$$= 7582 \text{ W}$$

Power produced at the PV array is adequate to the required output.

5. POWER FLOW OF SYSTEM

PV array is connected to the DC bus through a DC/DC boost converter, and then to the AC grid by means of a DC/AC inverter. The inverter has its autonomous control objective (boost converter controls the PV generator to produce the maximum power and grid inverter control the active and reactive power at AC bus to be uniform).

For first-arrange PV generation system, boost chopper circuit is constantly utilized as the boost DC/DC converter. The DC-DC converter ascents the low solar voltage to a suitable level comparing to the ideal PV power. A capacitor is for the most part connected between PV array and the boost circuit, which is utilized to decrease high frequency harmonics.

PV array with boost DC-DC inverter are connected to the grid by means of a DC/AC inverter. The inverter is utilized to venture down and to balance the yield voltage as according to the grid voltage. At last, the filter is intended to diminish high-order harmonics presented by the PWM tweak of the DC/AC converter.

6. MAXIMUM POWER POINT TRACKING

The 'Perturb and Observe' (P&O) algorithm is the most well-known MPPT algorithm, since it is much more straightforward and needs less measured variables. Fig. 7 demonstrates the flowchart of P&O technique. It works by continually measuring the terminal voltage and current of the PV array, then always perturbing the voltage by including a little aggravation, and then watching the progressions of the yield power to focus the following control signal. In the event that the power builds, the perturbation will proceed in the same course in the accompanying step, otherwise, the perturbation direction will be inversed.
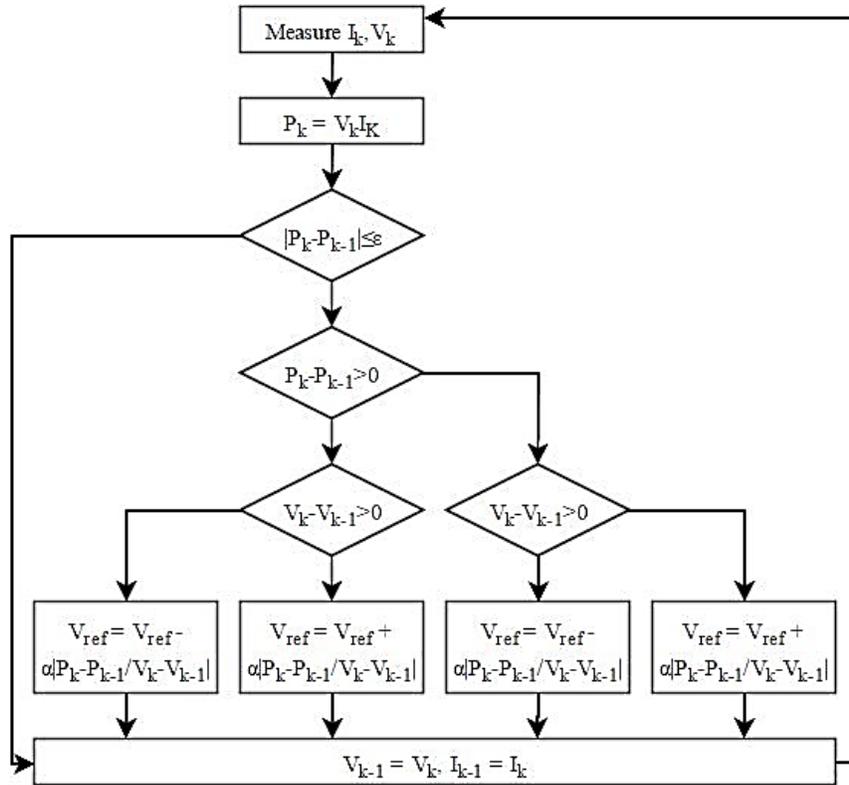
Figure 4: P&O algorithm flow chart. [6]

Where V_k and I_k are respectively the voltage and current of PV array at the moment whereas V_{k-1} and I_{k-1} are respectively the voltage and current of PV array at the last sampling time.

The P&O system functions admirably in moderate changing environment. How-ever, it has a few impediments under quickly changing climatic conditions. From the characteristics bends of the PV array, power increase dP and voltage increase dV have the accompanying relationship:

At the left of MPP: $dP/dV > 0$
At the right of MPP: $dP/dV < 0$
At the MPP: $dP/dV = 0$

Furthermore, as the operation point is closer to the MPP, the estimation of $|dP/dV|$ is smaller and smaller; thus, the perturbation can be set as $\alpha|dP/dV|$. At the point when the operation point is at a long way from the MPP, the perturbation is extensive, and when the PV array is working close to the MPP, the perturbation is little.

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7. RESULTS AND DISCUSSION

In order to prove of concept on the technical approach on the system design, the design is implemented in MATLAB/Simulink. The SimPowerSystems Library Pack is used to implement design

A successful display of obtained results ensure the design to be viable. Results obtained have been discussed thoroughly. A complete MATLAB/Simulink simulation of the grid connected PV System is shown in Figure 5
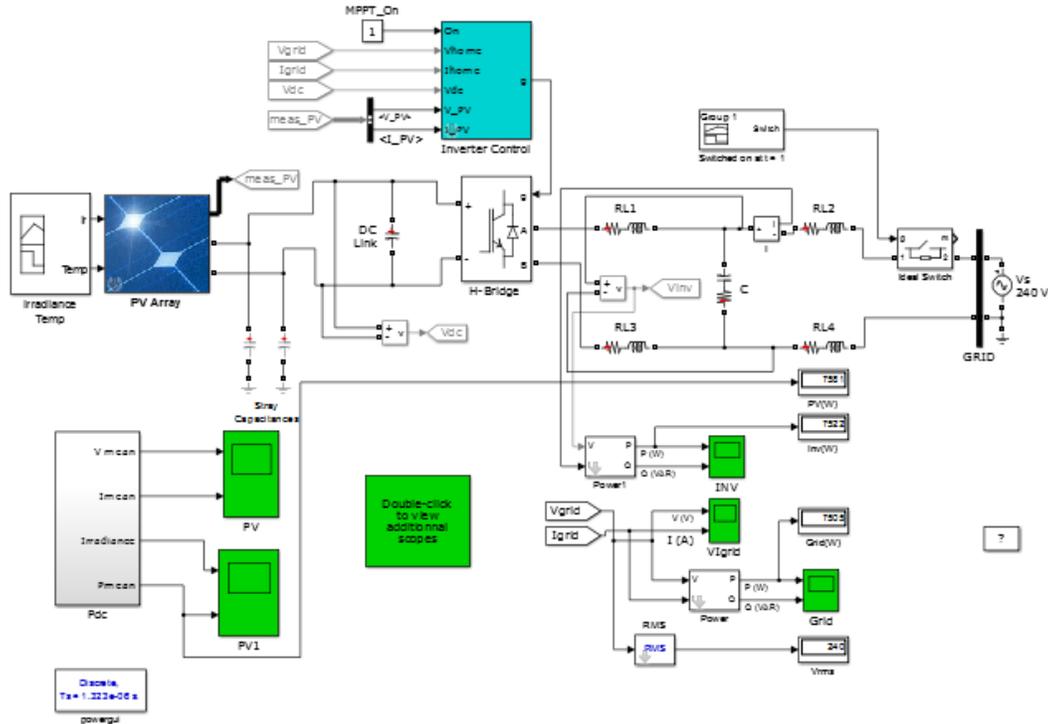

Figure 5: The entire modelling of the system in MATLAB/Simulink using SimPowerSystems.

The simulation result of the PV Voltage based on the system is shown in Figure 6 below.
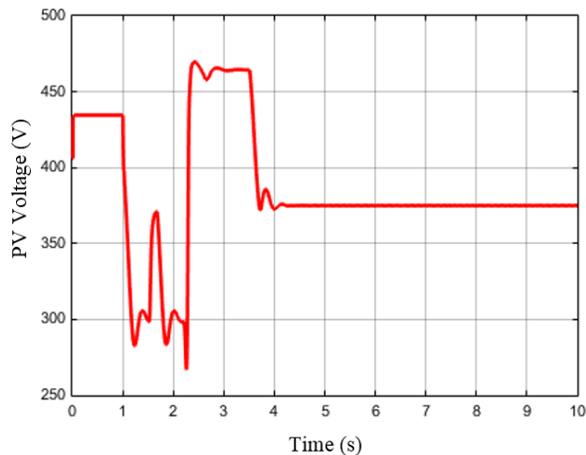
The simulation result of the PV Current based on the system is shown in Figure 7 below.
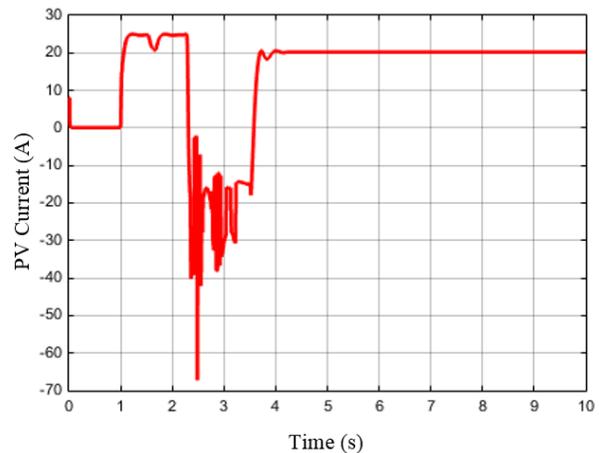

Figure 6: PV Voltage

Figure 7: PV Current

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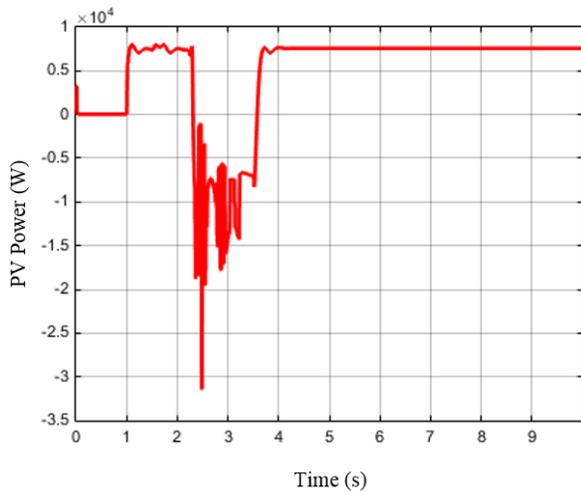The simulation result of the PV Power based on the system is shown in Figure 8 below.

Figure 8: PV Power

Figures below shows both the real and reactive current trends through simulation period at the AC bus which is initially generated by the PV system. The output shown have had its form changed from how it was initially through the control module of the system.
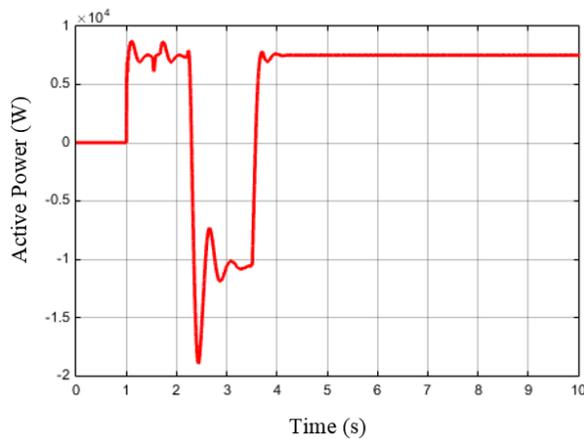

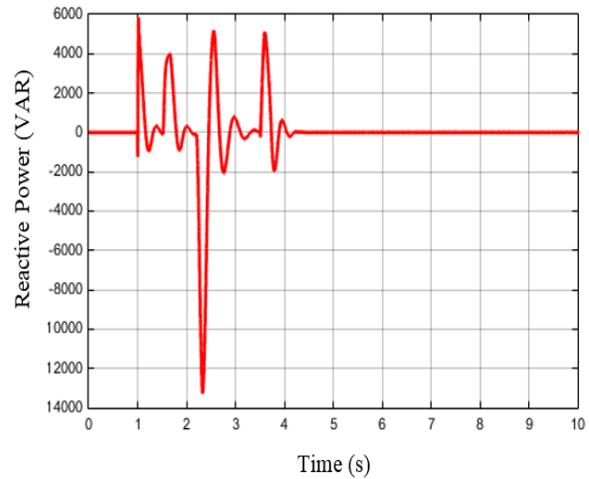**Figure 9:** Active power at the AC bus.

Figure 10: Reactive power at the AC bus.

The Table 3 shows the power losses of the system through the entire process according to every segment through the particular modules and positions. It can be said that the total losses through and of the system is only 0.6%. Thus making it a very optimized and efficient system.

Table 3: Power losses according to the segments of the system.

Equipment	Output Power (W)	Power Loss (W)
PV Module	7582	-
Control Module	7552	30
AC Bus	7535	17

8. CONCLUSION

This paper presented the planning, design and optimization method of developing a single-phase grid-connected photovoltaic power plant based on real world conditions. A specific output goal was set which was the entire sys-tem to be able to deliver at least 7.5 kW including the power needed to compensate the transmission losses while being sent to the grid. The output expected initially to be obtained with this paper which was successfully achieved through the planning, designing and optimization method.

Planning includes the sizing of the PV systems according to the environmental circumstances and the power demand. The designing was done by implementing the appropriate size of PV module and the MPPT technique for the control module in order to satisfy the needs of such an expected output which was directly affected by the environmental factors. The optimization was done with the needed calculation of connections for the PV module in order to achieve the needed output with the lowest number of panels.

The selection of parameters for the control module further reduces the losses. Total losses total up to only 0.6% of the power generated by the PV. This results ensure that such a system robust and efficient and can be implemented.

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