# Optimizing of the installed capacity of hybrid renewable energy with a modified MPPT model

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**ABSTRACT**

The lack of wind speed capacity and the emission of photons from sunlight are the problem in a hybrid system of photovoltaic (PV) panels and wind turbines. To overcome this shortcoming, the incremental conductance (IC) algorithm is applied that could control the converter work cycle and the switching of the buck boost therefore maximum efficiency of maximum power point tracking (MPPT) is reached. The operation of the PV-wind hybrid system, consisting of a 100 W PV array device and a 400 W wind subsystem, 12 V/100 Ah battery energy storage and LED, the PV-wind system requires a hybrid controller for battery charging and usage and load lamp and it's conducted in experimental setup. The experimental has shown that an average increase in power generated was 38.8% compared to a single system of PV panels or a single wind turbine sub-system. Therefore, the potential opportunities for increasing power production in the tropics wheather could be carried out and applied with this model.



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## 1. INTRODUCTION

The main objectives of developing renewable energy sources today are to reduce environmental damage, energy conservation, inexhaustible resources and increase safety and efficiency. Renewable energy systems can supply power either directly to the electricity grid or to isolated loads. A stand-alone system with wider application in remote areas far from the utility grid [1]-[6].

Solar and wind energy can decrease dramatically due to weather changes by combining these two energy sources so that the output power can be used optimally. Indonesia has facing some problems of wind speed and solar intensity in order to fulfil renewable energy supply [6]-[11]. Therefore, regulation and stabilization of the output power of solar panels and wind turbines are needed. Rapid voltage changes occur in need of power management using a maximum power point tracking (MPPT) device in sequence to determine the most efficient operating point in certain weather conditions so that the system becomes actively supporting each other dynamically [12]-[17]. It is important to keep a spare battery full when there is no sun or wind [18]-[21]. Solar and wind energy systems with the MPPT technique are carried out separately, the MPPT technique is used with a DC/DC converter to turn on/turn off the controlled buck boost converter switch. MPPT is usually implemented by an electronic power circuit that provides an interface between PV-wind, battery and load [22]-[24].

This research conducted by using a device that includes a 100 watt photovoltaic (PV) array and a 400 Watt wind subsystem using a permanent magnet synchronous generator (PMSG), a 12 V/100 Ah battery energy storage. In order to optimizing PV power and wind turbine, MPPT model using metal oxide semiconductor field effect transistor (MOSFET). The MOSFET acts as switching which is perform harvesting energy during ongoing process at the same time. Due to weather situations, MOSFET switching should be able to perform exchange harvesting automatically by received signal from the current sensor. Afterwards, electric power sources become one so that it can generate electrical energy even with different time and weather conditions. Therefore, the output values from both sources able perform optimally.

## 2. HYBRID PV WIND TURBINE SYSTEM

Figure 1 describing of hybrid PV wind system design which is connected to the MPPT control systems. There are three main elements: i) 100 Watt PV solar panel and 400 Watt wind turbine, ii) MPPT control system, and iii) LED and a $12\,V - 100\,Ah$ battery. Temperature, sunlight, and wind speed are the parameters that influence of the output voltage. MPPT system control is conducted to manage the battery storage and LED as shown in Figure 1. In this case, MPPT will conduct the changing of the weather which impacted to the supply energy power to the battery. Therefore, independent controlling of supply energy to the battery is the aimed of switching method within MPPT. Moreover, MPPT able to optimizing energy supply of the battery independently which does not depend on changes in weather [25]-[27].

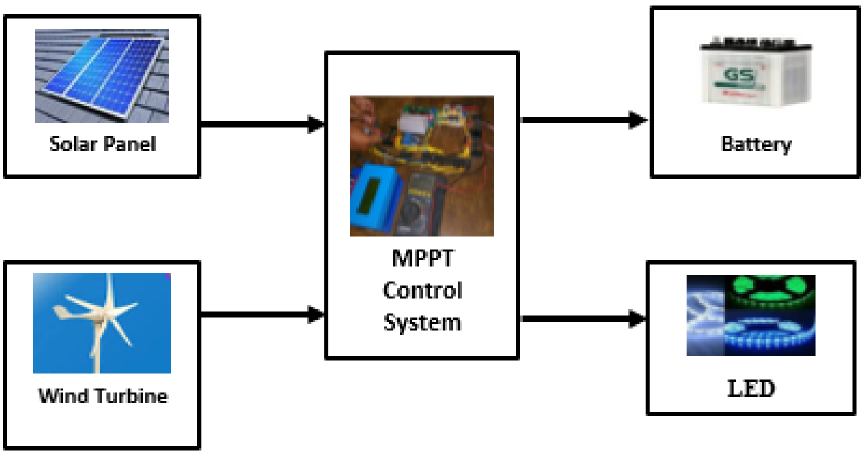


Figure 1. Hybrid PV-wind turbine systems

## 3. PHOTOVOLTAIC MODEL

Figure 2 show the equivalent series of solar panels which describing of the power output of the PV array based on solar radiation and temperature changes. The power output in this model is calculated as shown in (1):

$$P_{pv} = \eta_{pvg} A_{pvg} G_t \tag{1}$$

where $\eta_{pvg}$ is the efficiency of PV generation, $A_{pvg}$ is the area that produces PV (m$^2$), and $G_t$ is solar irradiation in the inclined plane (W/m$^2$) [28], [29]. Short circuit current (ISC) of a solar panel that is affected by the function of solar radiation (S) and the open circuit voltage (VOC) as shown in (2):

$$I_o = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{qV_o}{kTA_{n_s}}\right)\right] \tag{2}$$

where $I_o$ is the solar panel output current, $n_p$ number of cells connected in parallel, $n_s$ number of cells connected in series, Boltzmann constant, electron transfer velocity, $T$ panel surface temperature, and the constant deviation of the characteristics of PN junction cells. $I_{rs}$ is the cell saturation current which changes with temperature by (3). Current solar cell ($I_{ph}$) depends on sunlight and cell temperature shown in (4):

$$I_{rs} = I_n \left[\frac{T}{T_r}\right]^3 exp\left(\frac{qE_G}{kA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \tag{3}$$

$$I_{ph} = [I_{scr} + k_i(T - T_r)]\ \frac{\mathcal{S}}{100} \tag{4}$$

where:
$I_{scr}$=short circuit cell current
$k_i$=temperature coefficient short circuit current
$\mathcal{S}$=light radiation (Watt/m$^2$)

In the study, using two solar cell panels with a maximum power parameter has given $P_{max}$=2x50 W=100 W, maximum voltage $V_{mp}$=17.6 V, maximum current $I_{mp}$=5.69 A, open circuit voltage VOC=22.4 V, and short circuit current $I_{scr}$=6.03 Ampere.

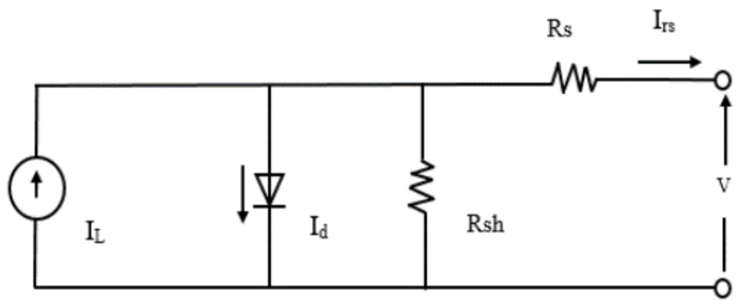


Figure 2. Equivalent circuit of solar panels

## 4. WIND TURBINE MODEL

Permanent magnet synchronous generator (PMSG) is used in the wind energy conversion system (WECS), which the aerodynamic power properties of the rotor can be calculated by (5):

$$P_w = \frac{1}{2} C_p(\lambda, \beta)\rho A V^3 \tag{5}$$

where ρ is the density of air (kg/m$^3$), $C_p$ is the power coefficient, a intercepts the area of the rotor blades (m$^2$), V is the average wind speed (m/s), λ is the tip of the speed ratio. The theoretical maximum value of the $C_p$ power coefficient is 0.593, also known as the betz coefficient 42 [30]. Tip speed ratio (TSR) for wind turbines is defined as a ratio from the rotation speed of the tip of the blade to the speed of the wind and given by (6):

$$\lambda = \frac{R\omega}{V} \tag{6}$$

where R is the turbine radius (m), ω is the angular velocity (rad/s), V is the average wind speed (m/s). The energy produced by the wind can be obtained by (7):

$$Q_w = P \times (Time)[kWh] \tag{7}$$

## 5. HYBRID PV-WIND TURBINE SYSTEM DESIGN MODEL

To produce maximum power, hill-climbing algorithms is proposed in MPPT. Perturbation and observe model are uses in this algorithm [31]-[34]. The MPPT are comprises of DC-DC converters, controllers, buck boost converters that function to increase the voltage and reduce the tension as needed as shown in Figure 3. DC-DC converter has functions to vary the value of the input voltage from the source based on the value of the duty cycle received from the MPPT algorithm. To get the right and appropriate duty cycle values, a control system called a tracking algorithm, the tracking algorithm itself works based on information from the sensor reader.

Figure 4 shows the P and O engineering flow chart, if there is no change in power in the combination of solar panels and wind turbines, the duty-cycle ratio will not change. However, if there is an increase in power and voltage on solar panels and wind turbines, the duty-cycle ratio will decrease. If there is an increase in power but the voltage remains or decreases, the duty-cycle ratio will increase. And when the power and voltage of solar panels and wind turbines goes down, the duty-cycle ratio drops. Then if the power decreases but the voltage increases, the duty-cycle ratio increases. The duty-cycle changes in the MPPT system with the P and O technique are aimed at stabilizing the voltage [35], [36].

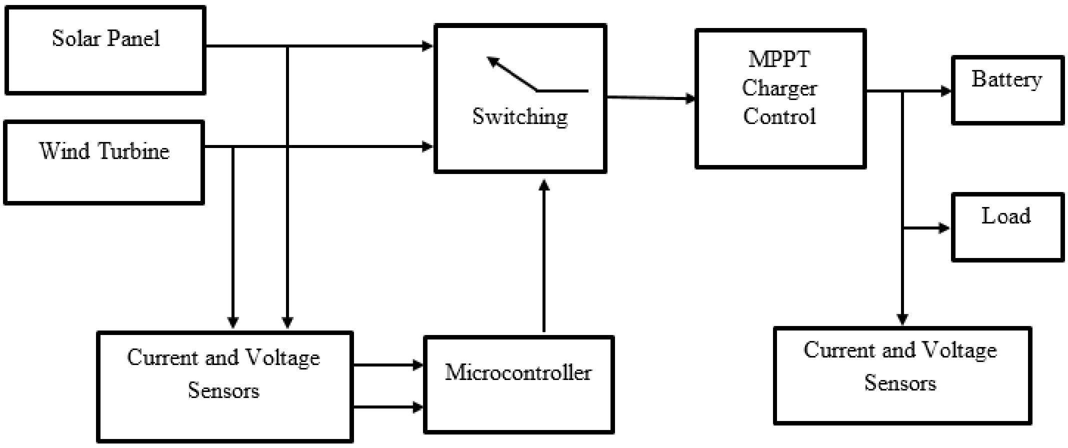


Figure 3. Design hybrid PV wind turbine systems with MPPT switching model

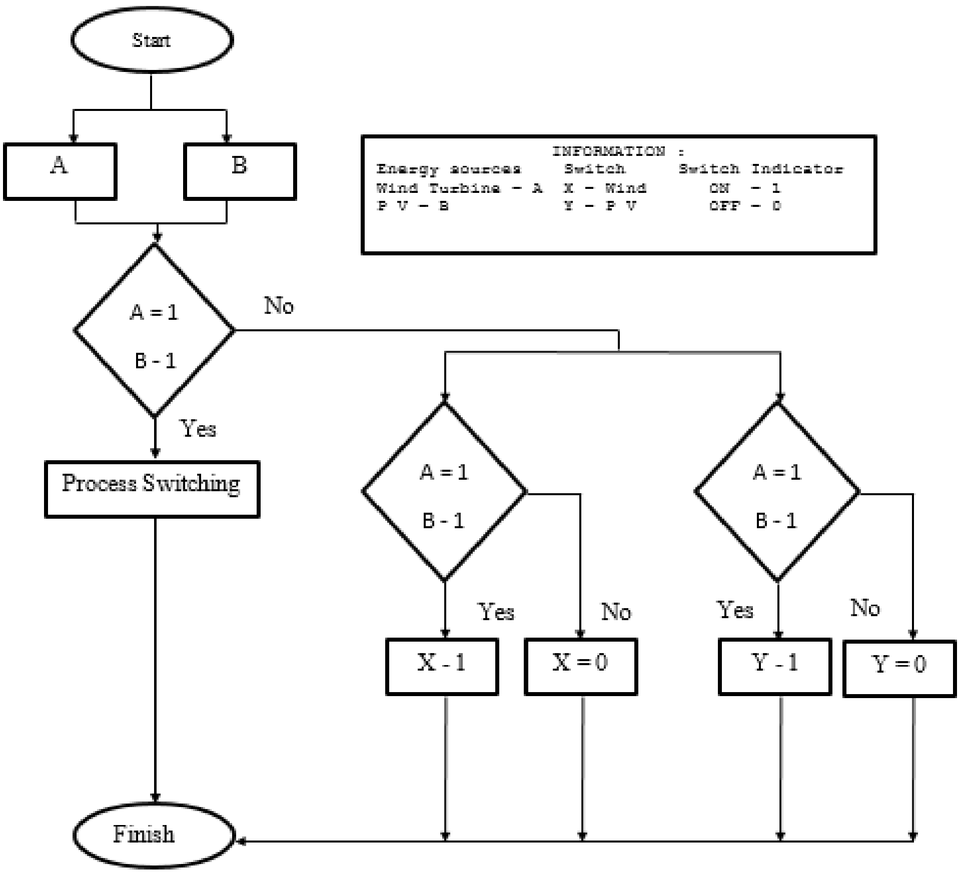


Figure 4. P and O incremental conductance algorithm

## 6. BUCK BOOST CONVERTER

The buck-boost converter functions to change the DC voltage level, either to a higher level or to a lower level. However, a buck-boost converter can also change the polarity of the output voltage towards the input voltage [37]-[39]. The size and small value of the output voltage is set based on the pulse width modulation (PWM) duty cycle (D) of the switch.

$$V_0 = -V_s\left(\frac{D}{1-D}\right) \tag{8}$$

The $L_{min}$ and $C_{min}$ parameters are used to determine the buck-boost converter in continuous current mode (CCM). (9) and (10) can be used to calculate the inductor and capacitor values used in the buck-boost converter so that the $L_{min}$ and $C_{min}$ values are 0.006 H and 0.0015 F. Figure 5 shows, a buck booster type power converter where the average output voltage vout is smaller than the input voltage.

$$L_{min} = \frac{R_{L_{max}(1-D_{min})}{}^{2}}{2fs} \tag{9}$$

$$C_{min} = \frac{V_0 D_{max}}{\Delta V_0 R_{L_{\min}}\ fs} \tag{10}$$

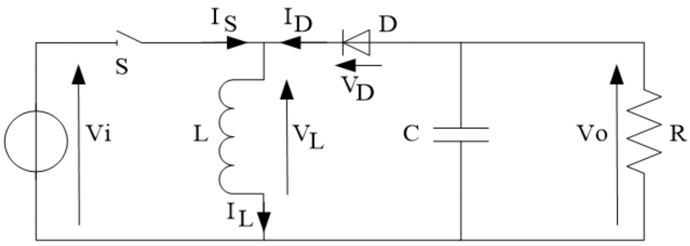


Figure 5. Buck boost converter circuit

## 7. BATTERY AND CHARGER CONTROL

For charging the battery, a device is needed that can supply power to the battery until it is full. Furthermore, when the battery is full, to avoid over charging it is necessary to control the power and current on the charger so as to avoid a decrease in battery cells [40]-[42]. To regulate the battery charging process sourced from the output power of the wind turbine system and PV panels, a battery control regulator is needed. A lithium-Ion battery type with a nominal voltage of 12 V and a capacity of 100 Ah is used in this experiment.

## 8. RESULTS AND DISCUSSION

This research was conducted on an 18-meter-high building in the tropical coastal area of Semarang, Central Java, Indonesia as shown in Figure 6. The experiment was carried out with three main processes, namely measuring the voltage and current of hybrid solar cells and wind turbines for 24 hours supported by a display and data logger. MOSFET-1 and 2 will perform energy management by setting a relay switch on the MPPT which can modify the voltage, and increase or decrease the voltage by changing the duty cycle. The relay will adjust the charging sequentially to get the optimal cycle for the hybrid device.

Table 1 has shown the results of measurements and testing of voltages and currents in hybrid conditions. PV-wind works together to produce electrical energy, where the MPPT function controls the PV-wind alternately according to the reference using switching and produces an average voltage output of 15 Volts and current 5 Ampere. Table 2 Shows the results of voltage and current measurements in PV-wind hybrid conditions where the MPPT function controls the PV-wind using switching according to the reference program compiler where only one source of electrical energy works in PV or wind turbines. Table 3 has shown the comparison of the results of electric power with MPPT Switching, the condition of the maximum power value generated in the solar panel is 67.05 Watts and in the wind turbines is 70.65 Watts and the PV-wind hybrid is 96.04 Watts.

Figure 7 shows the difference in electric power during the PV-wind turbine condition. PV-wind as a source of electrical energy generated by the MPPT switching method and an increase in the electric power generated by the PV-wind hybrid turbine. It is shown that the black line represents hybrid energy, which has a higher value than the blue line which represents only PV panels and the orange line represents only wind turbines. Hybrid combination can improve the performance of the power stored in the battery and optimized with MMPT.


Figure 6. MPPT test circuit battery charging hybrid PV-wind turbine

Table 1. Experiment results of measurement and testing of hybrid solar panels and wind turbines with MPPT switching

| No | PV (Out) Voltage (V) | Wind (Out) Voltage (V) | Hybrid (PV-Wind) Voltage (V) | Current (A) | Power (Watt) |
|---|---|---|---|---|---|
| 1 | 10.62 | 18.23 | 15.46 | 5.89 | 91.06 |
| 2 | 12.93 | 16.09 | 14.49 | 3.53 | 51.15 |
| 3 | 13.54 | 19.47 | 15.6 | 5.85 | 91.26 |
| 4 | 16.07 | 14.32 | 15.19 | 5.06 | 76.86 |
| 5 | 17.89 | 15.35 | 14.49 | 3.52 | 51.00 |
| 6 | 10.56 | 19.07 | 15.12 | 5.75 | 86.94 |
| 7 | 11.43 | 16.18 | 14.69 | 4.16 | 61.11 |
| 8 | 18.49 | 19.45 | 15.98 | 6.01 | 96.04 |
| 9 | 17.43 | 18.89 | 15.29 | 5.55 | 84.86 |
| 10 | 18.22 | 17.52 | 15.27 | 5.24 | 80.01 |

Table 2. Hybrid test results from solar panels and wind turbines with MPPT switching

| No | PV Voltage (V) | PV Current (A) | Power (Watt) | Wind Turbine Voltage (V) | Wind Turbine Current (A) | Power (Watt) |
|---|---|---|---|---|---|---|
| 1 | 15.12 | 3.81 | 57.61 | 0 | 0 | 0.00 |
| 2 | 14.69 | 3.7 | 54.35 | 0 | 0 | 0.00 |
| 3 | 15.14 | 3.94 | 59.65 | 0 | 0 | 0.00 |
| 4 | 14.69 | 2.88 | 42.31 | 0 | 0 | 0.00 |
| 5 | 14.45 | 3.5 | 50.58 | 0 | 0 | 0.00 |
| 6 | 15.45 | 4.34 | 67.05 | 0 | 0 | 0.00 |
| 7 | 14.43 | 3.14 | 45.31 | 0 | 0 | 0.00 |
| 8 | 15.29 | 4.11 | 62.84 | 0 | 0 | 0.00 |
| 9 | 14.45 | 3.5 | 50.58 | 0 | 0 | 0.00 |
| 10 | 15.14 | 3.94 | 59.65 | 0 | 0 | 0.00 |
| 11 | 0 | 0 | 0.00 | 15.46 | 4.57 | 70.65 |
| 12 | 0 | 0 | 0.00 | 14.49 | 3.31 | 47.96 |
| 13 | 0 | 0 | 0.00 | 15.13 | 4.46 | 67.48 |
| 14 | 0 | 0 | 0.00 | 14.69 | 3.33 | 48.92 |
| 15 | 0 | 0 | 0.00 | 14.42 | 2.83 | 40.81 |
| 16 | 0 | 0 | 0.00 | 14.49 | 3.31 | 47.96 |
| 17 | 0 | 0 | 0.00 | 15.12 | 4.44 | 67.13 |
| 18 | 0 | 0 | 0.00 | 15.09 | 4.25 | 64.13 |
| 19 | 0 | 0 | 0.00 | 14.38 | 3.14 | 45.15 |
| 20 | 0 | 0 | 0.00 | 14.45 | 3.42 | 49.42 |

Table. 3. Comparison of the electric power of solar panels, wind turbines and hybrids (PV-wind) with MPPT switching

| No | Power (Watt) | | |
|---|---|---|---|
| | PV | Wind | Hybrid (PV-Wind) |
| 1 | 57.61 | 70.65 | 91.06 |
| 2 | 54.35 | 47.96 | 51.15 |
| 3 | 59.65 | 67.48 | 91.26 |
| 4 | 42.31 | 48.92 | 76.86 |
| 5 | 50.58 | 40.81 | 51.00 |
| 6 | 67.05 | 47.96 | 86.94 |
| 7 | 45.31 | 67.13 | 61.11 |
| 8 | 62.84 | 64.13 | 96.04 |
| 9 | 50.58 | 45.15 | 84.86 |
| 10 | 59.65 | 49.42 | 80.01 |

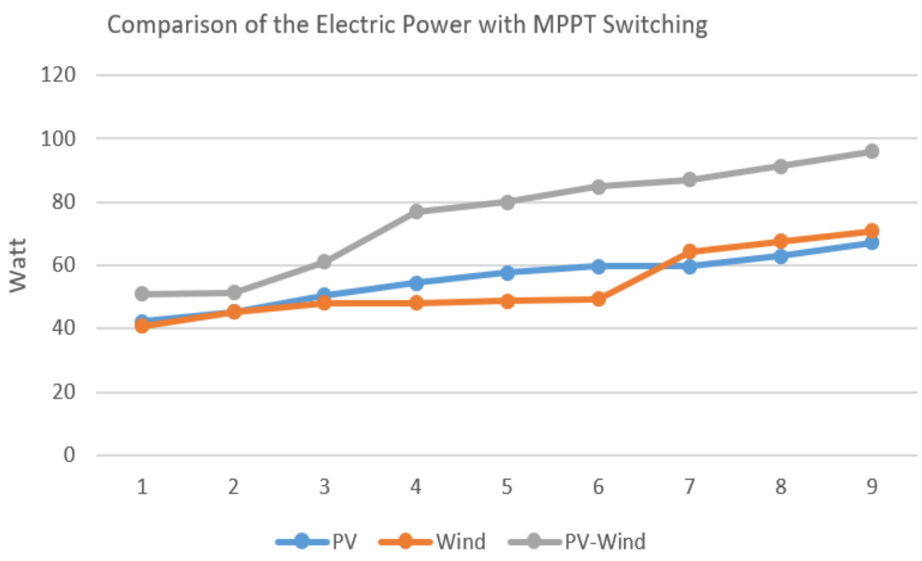


Figure 7. Characteristics of electric power using solar panel (1), wind turbines (2), and PV wind turbine hybrids (3) with the MPPT switching method

## 9. CONCLUSION

In this test, analyzing the implementation of MPPT in hybrid PV-wind turbine system energy power with management control using a switch from the test results can be concluded that The MPPT switching function controls the PV-wind turbines to take turns working after the reference produces an average voltage output of 15 Volts and a current of 5 Amperes. Moreover, the MPPT switching controls the PV-wind turbines using switching according to the reference it can work PV or wind turbines only from one of these sources of electrical energy. The maximum power value generated by the solar panel is 67.05 Watts and the maximum power value at the wind turbine is 70.65 Watts and the PV-wind turbines hybrid is 96.04 Watts, this shows that there is power optimization at the time of combining PV-wind turbine. The management method of solar cell energy and wind turbine hybrid management with the MPPT MOSFET switch setting gets the optimal PV-wind turbine hybrid energy consumption cycle with an average increase in electrical power of 38.8% and can work independently on small scale usage.

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