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# Feasibility Study of Autonomous Hybrid Wind/PV/Battery Power System in the Algerian Sahara Regions

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***Abstract***- This paper presents the study of methodology for study the feasibility of using hybrid (wind-solar) energy conversion system at Adrar (27°49'N Latitude, 00°17'E Longitude, 263m Altitude), Sahara of Algeria . A long term data of wind speed and solar radiation for every hour of the day were used. These data were used to calculate the average power generated by a PV-Wind installation for every hour of a typical day in a month. A load of a typical family house in a rural zone in Sahara of Algeria (desert area) was used as a load demand of the system. For a given load and a mixed multiple-criteria integer programming problem, the types and sizes of PV generator, wind turbine generators (WTG) and storage system was calculated.

The hybrid system considered in the present analysis consists of one 1Kw wind energy conversion system (WECS). 125w of (10) BP Photovoltaic panels together with battery storage system. A computer program has been developed to achieve this and to determine the specification of hybrid system component. The study was performed using a graphical user interface programmed in MATLAB environment.

***Keywords-*** *Hybrid, Wind Turbine, Photovoltaic, Feasibility, Modeling, Renewable Energy*

## I. INTRODUCTION

Climatic conditions determine the availability and magnitude of wind and solar energy at particular site.

Pre-feasibility studies are based on weather data (wind speed, solar insolation) and load requirements for specific site. In order to calculate the performance of an existing system, or to predict energy consumption or energy generated from a system in the design stage, appropriate weather data is required [1]. The global whether data could be obtained from internet [2] and other sources like local metrological station. The global weather pattern is taken from NASA surface metrological station. Wind and solar hybrid system can be designed with the help of these global weather patterns, for any location all over the world. Deciding on the best feasible solution will need to be done, on a site-to-site basis. Some sites can be best serviced by mains or grid power, others by generators, and some by combinations of the renewable energy solutions described above.

Some researchers used metrological station data for prefeasibility study and design of hybrid energy system. Combination of PV and wind in a hybrid energy system reduces the battery bank and diesel requirements. Feasibility of hybrid PV/wind energy system strongly depends on solar radiation and wind energy potential available at the site. Various feasibility [3-4] and performance studies are reported to evaluate option of hybrid PV/wind energy systems [5-6].

In Algeria context, a company of electricity, SONELGAZ, has used hybrid system based solar and wind energy to power the isolated villages and remote houses of south Algeria[7]. These locations incude Behar Adrar, Timimoun (Tala Hamou – moussa) and Tindouf (Gara Djbelet , Hassi Mounir, Draa el Khadra).

Dahbi and al. [8] presented the Modeling and Simulation of Hybrid (Wind + Photovoltaic + Battery) Power System In South West Algerian Site (Bechar) according to load demand.

The Adrar(South West Algerian) in new valley was selected as the site under consideration in this work since is the second largest province in Algeria, with an area of 427,368 km². It is composed of 299ksour.In the present study the daily average wind speed and solar for a given hour, averaged for that day over the 22-year were taken from NASA surface metrological station for Adrar (27°49'N Latitude,00°17'E Longitude, 263m Altitude) Algeria [9], have been analyzed to report the average daily variation of wind speed and solar radiation , probability distribution of wind speed and to investigate the feasibility of using hybrid (wind-solar) energy conversion system at Adrar.

In addition, this paper present a study and design of a complete hybrid system(one wind generator, ten PV panels and 12batteries storage for 2 day autonomie) for providing the electrical loads in a load of a typical family house in a rural zone in Sahara of Algeria (desert area) was used as a load demand of the system. For a given load and a mixed multiple-criteria integer programming problem, the types and sizes of PV generator, wind turbine generators (WTG) and storage system was calculated. A computer program is developed to achieve this and to determine the specification of hybrid system component.

## II. ENVIRONMENTAL DATA.

Climatic conditions determine the availability and magnitude of wind and solar energy at a site. Adrar is a province of southwestern Algeria, It is based around an oasis of the Sahara Desert. Two distinct seasons are noticed in this region: a very hot season (March to October) and a cold seasons (November to February) monthly mean temperature reach close to 35°c for hot months and in cooler months the mean temperatures drop by about 15°c as compared to the hot months [8]. For the site under consideration, 22 years long-term wind speed data and solar irradiation data have been used[10] .fig.1 shows the daily average wind speed and daily average solar insolation profile from the data recorded for the site (Adrar). It is clear from the figure wind speed are generally higher in spring and summer months (mar. to aug.), where it exceeds 6m/s. the minimum of wind speed during the year is 5.38m/s in Oct. and the maximum is 6.22m/s in jul . .This clearly reflects that a WECS would produce appreciably more energy during the year .The wind energy calculations are made by matching the power-wind speed characteristics of commercial wind machines with the long term hourly wind speed data.

The monthly average values of solar energy incident on the horizontal in the Adrar .It is clear from the result that solar energy incident in this region is very high specially during summer months, where it exceeds 7 KWh/sq.m/day as compared to other months. The average solar radiation is 5.84Kwh/sq.m/day .As it can be seen, the variation between the years is minimal (see figure 1).

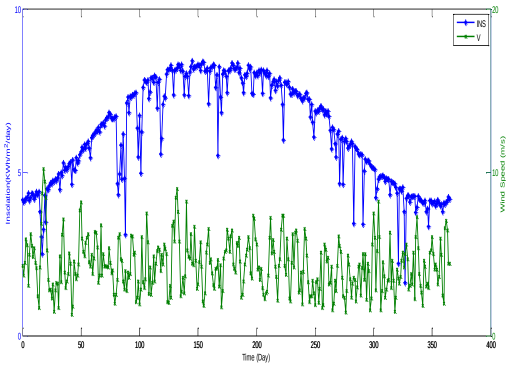


Fig 1. Daily average wind speed (m/s), and daily average solar insolation of Adrar site (KWh/m^2/day).

## III. THE SYSTEM MODELING

To design a Hybrid wind photovoltaic system (PV/WG) for a family house in rural zones, fig. 2 shows the component of the system.

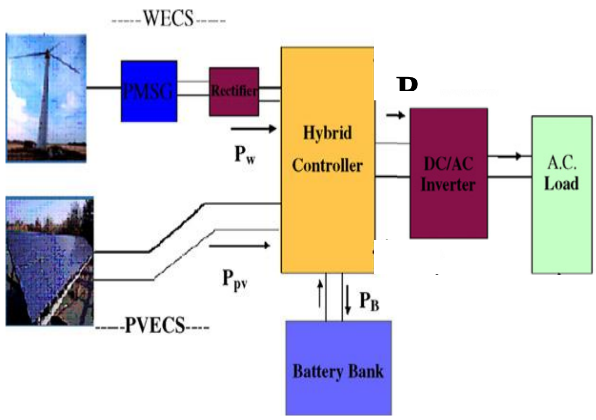


Fig 2. Hybrid system component.

### A. Modeling of wind system

The wind turbine is characterised by the nondimentional curve of coefficient of performance $C_p$ as a function of tip speed ratio. $\lambda$ is the ratio of linear speed of the tip of blades to the rotational speed of wind turbine. It can be expressed as follows [11-12]:

$$\lambda = \omega_w \cdot r / v \qquad (1)$$

Where $r$ radius of the rotor is, $\omega_w$ is mechanical angular velocity of the rotor and $v$ is speed of wind.

The coefficient of performance is also known as power coefficient. The power coefficient $C_p$ versus tip speed ratio $\lambda$ is given in fig.3. For the wind turbine used in the study (BWC XL.1 1KW). The $C_{p\_opt} = 0.44$ as of tip speed ratio $\lambda_{\_opt} = 6.9$.

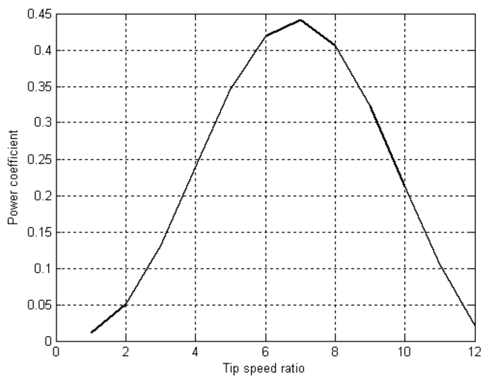


Fig 3. Power coefficient $C_p$ versus tip-speed ratio $\lambda$

Average hourly wind speed data is evaluated and converted to wind turbine power. If the wind speed is between the cut-in and the rated speed of the wind turbine, then the power output is defined as [13].

$$P_{Wind}(t) = \frac{1}{2}\rho A_w v(t)^3 C_p \eta_{ad} \quad (2)$$

Where $\rho$ is the air density (Kg/m$^3$), $A_w$ is the swept area of the rotor (sq.m) , $v$ is the wind speed (m/s), $C_p$ is the efficiency of the wind turbine(0.442), and $\eta_{ad}$ is the efficiency of the AC/DC converter (assumed to be 95% in this study) .

If wind speed is between the rated wind speed and the furling speed of the wind turbine, the power output will be equal to the rated power of the wind turbine. Finally, if the wind speed is less than the cut-in speed or greater than the furling speed, there will be no output power from the turbine.

For example, the relation between the electrical power output of a BWC XL.1 1KW generator and mechanical angular velocity of the rotor $\omega_w$ , for different wind speed is shown in fig.4. This illustrates the fact that for any given wind speed there is a rotation speed $\omega_w$ , which generate the maximum power .

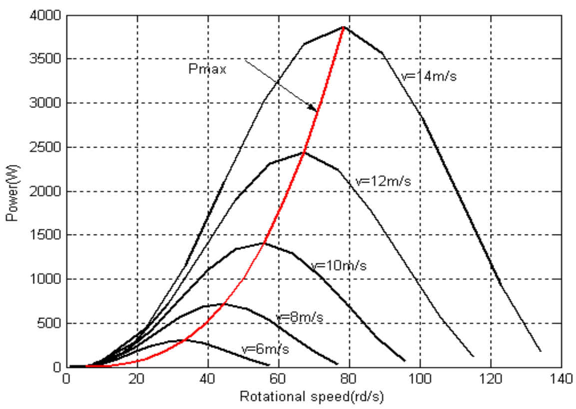


Fig 4. Wind turbine power characteristics

## B. *Modeling of PV system*

Insolation data is converted into power output from the PV array using the following equation [3]:

$$P_{pv}(t) = Ins(t) \times A \times \eta_{PV} . \eta_{pc} . P_f \quad (3)$$

Where $Ins(t)$ is the insolation data at time t (kWh/m2), A is the area of the single PV panel (sq.m) , $\eta_{PV}$ is the overall efficiency of the PV panel and the DC/DC converter, $\eta_{pc}$ is the power conditioning efficiency (0.86)and $P_f$ is the packing factor (0.9).

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

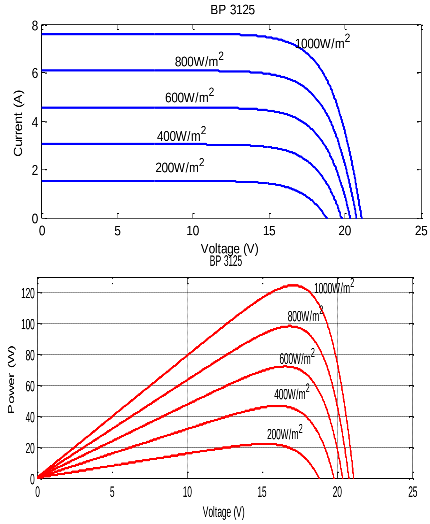


Fig 5. The I-V and P-V characteristic of PV module.

Fig. 5 gives the result for different PV solar radiation levels with constant PV temperature (25°c). The current and the power of a PV module change significantly with the change PV solar radiation.

The total wind and PV –generated power during each hour is first computed as follows[8]:

$$P_T(t) = N_w P_{wind}(t) + N_{pv} . P_{pv}(t) \quad (4)$$

Where $N_w$ and $N_{pv}$ are the number of wind turbines and PV panels, and $P_{wind}(t)$ and $P_{pv}(t)$ are the power from wind and solar PV at time t, respectively. $P_T(t)$ is equivalent to the energy generated at a particular hour (since there is a one hour time step).

## C. *Modeling of battery system*

When the total output power of PV panels and wind turbines is greater than the power demand, the battery bank is in charging state. The charge quantity of battery bank at the time t can be described by[14]

$$E_B(t) = E_B(t-1).(1-\sigma) + (P_T(t) - W_L(t)/\eta_{inv}).\eta_B \quad (5)$$

On the other hand, the battery bank is in discharging state. In this paper, the discharging efficiency of battery bank is assumed to be 1. Therefore the discharge quantity of battery bank at the time t can be expressed as:

$$E_B(t) = E_B(t-1).(1-\sigma) + (W_L(t)/\eta_{inv} - P_T(t)) \quad (6)$$

Where $E_B$ (t) and $E_B$ (t-1) are the charge quantities of battery bank at the time t and t-1, $\sigma$ is the hourly self-discharge rate, $P_T(t)$ is the total power generated by renewable energy source after energy loss in controller, $W_L$ (t) is load demand at time t, $\eta_{inv}$ and $\eta_B$ are the efficiency of inverter and charge efficiency of battery bank.

## IV. UNIT SIZING

After pre-feasibility study the selection of proper sizing of equipment is made based on weather data and maximum capacity.

The unit sizing of integrated power system plays an important role in deciding the reliability and economy of the system. In this section, a procedure for determines the sizes of the PV array and wind turbine in a PV/wind energy hybrid system. Using the measured data of solar and wind energy at a Adrar location, to determining the wind generator capacity and the number of PV panels and number of battery needed for the stand-alone system.

### *A. Load calculation*

Typical family houses in the rural zones of Adrar in Algeria are expected to be very simple and do not need large quantities of electrical energy for lighting or operating electric appliances. It is expected that most of these houses will have electrical loads as shown in table I.

TABLE I. THE DAILY LOAD ENERGY REQUIREMENT FOR A TYPICAL FAMILY HOUSE IN RURAL ZONES.

| **Load type** | **N° of Unit** | **Load Power(W)** | **Operating period h/day** |
|---|---|---|---|
| lamps (light) | 5 | 5x40 | From 20h to 24h |
| Refrigerator | 1 | 100 | 24h/day |
| TV | 1 | 80 | From 17h to 24h |
| Motor pump | 1 | 120 | From 10h to 14h |
| Washing machine | 1 | 250 | From 12h to 16h |
| Electric fan | 1 | 100 | From 11h to 16h |
| Total energy (Wh/day) | | | 5740 |

Then according to this, the total required daily demand is [15]:

$$W_T = \frac{W}{\eta_{Total}} = \frac{5740}{0.46} = 12478 Wh / day \tag{7}$$

### *B. Size of wind generator*

The acquired power from the wind turbine (BWC XL.1 1KW) considering 16h is [16]:

$$W_{wind} = W \times N_{wind} \times H_{wind-day} = 370 \times 1 \times 16 = 5920 Wh \tag{8}$$

### *C. Size of PV generator*

The required power from the PV panels will be:

$$W_{pv} = W_T - W_{wind} = 12478 - 5920 = 6558 Wh \tag{9}$$

For The hybrid system considered in the present paper it was used PV module type : BP3125 solar module[17].

PV panel efficiency $\eta_{pv} = 12\%$

Nominal capacity of PV panels: 125$W_P$

$V_{OC} = 22.1V$

$I_{SC} = 7.54A$

Max power=125$W$

Voltage selection for the system $24V_{DC}$;

Then;

Required $[Ah]$ daily;

$$E[Ah] = \frac{W_{PV}}{V_{DC}} = \frac{6558}{24} = 271.21 Ah/day \tag{10}$$

Based on the average solar intensity month where the number of daily hour solar intensity is 7.78 hours[18] and according the total current required for the system is:

$$I_{Total} = \frac{E(Ah)}{Hours} = \frac{271.21}{6} = 34.85A \tag{11}$$

To calculate the required number of PV panels that would he connected in series and in parallel, and based on the system voltage (i.e.24V), then:

$$N_{SPV} = \frac{V_{DC}}{V_{OC}} = \frac{24}{22.1} = 1.08 \approx 2 \tag{12}$$

$$N_{PPV} = \frac{I_{Total}}{I_{SC}} = \frac{34.85}{7.54} = 4.62 \approx 5 \tag{13}$$

The total required and applied number of PV panels is:

$$N_{PV} = N_{SPV} \times N_{PPV} = 2 \times 5 = 10 \tag{14}$$

### *D. Size of battery capacity*

The battery capacity is obtained by the following equation [19]:

$$C_{bat}(Wh) = \frac{W_T \times autonomy(day)}{D \times \eta_B} \tag{15}$$

$$C_{bat}(Ah) = \frac{C_{bat}(Wh)}{V_n} \tag{16}$$

Where $W_T$ (Wh) is the total daily load demand, $D$(%) and $\eta_B$ are the degree of discharge of the batteries and charge efficiency of battery bank. Two (2) day of autonomy were fixed for this study.

$$C_{bat}(Wh) = \frac{12478 \times 2}{0.5 \times 0.8} = 62391 Wh \tag{17}$$

$$C_{bat}(Ah) = \frac{62391}{24} = 2599 Ah \tag{18}$$

To meet the load profile, the number of battery capacity is 6 batteries 385Ah (for 12V) are needed.

## V. ENERGY MANAGEMENT STRATEGY

One of the main problems of the HES is related to the control and supervision of the energy distribution system. The dynamic interaction between the hybrid system (PV/WEC) and the loads and the power electronic interface of renewable source can lead to, critical problems of stability and power quality in new system, that are not very common in conventional power systems.

Managing the flow of energy throughout the proposed system to assure continuous supply of the load demand is to be done. The main objective of the energy flow and management system is to supply the load with its full demand. The operating strategy for energy flow in the system has been outlined before unit sizing and the same will be satisfied for efficient operation of integrated power system.[16]. To overcome the problem of intermittent power generation, PV power systems may be integrated with other power sources. On the other hand, current technology batteries by themselves are usually insufficient to provide the long-term energy that the increasing loads require. Hybrid systems composed of wind and batteries can be integrated with PV power systems to provide uninterrupted high-quality power. In this study the following operating strategy is employed:

-The use of electric power generated by the PV panels and wind turbines has priority in satisfying electricity demand over that provided by the batteries.

- If the total electric power generated by the PV panels and wind turbines is higher than the demand, the addition electric power will be charged into the batteries.

-If the total electric power generated by the PV panels and wind turbines is less than the demand, electric power will be discharged from the batteries to supply the demand.

## VI. DETAILED INFORMATION OF THE CHOSEN COMPONENTS

The performance data of the wind turbine, PV panels and battery storage used in this evaluation are provided in table 2, 3and 4, respectively. A bergey BWC XL.1 1KW wind turbine and a BP SX-12S (120W) solar panel were selected for the study.

TABLE II. WIND TURBINE PARAMETERS

| | |
|---|---|
| Rated output (KW) | 1 |
| Cut-in speed (m/s) | 2.5 |
| Rated speed (m/s) | 11 |
| Cut-out speed (m/s) | 13 |
| Rotor diameter (m) | 2.5 |
| Air density (Kg/m^2) | 1.225 |
| Efficiency of wind turbine (%) | 0.442 |

TABLE III. PV PANEL PARAMETERS

| | |
|---|---|
| Maximum power (W) | 125 |
| Efficiency (%) | 12 |
| Area (m^2) | 1.01 |
| $V_{OC}$ (V) | 22.1 |
| $I_{SC}$ (A) | 7.54 |
| $V_n$ (V) | 24 |

TABLE IV. PARAMETERS OF BATTERY

| | |
|---|---|
| Manufacturer | TOYO |
| Type | GFM-100 |
| Rated voltage | 12V |
| Rated capacity | 385 Ah |
| Hourly self –discharge rate | 0.0001 |
| Efficiency (%) | 80 |

## VII. SIMULATION RESULTS AND DISCUSSION

The hybrid system simulated in the present investigation consists of 1KWwind generator, 10 panels of photovoltaic solar array (120w) and six batteries storage.

Fig. 6 and Fig.7 show the daily curve and output power from the hybrid PV/Wind system and charge/discharge of battery storage.

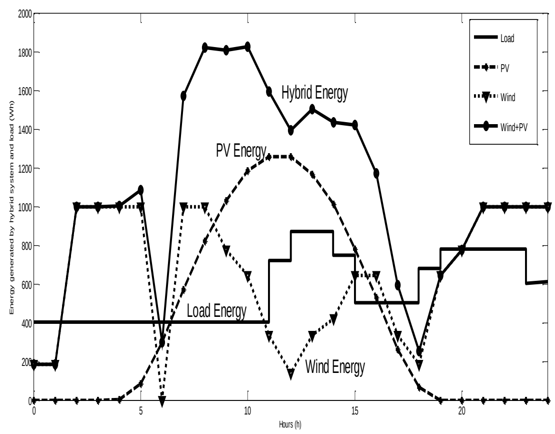


Fig 6. The daily energy production and consumption situations of typical hybrid system.(Wh)

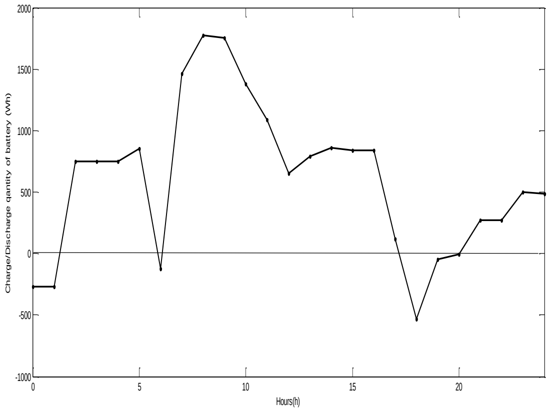


Fig 7. The hourly char /disc quantity of battery (Wh)

The daily energy production and consumption situations of typical hybrid system as given in fig.6.The maximum daily energy consumption is 869wh between 14h and 15h,and the minimum value is 400wh during the morning of day .

The fluctuation of the total outputs is all fairly violent. Furthermore, the output of wind generator change more fiercely than that of the PV array, which is determined by the in homogeneity nature of wind power and solar energy distribution.

The production exceeds the loads between (6h) to 17h, the battery also charged. It is found that the low PV power during this period can be observed. Moreover, the wind production exceeds the load demand. It is clear from the results obtained from the simulation of typical days that, the advantage of the complementarily of wind power and PV power and while minimizing the use of battery storage.

It is also observed that in most cases, the mean energy production of PV-WG system is 1062Wh. The wind energy is 649.36Wh, and the PV energy is 412.63Wh.

The surplus of power is stored in batteries, in order for use during the insufficient production of PV-WG system (the low insolation and low wind speed period) between 17PM to 20PM (see figure .6)..

The batteries are necessary for a buck up during period of insufficient energy of both two energy sources (WG system and PV system) due to weak wind speed and solar radiation.

The hourly charge /discharge quantity of battery are given in figure 7. It is clear from the results obtained from the simulation of the typical days that, the maximum charge quantity of battery $E_{B\max}$ is 370w of 12AM, and the maximum discharge quantity is 250w of 20 PM.

The situation of hourly discharge quantity of battery losses are also comparatively severe in 18h which are caused by the poorest wind power in this hour of day.

In summary, the operating situation of the system are determined by various factors such as the load demand, distribution of the natural resources and the capacities of chosen components..

Also it can be noticed, that either the advantage of the complementarily of wind power and solar energy the power failure time is dramatically decreased.

It is noted that surplus energy is generated in each hour, which results from the in homogeneity of the distributions of natural resources.

## VIII. CONCLUSION

This paper presents the feasibility of using autonomous hybrid photovoltaic-wind generator witbattery storage (PV/WG) in the site of Adrar(South West of Algeria).

The monthly average wind speeds for Adrar range from 5.38 to 6.22 m/s. The monthly average daily value of solar radiation for Adrar range from 3.21 Kwh/sq.m to 7.49 Kwh/sq.m . It indicates that the site of Adrar (South West of Algeria) consist an appropriate candidate for deployment of hybrid PV/WG systems.

Effective power generation from wind generator is expected during 79 %( 6253hour of the year) for condition in Adrar site .It is observed that in most cases, the system is able to produce more power than the loads during the year.

The batteries are necessary for a buck up during period of insufficient energy of both two energy sources (WG system and PV system) due to weak wind speed and solar radiation.

The complementary feature of PV and wind makes the system more reliable.

Finally, it can be concluded that the use of renewable energy source as a reliable option for rural site in South West of Algeria is justified. In addition, the impact of this system in providing electricity will create many new opportunities and avenues leading to national development through rural development.

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