



Integrated with Boost-Buck-Boost Topology on Solar & Wind Renewable Energy Resources

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Abstract: The integration was started with wind farms. When the price for photovoltaic panels became affordable, the penetration of PV became to be used more often but not necessarily at the same level of power as wind. For medium to high power the PV's are modularly used. Many studies propose small power integration (few kW) for both wind and solar PV as hybrid stand-alone systems. Other studies added fuel cells and batteries creating the concept of multi-port system. I have proposed a double-port boost-buck-boost (BBB) topology that enhances the power capability of the PV-Wind power system during partial solar irradiation and weak winds. In this paper a hybrid power electronics interface that combines the energy from solar photovoltaic panel and wind generator into a small scale stand-alone system is proposed. After the description of operation of this Dual-port interface, a simulation model for 1 kW PV array integrated together with a 1.5 kW wind generator was developed and simulation results are presented.

I. Introduction

In general, demand in classic energy resources made expensive affair like oil and coal. So there is a need to solve with clean renewable energy sources among other solar and wind. The progress in power electronics facilitated integration of these renewable energy sources either grid or as stand-alone for small scale use. Historically, the integration was started with wind farms. When the price for photovoltaic panels became affordable, the penetration of PV became to be used more often but not necessarily at the same level of power as wind. For medium to high power the PV's are modularly used. Many studies propose small power integration (few kW) for both wind and solar PV as hybrid stand-alone systems. Other studies added fuel cells and batteries creating the concept of multi-port system. Apart from methods of integration a continuous attention was towards controlling the systems in order to maximize solar PV efficiency or wind.

Stability of renewable system was also under scrutiny. Double or multi-port integration systems for renewable have been previously proposed. The communality of all these studies proposed parallel connection of various renewable sources on a single dc bus. In this study a double-port integration system for renewable energy sources is proposed. Figure 1 shows a small scale system of 1 kW PV array integrated together with a 1.5 kW wind generator (WG).

II. Small Scale Renewable System

When an operating at nominal conditions, the dual input interface converts energy delivered by the PV array and wind generator in a comparable DC voltage. Due to the variable nature of wind and sun irradiation, the system must have a battery backup. In this proposed solution the corresponding DC output voltage for each renewable source is connected in series and thus increasing the power availability at partial solar irradiation and weak wind.

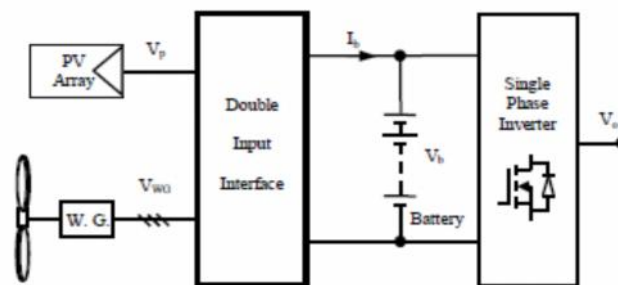


Fig.1 Double Input Renewable System

The third stage of the interface produces a charging current for the battery. During the day light, the consumption is lower than the PV can produce and the greatest part of this energy is stored into the battery. When the wind blows, the energy produced by the wind generator is also stored into battery. Energy stored is then released for the period when there is no sun or wind. The output of the system is a single-phase standard voltage 50 Hz PWM inverter capable of delivering 3 kW at peak demand.

Photovoltaic system:

Photovoltaic systems (PV system) use solar panels to convert sunlight into electricity. A system is made up of one or more photovoltaic (PV) panels, a DC/AC power converter (also known as an inverter), a racking system that holds the solar panels, electrical interconnections, and mounting for other components. Optionally it may include a maximum power point tracker (MPPT), battery system and charger, solar tracker, energy management software, solar concentrators or other equipment. A small PV system may provide energy to a single consumer, or to an isolated device like a lamp or a weather instrument. Large grid-connected PV systems can provide the energy needed by many customers. The electricity generated can

be either stored, used directly (island/standalone plant), or fed into a large electricity grid powered by central generation plants (grid-connected/grid-tied plant), or combined with one or many domestic electricity generators to feed into a small grid (hybrid plant). Systems are generally designed in order to ensure the highest energy yield for a given investment.

Background

Today, solar-generated electricity serves people living in the most isolated spots on earth as well as in the centre of our biggest cities. First used in the space program, photovoltaic (PV) systems are now both generating electricity to pump water, light up the night, activate switches, charge batteries, supply the electric utility grid, and more. Whether you are a homeowner, farmer, planner, architect, or just someone who pays electric utility bills, PV may already touch your life in some way.

We group PV applications into the following categories:

- Simple or "Stand Alone" PV Systems
- PV with Battery Storage
- PV with Backup Generator Power
- PV Connected to the Local Utility
- Utility-Scale Power Production
- Hybrid Power Systems

Simple PV Systems

The same sunny days that dry out plants, make animals thirsty, and heat up buildings and cars are also good days for generating electricity with photovoltaic's. This electricity can be used to power water pumps for irrigation and drinking wells, and ventilation fans for air cooling. For this reason, the most simple PV systems use the dc electricity as soon as it is generated to run water pumps or fans.

These basic PV systems have several advantages for the special jobs they do. The energy is produced where and when it is needed, so complex wiring, storage, and control systems are unnecessary. Small systems, under 500 watts (W), weigh less than 68 kilograms (150 pounds), making them easy to transport and install. Most installations take only a few hours. And, although pumps and fans require regular maintenance, the PV modules require only an occasional inspection and cleaning.

PV with Battery Storage

Storing electrical energy makes PV systems a reliable source of electric power day and night, rain or shine. PV systems with battery storage are being used all over the world to power lights, sensors, recording equipment, switches, appliances, telephones, televisions, and even power tools.

PV systems with batteries can be designed to power dc or ac equipment. People who want to run conventional ac equipment add a power conditioning device called an "inverter" between the batteries and the load. Although a small amount of energy is lost in converting dc to ac, an inverter makes PV-generated electricity behave like utility power to operate everyday ac appliances, lights, and even computers.

A. Photovoltaic cell model for proposed system

The equivalent model of a photovoltaic cell is shown in figure 2. The current-voltage characteristic of the cell is:

$$I = I_{ph} - I_o \left\{ \exp \left[\frac{q(V + I \cdot R_s)}{nKT} \right] - 1 \right\} - \frac{V + I \cdot R_s}{R_{sh}} \quad (1)$$

Where:

- I = output current;
- I_{ph} = photo current;
- I_o = saturation current of the diode;
- V = output voltage;
- q = the charge of electron;
- $n \in [1, 2]$ is the diode constant;
- K = Boltzmann constant;
- T = cell's temperature in Kelvin degrees;
- R_s = series resistance;
- R_{sh} = shunt resistance.

In this study, four panels rated at approximate 250 W with V_{oc} of 37 V and I_{sc} – 8.9 A. Figure 3 and 4 shows the I-V and power characteristic of one panel at standard conditions respectively. For an efficient energy conversion, the panel should be operated in the MPP point.

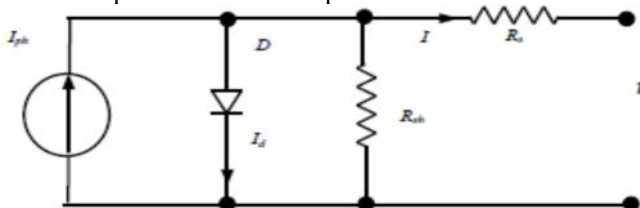


Fig.2 PV Cell's equivalent model

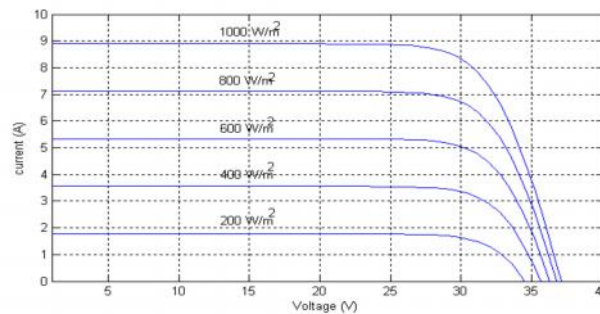


Fig.3 I/V characteristics

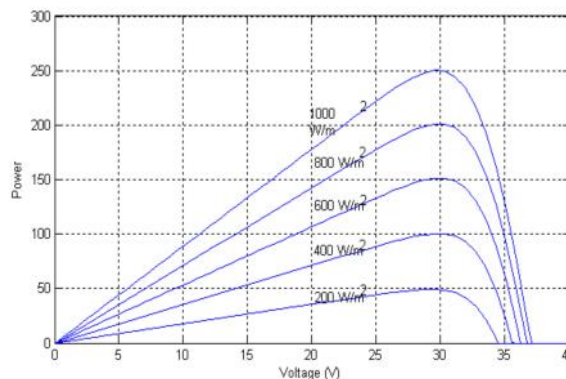


Fig.4 Power characteristics

B. Wind generation model

The mechanic power produced by the wind blowing the blades is given as:

$$P_{m-w} = 0.5 \rho \cdot A \cdot C_p(\lambda, \beta) \cdot v_w^3 \tag{2}$$

Where ρ is the air density (kg/m³), A is the turbine swept area (m²) and v_w is the wind speed (m/s). Coefficient C_p is a dimensionless power coefficient which depends on λ and the blade pitch angle (β) [13]:

$$C_p = 0.5176 \left(\frac{116}{\lambda_i} - 0.4\beta - 21 \right) \exp\left(-\frac{21}{\lambda_i} \right) + 0.0068\lambda \tag{3}$$

With:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{4}$$

$$\lambda = \omega_m R / v_w$$

Where m is the angular speed of the turbine and R is the radius of the turbine/blades. Then, the electromagnetic torque (T_{em}) of the generator can be written as:

$$T_{m-w} - T_{em} = J \frac{d\omega_m}{dt} + B\omega_m \tag{5}$$

$$T_{em} = \frac{3EI}{2\omega} = \frac{3p\Psi}{4} I$$

Where J is total inertia, B is the effective friction coefficient, p is the number of poles, Ψ is the flux linkage, E is the amplitude of the emf and I is the amplitude of the generator output current. Then the wind turbine maximum power for different wind speeds (see figure 5) is going to be matched by electric load connected to the generator.

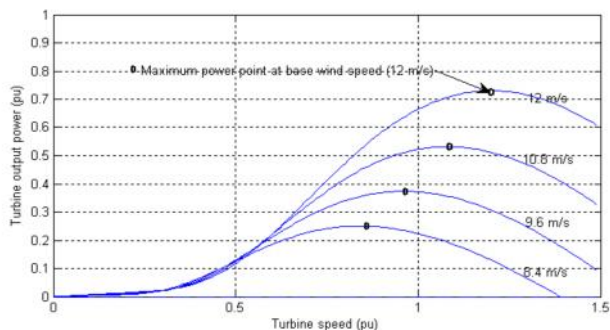


Fig. 5 Turbine output power and speed

Hydroelectricity:

The energy from moving water is converted to electricity when water passes by blades similar to those on a ship's propeller. The blades are connected to a rotating shaft which turns a generator to produce electricity. Hydroelectric power plants in Wisconsin range from large, utility-owned dams on major rivers to small locally-owned dams on small streams.

III. Power Electronic For Wind Power Generation Systems

A. Characteristics of Wind Power Conversion

The aerodynamic power, P , of a wind turbine is given by

$$P = \frac{1}{2} \rho \pi R^2 v^3 C_p \tag{1}$$

where R is the turbine radius, v is the wind speed, and C_p is the turbine power coefficient which represents the power conversion efficiency of a wind turbine. C_p is a function of the tip speed ratio, λ , as well as the blade pitch angle β in a pitch controlled wind turbine. λ is defined as the ratio of the tip speed of the turbine blades to wind speed, and given by

$$\lambda = \frac{R \cdot \Omega}{v} \tag{2}$$

where Ω is the rotational speed of the wind turbine. A typical $C_p - \lambda$ curve for a fixed pitch angle β is shown in Fig. 1. It can be seen that there is a maximum power coefficient, $C_{P,max}$.

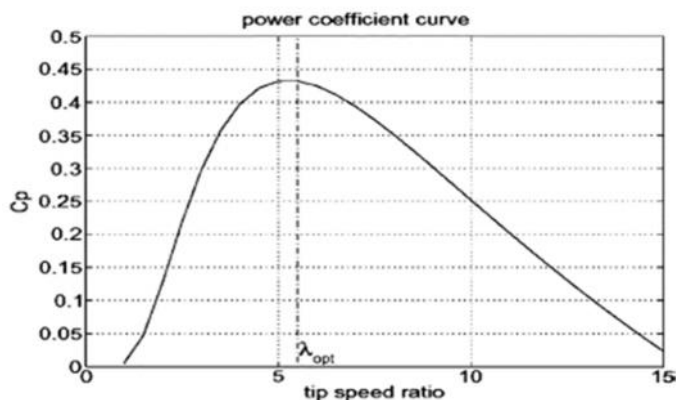


Fig. 6 Typical Cp- curve for a wind turbine

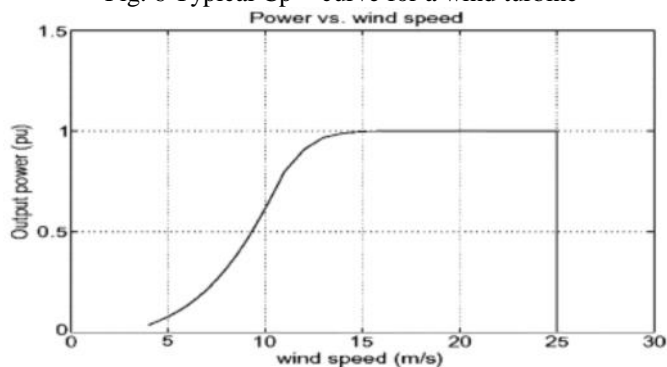


Fig. 2. Power-wind speed characteristics for a wind turbine.

Fig. 7 Power-wind speed characteristics for a wind turbine

Normally, a variable speed wind turbine follows the $C_{P,max}$ to capture the maximum power up to the rated speed by varying the rotor speed to keep the system at λ_{opt} . Then it operates at the rated power with power regulation during the periods of high wind by the active control of the blade pitch angle or the passive regulation based on aerodynamic stall. A

typical power- wind speed curve with a cut-off wind speed of 25 m/s is shown in Fig. 2, however, the cut-off wind speed may vary depending on the type of wind turbines.

B. Variable Speed Wind Turbines

The development in wind turbine systems has been steady for the last 25 years and four to five generations of wind turbines exist [1]. The wind turbine technology can basically be divided into three categories: the systems without power electronics, the systems with partially rated power electronics and the systems with full-scale power electronic interfacing wind turbines. The wind turbine systems in Fig. 3 using induction generators, which independent of torque variation, keep an almost fixed speed (variation of 1–2%). The power is limited aerodynamically either by stall, active stall or by pitch control. A soft-starter is normally used in order to reduce the inrush current during start-up. Also a reactive power compensator is needed to reduce (almost eliminate) the reactive power demand from the turbine generators. It is usually done by activating continuously the capacitor banks following load variation (5–25 steps). Those solutions are attractive due to low cost and high reliability.

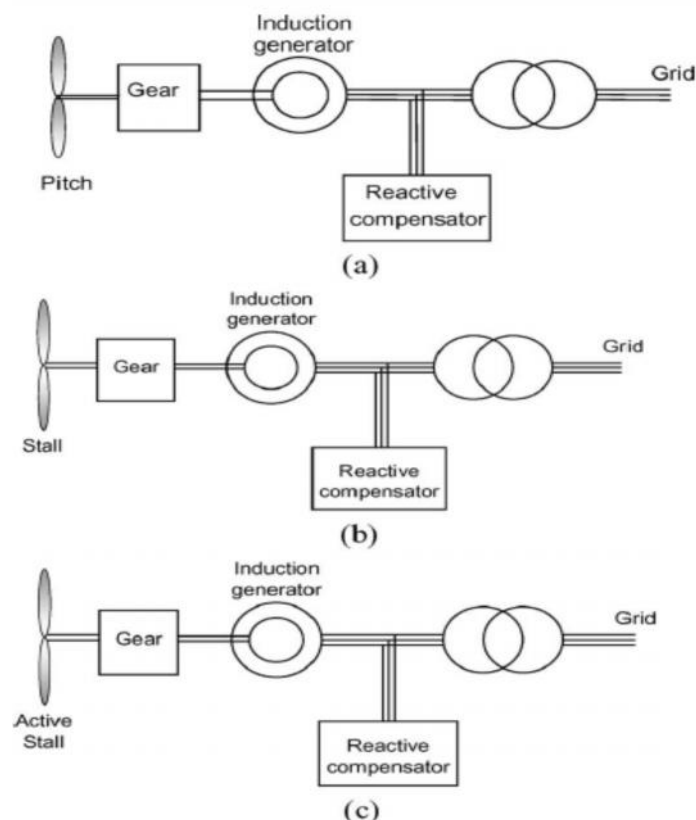


Fig. 8 Wind turbine systems without power converter but with aerodynamic power control: (a) pitch controlled, (b) stall controlled, and (c) active stall controlled.

The next category is wind turbines with partially rated power converters and much more improved control performance can be obtained. Fig. 4 shows two such solutions. Fig. 4(a)

shows a wind turbine system where the generator is an induction generator with a wounded rotor. An extra resistance controlled by power electronics is added in the rotor, which gives a speed range of 2 to 4%. The power converter for the rotor resistance control is for low voltage but high currents. At the same time an extra control freedom is obtained at higher wind speeds in order to keep the output power fixed. This solution also needs a softstarter and a reactive power compensator.

Another solution of using a medium scale power converter with a wounded rotor induction generator is shown in Fig. 4(b). A power converter connected to the rotor through slip rings controls the rotor currents. If the generator is running super-synchronously, the electrical power is delivered through both the rotor and the stator. If the generator is running sub-synchronously the electrical power is only delivered into the rotor from the grid. A speed variation of 60% around synchronous speed may be obtained by the use of a power converter of 30% of nominal power. Furthermore, the required rating of the power converter can be higher, depending on the designed fault handing capability as well as the ability of controlling reactive power,

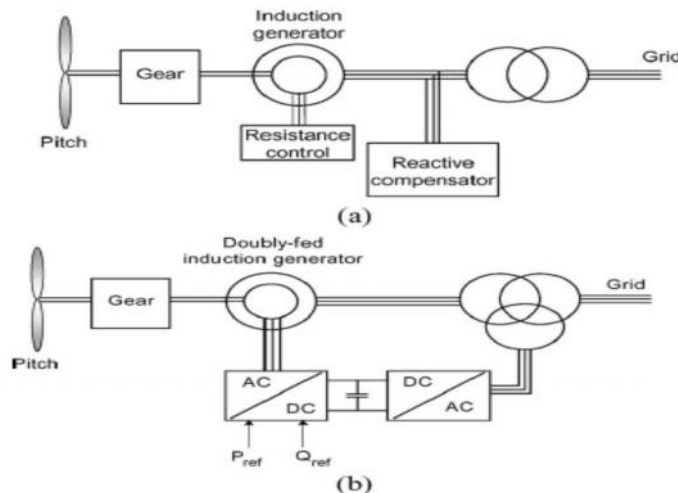


Fig. 9. Wind turbine topologies with partially rated power electronics: (a) rotor-resistance converter and (b) doubly fed induction generator.

which give a better grid performance. The solution is naturally a little bit more expensive compared to the classical solutions, however it is possible to save on the safety margin of gear, having reactive power compensation/production and more energy captured from the wind.

The third category is wind turbines with a full-scale power converter between the generator and grid, which gives extra losses in the power conversion but it will gain the added technical performance. Fig. 5 shows four possible solutions with full-scale power converters.

The solutions shown in Fig. 5(a) and (b) are characterized by having a gear. A synchronous generator solution shown in Fig. 5(b) needs a small power converter for

field excitation. Multipole generator systems with the synchronous generator without a gear are shown in Fig. 5(c) and (d). Permanent magnets are used for the system shown in Fig. 5(d), which are still becoming cheaper. Various power electronic interfaces may be used with permanent magnet wind power generators [6]–[8]. Simulation tools are developed to investigate the design and operation of the wind turbines [9]. All four solutions have the same controllable characteristics since the generator is decoupled from the grid by a voltage-sourced dc-link. The power converter to the grid enables a fast control of active and reactive power. However, the negative side is a more complex system with a more sensitive power electronic part. Comparing the different wind turbine systems in respect to performance shows a contradiction between the cost and the performance. By introducing power electronics many of the wind turbine systems behave like a power plant [10]. In respect to control performance they are faster, but the produced real power depends on the available wind. On the other hand they may always be able to deliver reactive power, which can be used for power system control.

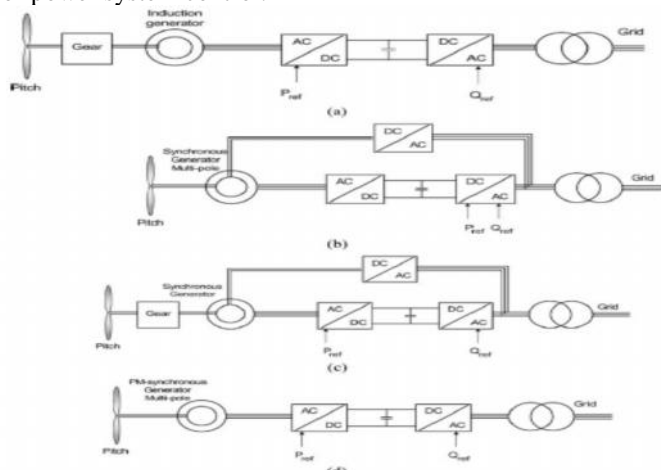


Fig. 10 Wind turbine systems with full-scale power converters with active and reactive power control: (a) induction generator with gear, (b) synchronous generator with gear, (c) multipole synchronous generator, and (d) multipole permanent magnet synchronous generator.

Power electronic interface, the real power cannot easily be controlled without a pitch control mechanism or dumping devices. However, if the rotor is connected to the grid via power electronic converters as shown in Fig. 4(b), the offshore wind farm equipped with doubly fed induction generators can perform both real and reactive power control while operate the wind turbines in variable speed to maximize the energy capture and to reduce the mechanical stress and noise. The power electronic converters are normally only rated as a small part of the system capacity, say 20–30%. Since the controllability is related to the rating of the power electronic converters, other compensation methods/devices may still be required dependent on system demands. For long distance transmission of power from offshore

wind farm, HVDC may be a viable option. In a HVDC transmission, the low or medium ac voltage at the wind farm is converted into a high dc voltage on the transmission side and the dc power is transferred to the on-shore system where the dc voltage is converted back into ac voltage. For certain power level, a voltage source converter (VSC) based HVDC transmission system may be used instead of the conventional thyristor based HVDC technology. A configuration of using dc local network, decentralized control with a dc transmission, where each wind turbine has its own power electronic converter, so that it is possible to operate each wind turbine at an individual optimal speed. Each system configuration has its own feature and suitability; the most suitable system configuration for a particular wind farm has to be determined by taking the details of the concerned wind farm into consideration.

IV Control Strategy

The main purpose of the proposed system is to harvest energy from renewable sources in an efficient way. Hence the control strategy is towards each input converter to match the maximum power point for the corresponding source.

A. PV Input Control

For this application a simple PI regulator (figure 7) has been used for controlling the input current $I_{pv} = I_{L1}$. The initial set point (1) for switch S1 and value for L1 are chosen to satisfy the maximum power point corresponding with standard solar irradiation of 1000 W/m². One other parameter considered is panel temperature (T_{pv}); because the performances of photovoltaic cells depend on temperature.

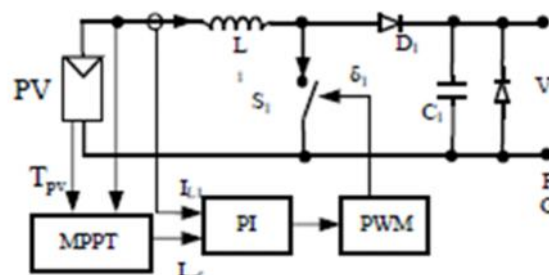


Fig. 11 Control for solar PV MPPT

Maximum power point tracking:

(MPPT) is a technique that grid-tie inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels, though optical power transmission systems can benefit from similar technology. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

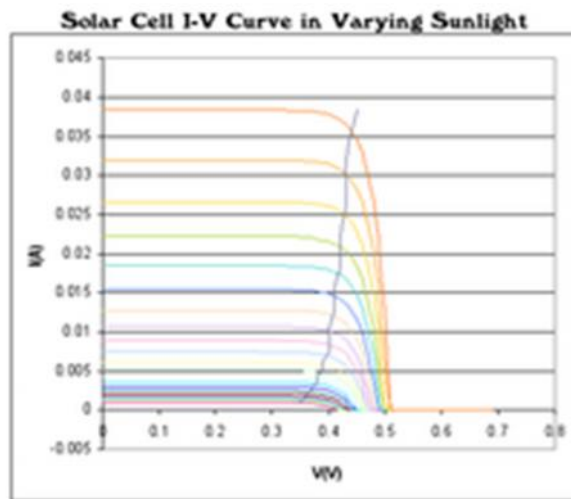


Fig. 12 I-V curve

Solar cell I-V curves where a line intersects the knee of the curves where the maximum power point is located.

Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, abbreviated FF , is a parameter which characterizes the non-linear electrical behavior of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of Open Circuit Voltage V_{oc} and Short-Circuit Current I_{sc} . In tabulated data it is often used to estimate the maximum power that a cell can provide with an optimal load under given conditions, $P = FF * V_{oc} * I_{sc}$. For most purposes, FF , V_{oc} , and I_{sc} are enough information to give a useful approximate model of the electrical behavior of a photovoltaic cell under typical conditions.

For any given set of operational conditions, cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V / I as specified by Ohm's Law. The power P is given by $P = V * I$. A photovoltaic cell, for the majority of its useful curve, acts as a constant current source.^[4] However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) dI/dV of the I-V curve is equal and opposite the I/V ratio (where $dP/dV=0$).^[5] This is known as the **maximum power point** (MPP) and corresponds to the "knee" of the curve.

A load with resistance $R = V/I$ equal to the reciprocal of this value draws the maximum power from the device. This is sometimes called the **characteristic resistance** of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be.

Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the source impedance matches with the load impedance. In the source side a boost converter is connected to a solar panel in order to enhance the output voltage. By changing the duty cycle of the boost converter appropriately the source impedance is matched with that of the load impedance. Several approaches have been proposed for tracking the MPP [4]. Among those methods, the perturb and observe (P&O) and incremental conductance (INC) methods are widely used although they have some problems such as the oscillation around MPP and confusion by rapidly changing atmospheric conditions [6,7]. In general, these tracking approaches use a fixed iteration step size, which is determined by the accuracy and tracking speed requirement.

MPPT placement:

Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows through all panels in the string. Because different panels have different IV curves and different MPPs (due to manufacturing tolerance, partial shading,^[16] etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy.^[1]

Some companies (see power optimizer) are now placing peak power point converters into individual panels, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

Operation with batteries:

At night, an off-grid PV power system may use batteries to supply loads. Although the fully charged battery pack voltage may be close to the PV panel's maximum power point voltage, this is unlikely to be true at sunrise when the battery has been partially discharged. Charging may begin at a voltage considerably below the PV panel maximum power point voltage, and an MPPT can resolve this mismatch.

When the batteries in an off-grid system are fully charged and PV production exceeds local loads, an MPPT can no longer operate the panel at its maximum power point as the excess power has no load to absorb it. The MPPT must then shift the PV panel operating point away from the peak power point until production exactly matches demand. (An alternative approach commonly used in spacecraft is to divert surplus PV power into a resistive load, allowing the panel to operate continuously at its peak power point.)

In a grid connected photovoltaic system, all delivered power from solar modules will be sent to the grid. Therefore, the MPPT in a grid connected PV system will always attempt to operate the PV panel at its maximum power point.

Fractional Open-Circuit Voltage:

The near linear relationship between V_{mpp} and open circuit voltage of a PV array, under varying irradiance and temperature levels, has given rise to the fractional V_{oc} method; the relationship between the V_{mpp} and V_{oc} is almost linear.

$$V_{mpp} \approx K1 * V_{oc}$$

Where $k1$ is proportionality constant, since $k1$ is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining V_{mpp} and V_{oc} for the specific PV array at different irradiance and temperature levels. The factor $k1$ has been reported to be between 0.71 and 0.78.

Once $k1$ is known, V_{mpp} can be computed with V_{oc} measured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power. To prevent this, it can use pilot cells from which V_{oc} can be obtained. These pilot cells must be carefully chosen to closely represent the characteristics of the PV array. Once V_{mpp} has been approximated, a closed-loop control on the array power converter can be used to reach this desired voltage. Since the relation is only an approximation, the PV array technically never operates at the MPP.

Fractional short-Circuit Current

Fractional short circuit current results from the fact that, under varying atmospheric conditions, I_{mpp} is approximately linearly related to the I_{sc} of a PV array thus $I_{mpp} \approx K2 * I_{sc}$

Where $K2$ is proportionality constant, just like in the fractional V_{oc} technique, $K2$ has to be determined according to the PV array in use. The constant $K2$ is generally found to be between 0.78 and 0.92. Measuring I_{sc} during operation is problematic. An additional switch usually has to be added to the power converter to periodically short the PV array so that I_{sc} can be measured using a current sensor. This increases the number of components and cost. It is clear that this method and the previous one have major drawbacks, the power output is not only reduced when finding I_{sc} but also because the MPP is never perfectly matched.

Fuzzy Logic Control

Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity. Fuzzy logic control generally consists of three stages: fuzzification, rule base lookup table, and defuzzification. During fuzzification, numerical input variables are converted into linguistic variables based on a membership function. In this case, five fuzzy levels are used: NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big).

TABLE I. FUZZY RULE BASE TABLE

$E \backslash \Delta E$	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

The inputs to a MPPT fuzzy logic controller are usually an error E and a change in error ΔE . The user has the flexibility of choosing how to compute E and ΔE . Since dP/dV vanishes at the MPP By calculate the following

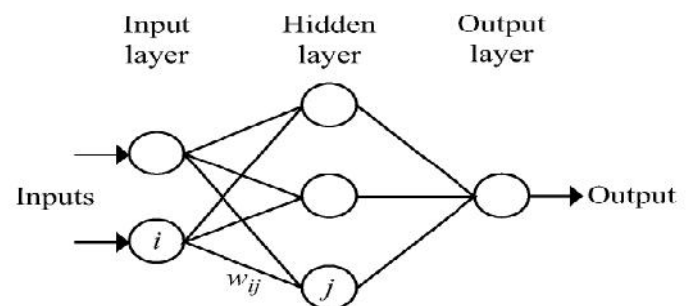
$$E(n) = \frac{P(n) - P(n - 1)}{V(n) - V(n - 1)}$$

and

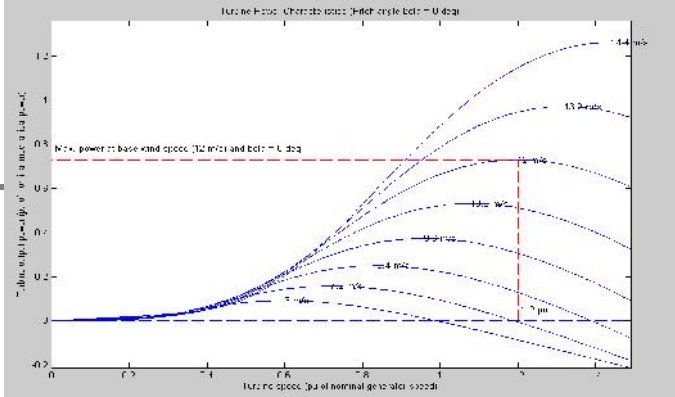
$$\Delta E(n) = E(n) - E(n - 1)$$

Neural Network

Neural networks commonly have three layers: input, hidden, and output layers. The number of nodes in each layer varies and is user-dependent. The input variables can be PV array parameters like V_{oc} and I_{sc} , atmospheric data like irradiance and temperature, or any combination of these. The output is usually one or several reference signal(s) like a duty cycle signal used to drive the power converter to operate at, or close to, the MPP, how close the operating point gets to the MPP depends on the algorithms used by the hidden layer and how well the neural network has been trained.



The links between the nodes are all weighted. The link between nodes i and j is labeled as having a weight of w_{ij} . To accurately identify the MPP, the w_{ij} 's have to be carefully determined through a training process, whereby the PV array is tested over months or years and the patterns between the input(s) and output(s) of the neural network are recorded. Since most PV arrays have different characteristics, a neural network has to be specifically trained for the PV array with which it will be used.



The characteristics of a PV array also change

with time, implying that the neural network has to be periodically trained to guarantee accurate MPPT.

DC-Link Capacitor Droop Control

DC-link capacitor droop control is MPPT technique that is specifically designed to work with a PV system that is connected in cascade with an AC system line as. The duty ratio D , of an ideal boost converter is given by

$$D = 1 - \frac{V}{V_{link}}$$

Where V is the voltage across the PV array and V_{link} is the voltage across the DC link. If V_{link} is kept constant, increasing the current going to the inverter increases the power coming out of the boost converter, and consequently increases the power coming out from the PV array. While the current is increasing, the voltage V_{link} can be kept constant as long as the power required by the inverter does not exceed the maximum power available from the PV array. If that is not the case, V_{link} starts drooping. Right before that point, the current control command I_{peak} of the inverter is at its maximum and the PV array operates at the MPP. The AC system line current is fed back to prevent V_{link} from drooping and D is optimized to bring I_{peak} to its maximum.

dP/dV or dP/dI Feedback Control

Thanks to the digital signal processors and microcontrollers being able to handle complex computations, an obvious way of performing MPPT algorithms is to compute the slope dP/dV , or dP/dI , of the PV power curve and feed it back to the power converter with some control to drive it to zero. The way the slope is computed and its sign is stored for the past few cycles. Based on these signs, the duty ratio of the power converter is either incremented or decremented to reach the MPP. A dynamic step size is used to improve the transient response .

B. Wind Input Control

Figure 8 shows the schematic for the control strategy. In order the turbine to operate efficiently, the electrical load of the generator should match mechanic power at MPP. Usually, the generator is a permanent magnet synchronous type and frequency of the three-phase output voltage is directly proportional with the wind turbine speed. Hence, the information needed to determine the maximum power point is taken from the output of the wind generator. One easy method to find the optimal load (and turbine speed) corresponding to that wind speed (vW), for maximum power point is using a look-up table which has been previously determined and stored [22]. Same as

before, the choice of inductor L_2 and initial duty cycle 2 are taken to match the standard output at base wind speed.

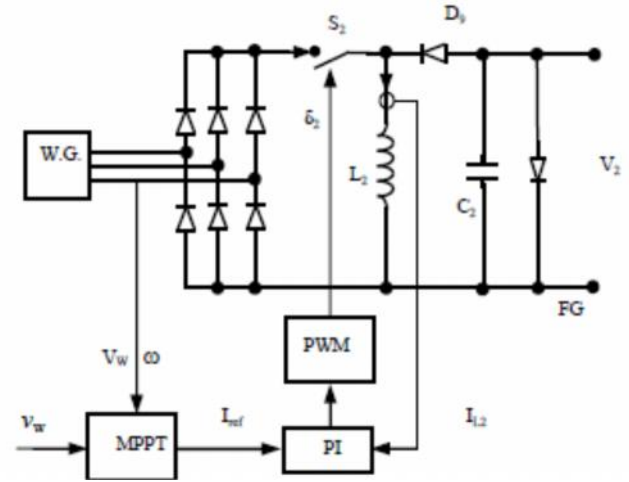


Fig.13 Control for wind generator MPPT

C. Output Regulation

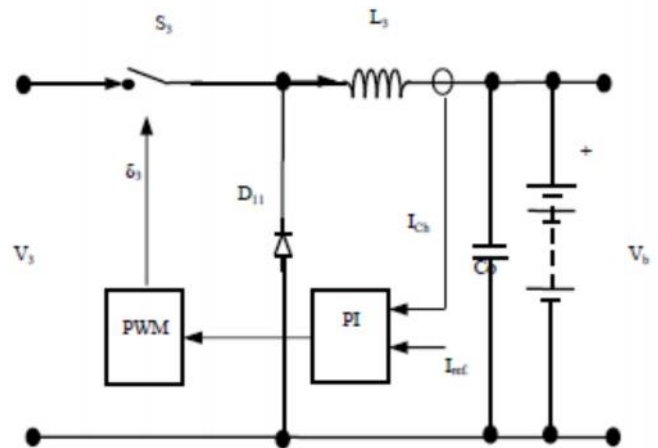


Fig.14 Control for output/charging current

The regulation of the output/charging current for the battery is done using the same type of PI controller. The reference current depends on choice of battery and its capacity in Ah. The value of L_3 and the range of duty cycle 3 for S_3 depend on the range of variation of input voltage V_3 . The switching should stop when the input conditions for solar PV and wind generation combined do not produce a voltage V_3 higher than battery voltage (V_b).

V Simulation results

The efficiency of the system has increased by using these methods presented this project and results suggests that its effectiveness.

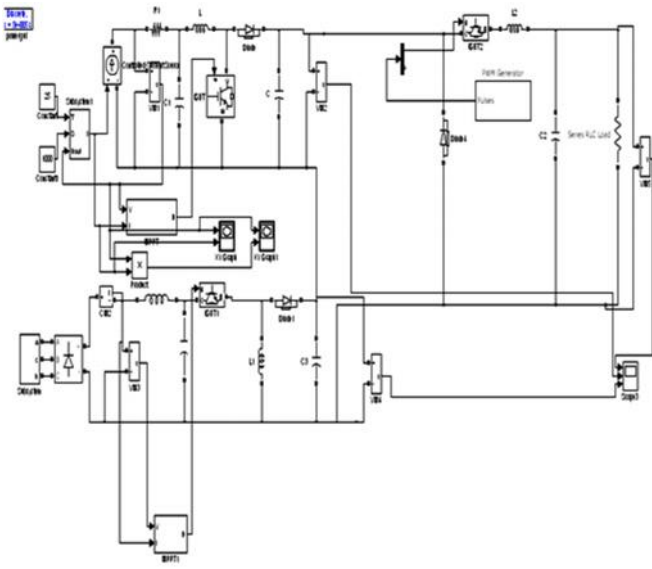


Fig. 15 Simulation diagram

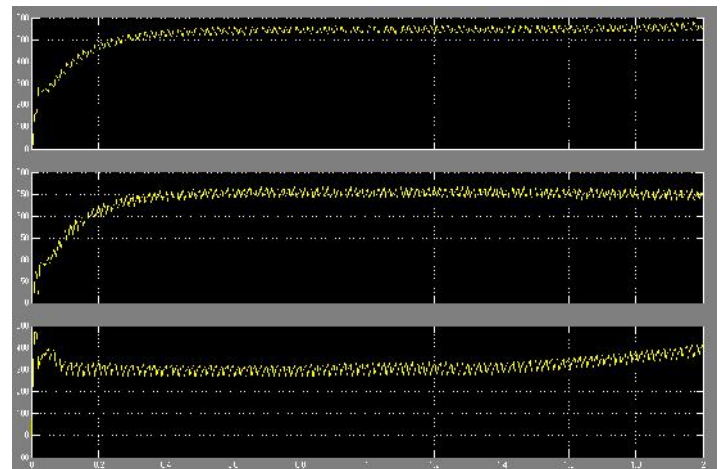


Fig. 19 Voltages for nominal input conditions(vdc, v windconv, v pv conv)

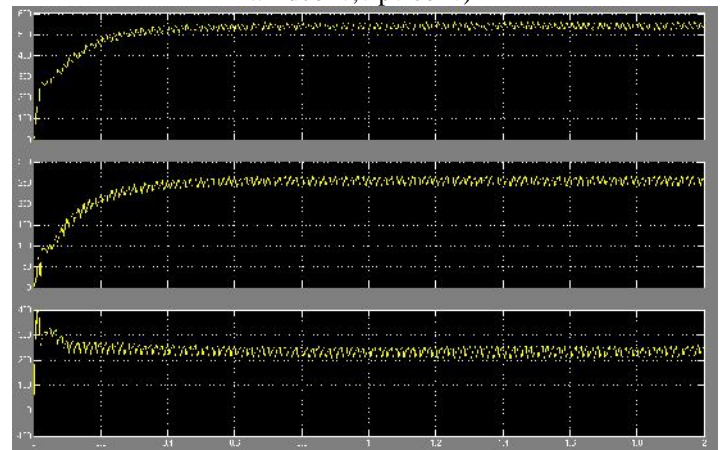


Fig. 20 Interface voltages for 10.8 m/s and 1000W/m2

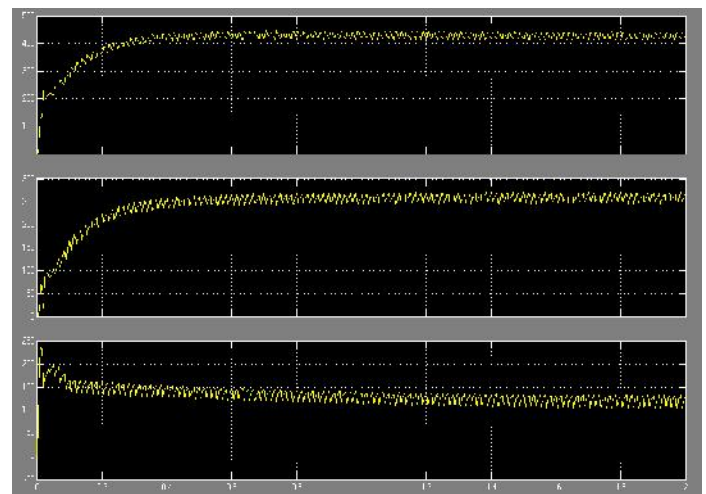


Fig. 21 Interface voltages for 9.6 m/s and 1000W/m2

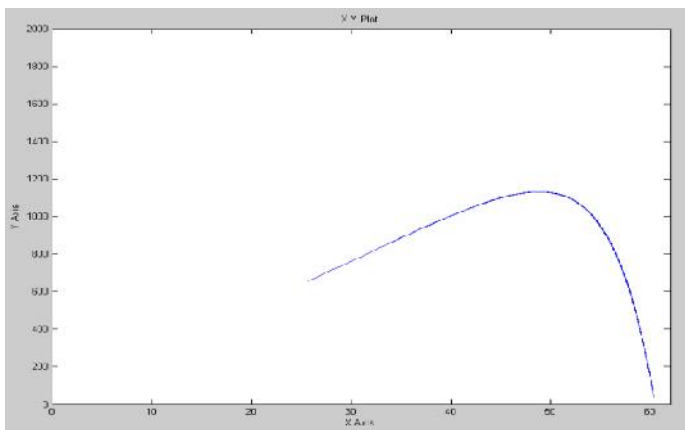


Fig. 16 Power characteristics

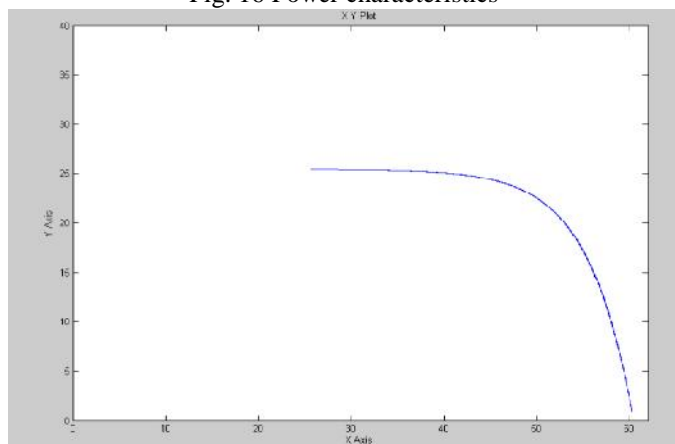


Fig. 17 I/V characteristics

Fig. 18 ATurbine's power characteristics DC link voltage

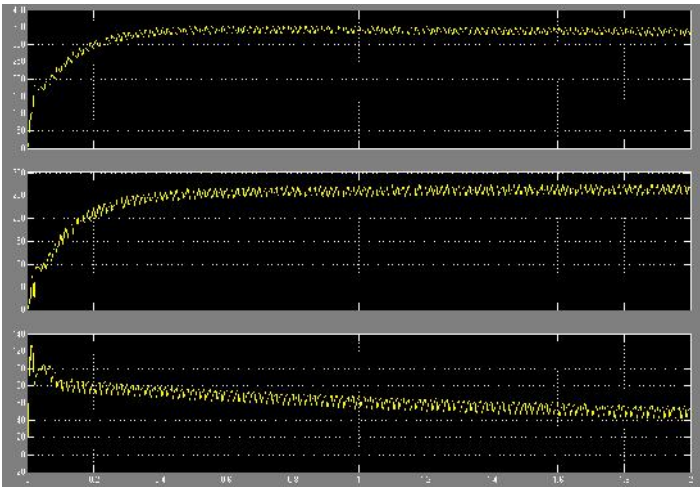


Fig. 22 Interface voltages for 8.4 m/s and 1000W/m²

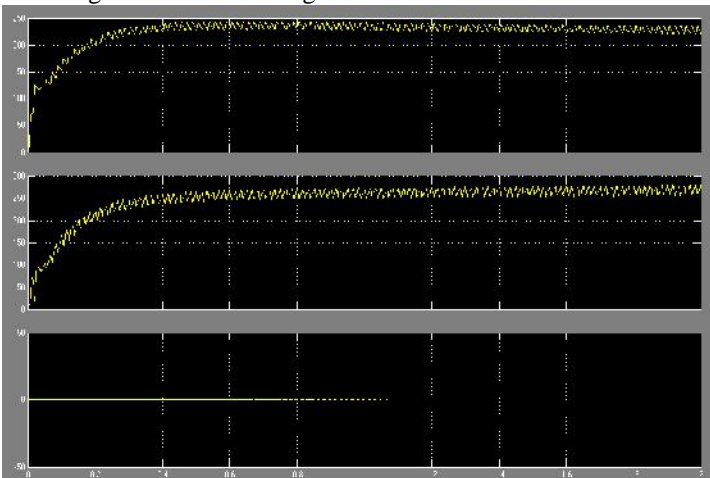


Fig. 23 Interface voltages for 0 m/s and 200W/m²

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Conclusion

In this paper a double-port interface has been presented. The specific of this interface consist on naturally series connection of the outputs of the two different dc/dc converter. The system is stable and there is no interference between the two input converters. Using the data for a 1 kW PV system and 1.5 kW wind generator, the simulation results shown and extended power capability even for partial operating conditions and thus greater energy stored. Hence, this system is recommended for small scale stand-alone renewable energy system.

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