

Single Stage Multimode Converter Based Solar Powered BLDC Drive

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Abstract— Solar energy maintains life on the earth, and it is an infinite source of clean energy. Modeling and simulation of renewable sources have enhanced the optimal integration of Photovoltaic systems into smart grids and other applications. The main notion of the new converter presented is to use a single-stage three phase solar PV converter to perform dc/ac and dc/dc operations. The system incorporates fuzzy logic controller for optimized performance. This converter solution is urging for PV-battery application, reducing the number of conversion stages, thus superior to the conventional system regarding efficiency, cost, weight, and volume. The model is efficient in computational complexity, and it is easy to configure for representing wide-range of PV installations. The overall system is designed, developed and validated by using MATLAB/SIMULINK. The hardware setup is also implemented and the proposed scheme is validated.

Index Terms— conventional system, fuzzy logic controller, PV-battery application , renewable sources, single stage conversion, smart grid, solar converter

1 INTRODUCTION

Among several renewable energy resources, energy harvesting from the photovoltaic (PV) effect is the most essential and sustainable way because of abundance and easy accessibility of solar radiant energy around the earth. In spite of the intermittency of sunlight, solar power is widely available during daylight and it is free to use. Recently, the photovoltaic system is recognized to be the forefront in renewable electric power generation because it can generate direct current electricity without any environmental impacts and contamination.

PV modules are the fundamental power conversion unit of a PV generator system. Factors like temperature, irradiation, and spectral distributions of sunlight, dirt, and shadow affect the efficiency of solar cell. Abrupt climatic changes like cloudy weather and temperature rise result in reduced output power of PV array. In addressing the low efficiency of PV systems, some methods are proposed, among which is a new concept called maximum power point tracking (MPPT). All MPPT methods follow the same goal which is optimising the PV array output power by tracking the maximum power on every operating condition.

There are different options for incorporating energy storage into a solar PV system. Energy storage can be integrated into either the ac or dc side of the solar PV power conversion systems which may introduce multiple conversion stages. This paper introduces a novel converter that is developed for single stage power conversion for operation in different modes such as solar to the load (dc to ac), solar to a battery

(dc to dc), battery to the load (dc to ac), and battery/solar to the load (dc to ac) for solar PV systems with energy storage.

2 BASIC CONVERTER AND ITS MODES

2.1 Basic Scheme

The conventional solar PV system consists of multiple conversion stages, which makes the system complex. The proposed system involves a single stage conversion. The system is capable of performing different operation modes such as solar to the load (dc to ac), solar to a battery (dc to dc), battery to the load (dc to ac), and battery/solar to the load (dc to ac) for solar PV systems with energy storage.

Fig 1 shows the schematic diagram of the system. The system adds a charging section to the conventional three-phase PV connected inverter system thereby increasing its reliability. Further, the proposed system includes mechanical switches which provide power flow for operating among the different modes. As the load, a brushless dc motor (BLDC) is used.

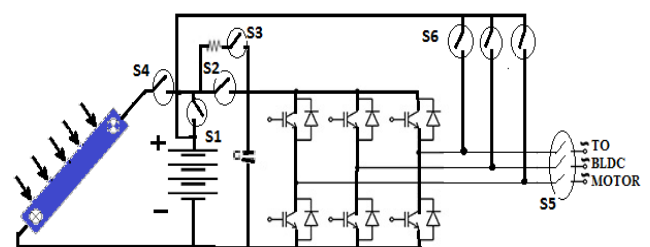


Fig 1: Schematic diagram of the system

2.2 Various Modes of Operation

Fig. 2 presents all possible modes of operation. In Mode 1, the solar panel is directly connected to the load through a

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dc/ac operation of the converter by closing switches S4, S3, S5 with the S1 and S6 switches remaining open. In Mode 2, the battery is charged from the solar output through the dc/dc operation of the converter by closing the S6 switch. Switches S4, S3 remain closed and the S5 switch open. In mode 3, both the solar output and battery provide the power to the load by closing the S1 switch. Mode 4 is accomplished by closing switches S1, S3, S5 in which battery delivers its stored energy to the load. In modes 1, 2, and 4 the MPPT function is performed; therefore, maximum power is generated from PV. In mode 3, the dc-link voltage that is the same as the PV voltage is enforced by the battery voltage; therefore, MPPT control is not possible.

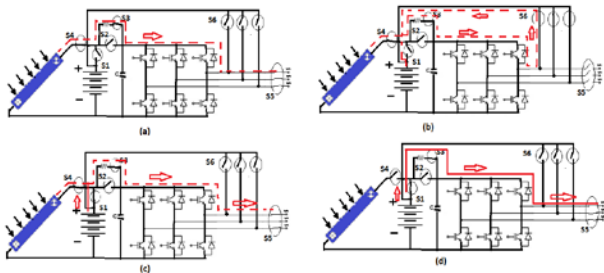


Fig 2: Modes of operation (a) Mode1: Solar to the load (b) Mode2: Solar to a Battery. (c) Mode 3: Solar/Battery to the load. (d) Mode 4: Battery to the load.

3 CONVERTER CONTROL

3.1 Control for modes 1,3,4(dc/ac operation)

The dc/ac operation of the system delivers power from solar to the load, battery to the load, solar and battery to the load. The system introduced performs the MPPT operation using incremental conductance algorithm to deliver maximum power from the PV to the load. The available 3-phase quantities are first converted to 2-phase rotating quantity (stationary reference frame) and then to 2-phase stationary quantity (synchronous reference frame) using vector transformations. The control is therefore implemented in the synchronous reference frame in which the reference frame is rotating synchronously with the fundamental excitation while remaining stationary with respect to each other. Thus, the fundamental excitation signals get transformed into dc signals providing an ease working with the system. As a result, the regulation of AC current is possible over a wide frequency range with an added advantage of increased bandwidth and zero steady state error. The conventional sinusoidal PWM scheme generates the firing sequence for the inverter. Reactive power control is efficiently done using a fuzzy logic controller. Fig. 3 presents the control block for dc/ac operation.

3.2 Control for mode 2 (dc/dc operation)

The dc/dc operation of the system charges the battery from the solar output. Also, the system uses incremental conductance algorithm for delivering the maximum power from the PV to the battery. The MPPT output taken as a current command is used to adjust the duty cycle of the inverter switches.

The converter operation in the dc/dc conversion is a boost converter controlling the current flowing into the battery. Battery selected for the system is of Li-ion type and its specifications are given as in Table I. Li-ion batteries requires a unique charging algorithm i.e., Constant current, constant voltage algorithm. Till it reaches its final voltage, these batteries should be charged at a set current level. After attaining the final voltage, the necessary current to hold the battery at this voltage is provided, thus switching on to constant voltage mode. Thus, a stable control for maintaining either current or voltage at a constant value is required for the charging process taking place in the dc/dc converter. Constant voltage charging may result in reduced capacity up to some extent. Still, constant current charging is employed in some cases where there is a need for a less complex charging process. The latter has been used to charge the battery. Therefore, only the inductor current is to be controlled. Fig.4 shows the overall control block diagram of dc/dc operation.

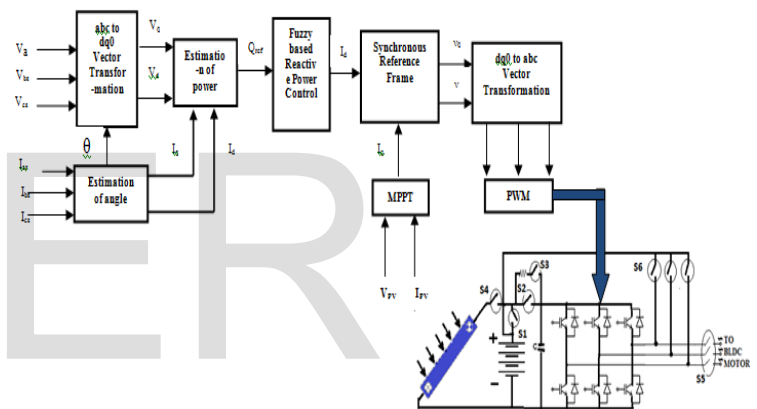


Fig 3: dc/ac Operation Mode

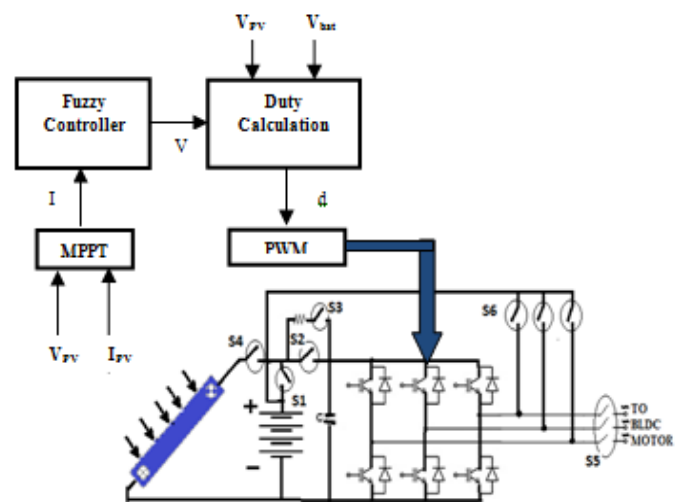


Fig 4: dc/dc Operation Mode

TABLE 1
LITHIUM-ION K2 BATTERY PARAMETERS

Battery capacity	KWhr/Ahr	5.9/51.2
Battery nominal voltage	V	115.2
Min. Battery voltage	V	90
Max. Discharge current	A	52
Max. Pulse discharge current	A	150(<2s)
Max. Charging voltage	V	132
Max. Charging current	A	10

3.3 Fuzzy Logic Controller

The conventional PI controllers being fixed-gain feedback controllers cannot compensate for the parameter variations in the process and cannot adapt changes in the environment. Moreover, the PI-controlled system is less responsive to real and relatively fast alterations in state, and so the system will be slower to reach the set point. Fuzzy logic system overrules the above disadvantages and can also provide nonlinear control because it does not use complex mathematical equation.

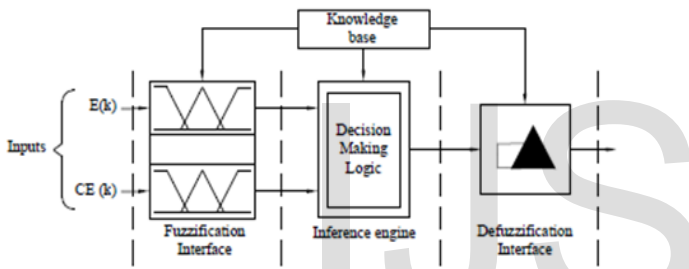


Fig 5: Fuzzy Logic Block Diagram

The two inputs to the controller are error, and change in error. The membership function values assigned to the linguistic variables are five fuzzy subset called negative big (NB), negative small (NS), zero (ZE), positive small (PS), positive big (PB) and the output variable is the duty cycle reference signal for PWM generator. The output linguistic variables include negative huge (NH), negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (NM), positive big (PB), positive huge (NH). Based on the observed values of proposed scheme parameters, the range of each membership function is determined. Figure 5 presents the Fuzzy block diagram.

The inference engine mainly consists of the Fuzzy rule base and fuzzy implication sub blocks. The inputs are fuzzified and are fed to the inference engine, and the rule base is then applied according to experience and operation of the system to be controlled. Output fuzzy sets are identified using MIN-MAX fuzzy implication method. Thus, the fuzzy inference engine will generate a logical decision based on the fuzzy rule setting.

TABLE 11
IMPLEMENTATION OF THE RULE

E	NB	NS	ZE	PS	PB
ΔE					
NB	NH	NH	NH	NM	ZE
NS	NH	NM	NS	ZE	PB
ZE	NH	NS	ZE	PH	PH
PS	NB	ZE	PS	PB	PH
PB	ZE	PB	PH	PH	PH

Based on the power converter being used and also, on the knowledge of the user, the linguistic variables are assigned to the output for different combinations of error and change in error. Fuzzy output range is determined after fuzzification and it is then defuzzified using centroid method.

4 FLOWCHART

Programming is done in the PIC Microcontroller to generate the switching sequence for enabling the operation of the four modes. The input is enabled using four push buttons k1, k2, k3, k4 and based on the input, the output is generated facilitating the power flow in the respective modes by operating the four switches S1, S2, S3, S4.

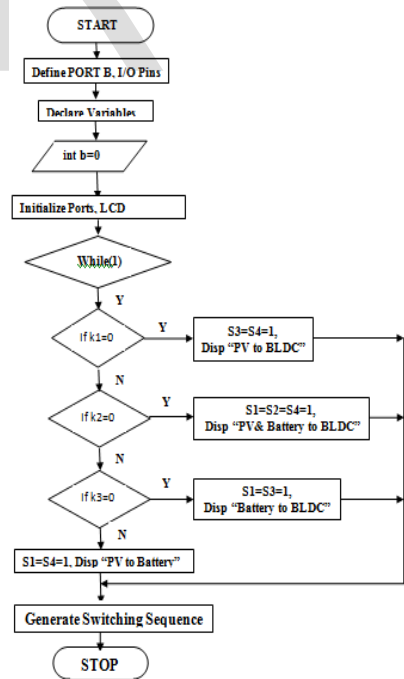


Fig 6. Flowchart for generating the switching sequence for the operation of the four modes.

5 SIMULATION OF THE MODEL

Figure 7 shows the simulation model of the system. Since the system uses the same algorithm for grid synchronization and power factor control functions as the conventional grid-tie PV inverter, these are not verified here. So the system is connected to a passive load. A KC200GT solar panel operating at STC i.e., 25°C and 1000W/m² is modeled. The inverter section consists of six IGBTs and diode of rating of 1.2 kV and 100 Apeak. When the three-phase Inverter is connected to the dc power supply, an inrush current flows into the capacitors initially. This current is limited using a pre-charging circuit. The voltage and current ripples of the batteries are reduced using filter capacitors. Likewise, a voltage balancing circuit is incorporated to limit the inrush current flowing into the filter capacitors due to the abrupt connection of the battery system to the inverter.

The Embedded MATLAB function block is used for generating the control signals to operate the six mechanical switches employed for providing efficient power flow in the four different modes. There are seven inputs namely a₁, a₂, b₁, b₂, c₁, c₂ and 'mode'. For mode 1 operation, the input 'mode' is set to 1. Likewise for mode 2 operation, 'mode' is set to 2. For each mode specified, the corresponding switches are triggered by providing a high input. Thus, power flow takes place through the activated switches and the converter operates in the respective mode.

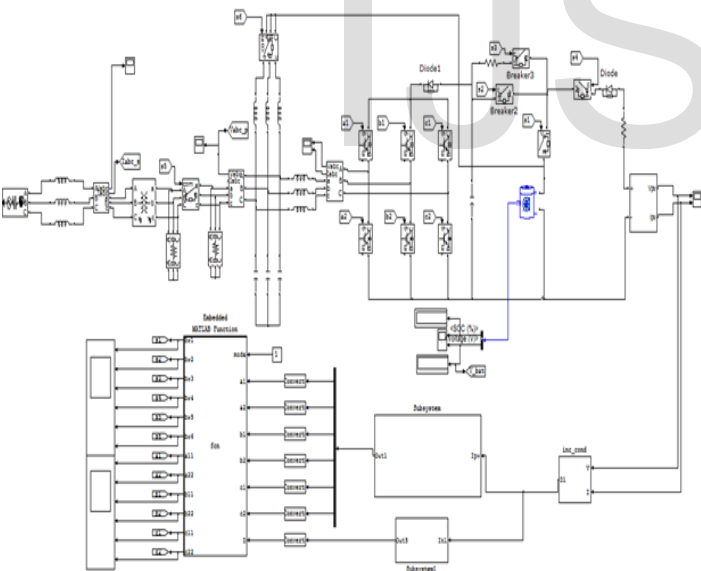


Fig 7. Complete Simulation Model

The control algorithms are implemented in MATLAB/Simulink environment. The performance of the system in different operation modes is tested and the analysis for the different modes is presented separately.

5.1 Simulation Result

For a temperature input of 25°C and Irradiation of 500 W/m², the solar output provides a maximum voltage of 320.955V and a current of 8.023A. The MPPT block ensures

maximum power extraction from the solar panel. The incremental conductance algorithm used for MPPT provides a duty cycle control with an error of 0.01.



Fig 8. MPPT Output

The switches S₄, S₃, and S₅, are to be triggered for mode1 operation. The inverter switching sequence thus implemented provides a power flow from PV to load. Figure 9 (a) shows the inverter output with a voltage of 415 V_{peak}. Figure 9 (b) depicts the battery output. Since battery operation remains unaltered (no charging or discharging), it outputs the previous state of charge of the battery.

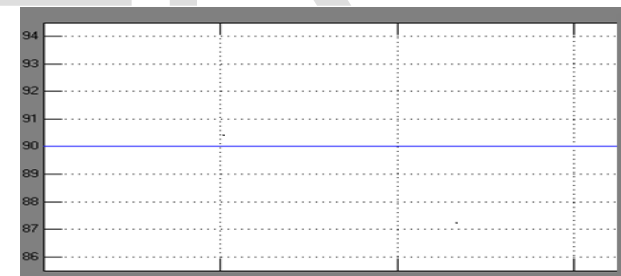
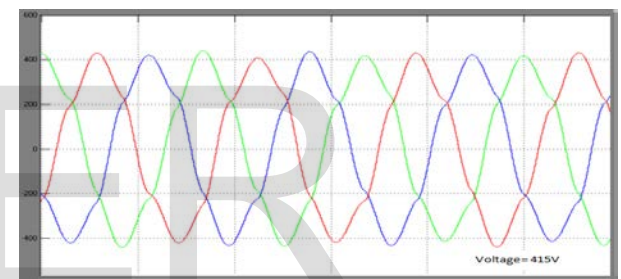


Fig 9. (a) Mode 1 Output (b) Battery output

Mode 2 deals with dc/dc operation control, charging the battery from PV output. The switching sequence is employed by turning on the switches S₄, S₃, S₆ enabling power flow from PV to Battery. Figure 10 shows the charging of the battery.

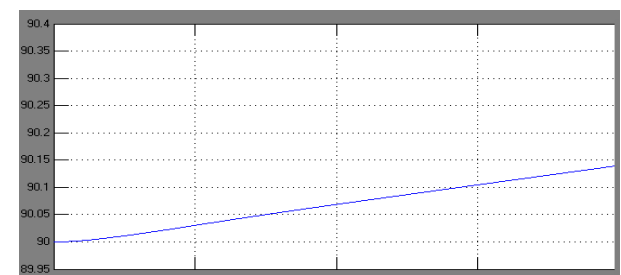


Fig10. Mode 2 Battery output

Mode 3 provides a power flow from solar/battery to the load by enabling switches S_4 , S_3 , S_6 and S_1 . Figure 11 shows the output for this case and is found to be a voltage of 270 V_{peak} .

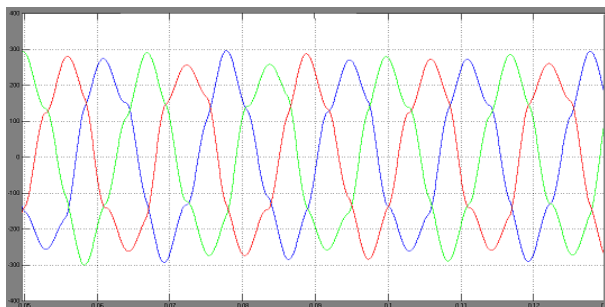


Fig 11: Mode 3 Output

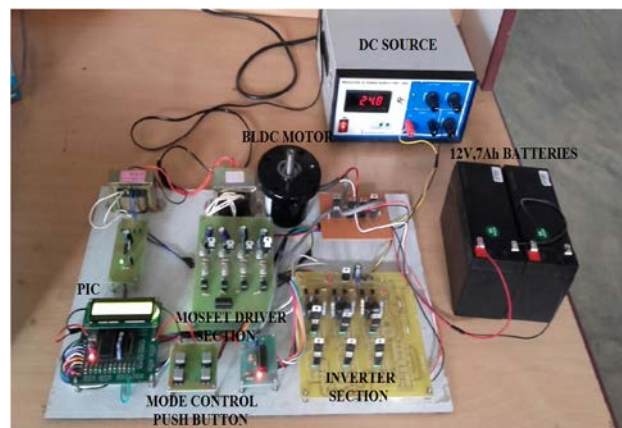


Fig 13: Complete Hardware setup

In Mode 4, switches S_3 , S_5 , and S_1 are triggered. The power flow from Battery to load is therefore made possible. Figure 12 (b) shows the battery output which is discharging as in this case the battery provides its supply to the grid. Figure 12 (a) shows the Mode 4 output with an output voltage of 160 V_{peak} .

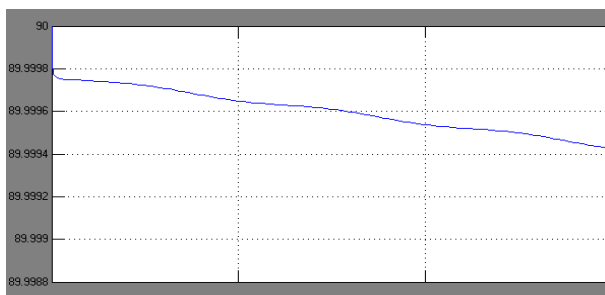
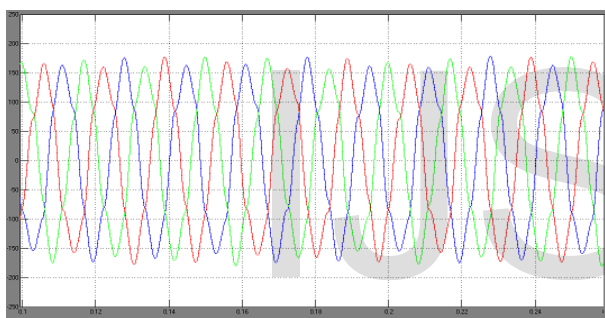


Fig12. (a) Mode 4 Output (b) Battery output

6 HARDWARE SETUP

The complete hardware setup is developed as in Figure 13. It comprises of the PIC Microcontroller and its power supply section, inverter and the MOSFET driver section, two 12V, 7Ah batteries, 30V dc source. As the load, a 24V, 1500rpm BLDC Motor is used. Four push buttons are used for selection of the four modes. A BLDC Driver IC is used to drive the motor by triggering the gate pulse of the inverter switches based on the switching sequence generated.

The BLDC drive gate pulse so obtained is shown as in Figure 14.

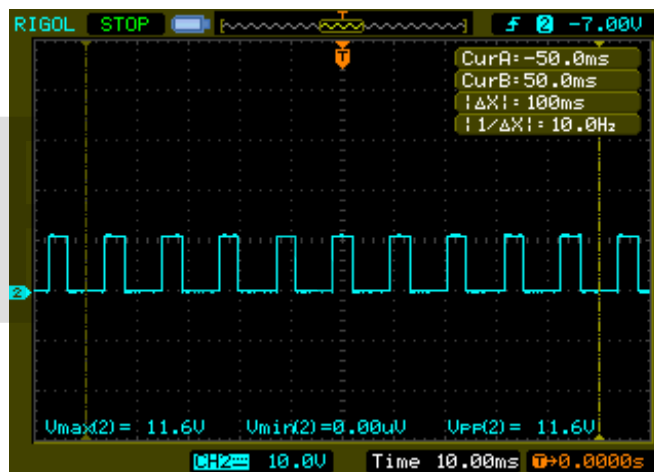


Fig 14: BLDC drive gate pulse

7 CONCLUSION

This paper introduces a new converter topology for PV-battery application, particularly utility-scale solar-battery application. A multimode operation providing power flow from solar to the load (dc to ac), solar to a battery (dc to dc), battery to the load (dc to ac), and battery/solar to the load (dc to ac) has enhanced the solar PV integrated system. The proposed concept is simpler than the conventional ones. The fuzzy controller, with accurate and easier computation and ability to work with a non linear system, enables the proposed system for efficient control over the various modes. But the major limitation of using a fuzzy logic controller requiring previous expertise knowledge of the system is a challenge for the system. Operation in the synchronous reference frame for dc/ac operation offers regulation of AC current over a wide frequency range with an added advantage of increased bandwidth and zero steady state error. The system, therefore, proves

beneficial for PV-battery application, with added advantage of improved efficiency and reduction in number of stages of conversion. Also, the cost, weight, and volume of the system is reduced to a large extent. The solution can thus be regarded as an optimal one for PV-battery power conversion systems. The hardware of the proposed system is also setup and the efficient operation of all the four modes have been performed successfully. Incorporating other intermittent energy sources like wind may increase the reliability of the scheme further.

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