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HYBRID POWER SYSTEM BASED ON RENEWABLE ENERGIES: A FUTURE FOR SUSTAINABLE ENERGY SOLUTIONS

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Abstract- Electricity is recognized as the key driver of economic growth and development for any developing country. Most of the electricity generation in India is carried by conventional energy source which also heavily harm the eco-system by the emissions of greenhouse gasses but still around one third of total population in India has no access to electricity, this is due to rapid growth of population and also the fact that extension of existing grid is a long term process. This work gives an overview on the role of hybrid Renewable Energy Sources (RES) precisely solar and wind to meet the electricity demand of country keeping in view the production and consumption. It also deals with the concepts of using hybrid RES which may provide an intermediary solution especially for small towns and villages which are yet to be electrified under rural electrification program. The major system components of a PV-wind hybrid system and their technological configurations along with design parameters for supplying electricity to individual house of a rural area with basic needs are presented in this paper.

Key words: **Hybrid (RES), Electricity demand, Rural Electrification and Technological configurations.**

1. INTRODUCTION

Most of the countries have been focusing on renewable energy systems as they resolve the dependency on fossil fuels. In India, renewable energy sources (solar, wind, biomass) play the vital role in reducing the gap between energy supply and demand to the possible extent [1]. At present, standalone solar photovoltaic and wind systems have been promoted around the globe on a comparatively larger scale [2] but due to their intermittent nature they cannot provide continuous source of energy and also the installation cost of individual renewable energy system increases the per unit energy cost. So far, it has been discussed only in combinations more than two renewable energy sources with battery backup are more efficient and cost-competitive.

More than 200 million people live in rural areas without access to grid-connected power. In India, over 80,000 villages remain to be un-electrified as the extension of existing grid lines experiences a number of problems such as high initial cost, high installation time, low load factor, poor voltage regulation. Those who live in urban areas face the problem of frequent power supply interruptions. Hence, Hybrid power system based on renewable energy sources provides a suitable and cost competitive solution for meeting the problem of energy demand and rural electrification.

PV modules and wind turbines are now widely used in developed countries to produce electrical power in locations where it might be inconvenient or expensive to use conventional grid supply. For mini-grid of a rural area or for small loads the most common combination is PV-wind hybrid system. PV-wind is good match, because inland wind speeds tend to be lower in summer, when solar energy can compensate, and higher in winter, when sunshine falls to very low levels.

In this work, a PV-wind hybrid system is presented that can supply electricity to a private house or a small company with electrical power depending on the need at the site where used.

2. SCENARIO

At present India is the fifth largest country in the world in terms of generating electricity having an installed capacity of 2,32,164 MW as of November 2013[3] out of which 68.19% is from thermal, 17.39% is from hydro, 2.08% is from nuclear and the remaining 12.32% is the share of renewable energy sources. Indian power sector accounts for about 22.65% transmission and distribution losses as of 2011-2012 & has set a target of reducing it to 17.1% by 2017 and to 14.1% by 2022. The International Energy Agency estimates India will add between 600 GW to 1200 GW of additional new power generation capacity before 2050[4]. This added new capacity is equivalent to the 740 GW of total power generation capacity of European Union (EU-27) in 2005.

3. RENEWABLE ENERGY SOURCES

3.1 Solar energy

Solar energy is available in abundance and considers the easiest and cleanest means of tapping renewable source of energy. Earth surface receives about 182 Peta-watts (PW) of energy from sun. The energy supplied by the sun in one hour is almost equal to the amount of energy required by the human population in one year. Solar energy is harnessed by using photovoltaic cells. These cells may be grouped to form panels or arrays.

Conversion process:

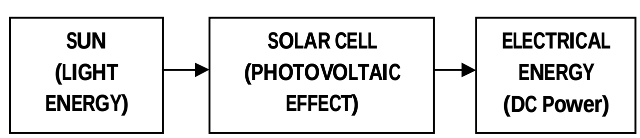

Figure 1: Solar Energy Conversion process

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The characteristic curve of PV module is shown in figure 2. From these performances it is shown that the total output PV voltage and current varies according to irradiation level with approximated 65W maximum power at G=1000W/m^2 [5] [6].

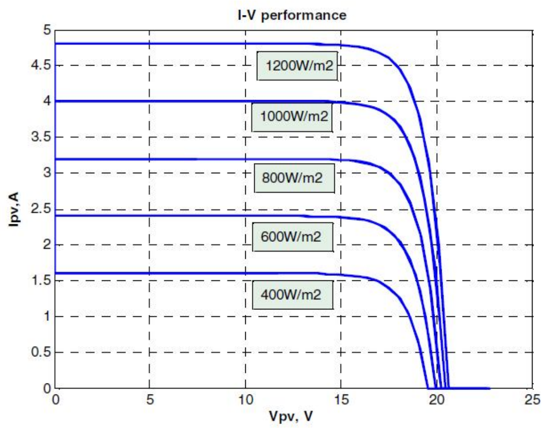

Figure 2: I-V Performance of PV module

3.2 Wind energy

As long as sunshine, the wind will exits and therefore can be considered as renewable source of energy. The movement of air (created because of pressure difference between two uneven heated places) is called wind. It is a clean, eco-friendly, safe and reliable source of energy.
Wind energy is harnessed by using wind turbine. Wind turbine can be design in number of different ways, integrating 1-3 blades with horizontal and vertical axis. In general commonly used horizontal wind turbine has a higher efficiency than vertical one, as well as higher reliability due to better rotor balance.

Conversion process:

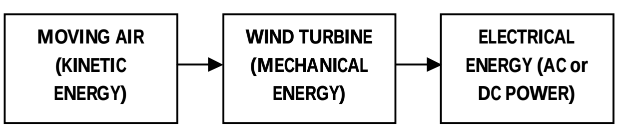

Figure 3: Wind Energy Conversion Process

Most small wind turbines have a permanent magnet generator and do not need a gearbox. This type of generator produces AC-voltage current, which must be rectified to DC by means of a simple bridge rectifier. The DC-voltage allows the use, similarly to PV systems, of SWT for battery charging or for grid connection. For in-battery charging systems, a charge controller is added to prevent the battery from over charging. For small loads DC wind generator can also be used for directly energizing DC bus line for charging the battery bank. A 200W DC wind generators data sheet and its power curve are shown in table 1 and figure 4 respectively [6].

Table 1: A Typical 12V DC Generator Data Sheet

Model No:	*MG-4520 WFD200W*
Rated Power	**200W**
Maximum Power	**300W**
Rated Dc Output Voltage	**12VDC**
Start Up Wind Speed	**2.5-3m/s**
Rated Wind Speed	**12 m/s**
Maximum Wind Speed	**40 m/s**
Cut-Off Wind Speed	**Typically 12 m/s**
Over Speed Protection	**Auto Furl**
Temperature Range	**-40 to +60 Deg. C**
Rotor/ Blade Diameter	**1.77m**
Rotor Speed	**450 rpm**
Blade Material	**Engineered Aluminium alloy**
Height Of Tower (Recommended)	**4.5m**

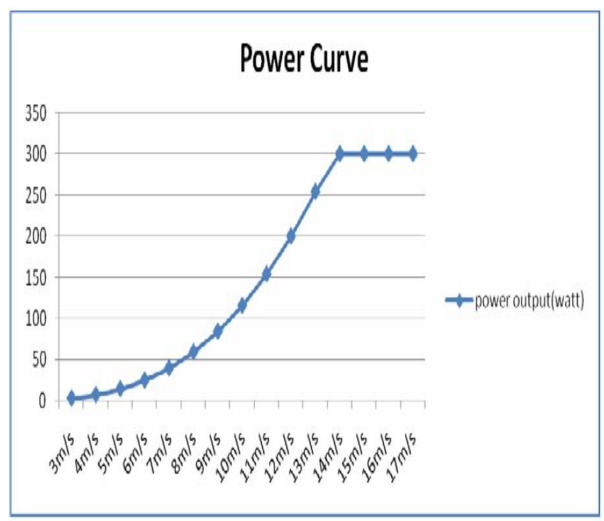

Figure 4: Power Curve for Wind DC Generator

4. BENEFITS OF HYBRID RENEWABLE ENERGY SYSTEM OVER DISTRIBUTED CONVENTIONAL GRID ENERGY

As a distributed energy resource available nearby load centers, Hybrid energy system could reduce transmission and distribution (T&D) costs and also line losses. **According to World Resources Institute (WRI)**, India's electricity grid has the highest transmission and distribution losses in the world – a whopping 24%. Numbers published by various Indian government agencies put that number at 25%, 32%, and greater than 32%. Hybrid technologies like PV and wind generator

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can carry very short gestation periods of development and, in this respect, can reduce the risk valuation of their investment. They could enhance the reliability of electricity service when T&D congestion occurs at specific locations and during specific times. By optimizing the location of generating systems and their operation, distributed generation resources such as solar can ease constraints on local transmission and distribution systems. They can also protect consumers from power outages. For example, voltage surges of a mere millisecond can cause brownouts, causing potentially large losses to consumers whose operations require high quality power supply. Moreover, the peak generation time of PV systems often closely matches peak loads for a typical day so that investment in power generation, transmission, and distribution may be delayed or eliminated.

5. PRINCIPLE TECHNOLOGICAL CONFIGURATIONS FOR HYBRID RES SYSTEMS

5.1 Electricity generation coupled at DC bus line

All electricity generating components are connected to a DC bus line from which the battery is charged as shown in figure 5. AC generating components need an AC/DC converter. The battery, controlled and protected from over charge and discharge by a charge controller, then supplies power to the DC loads in response to the demand. AC loads can be optionally supplied by an inverter.

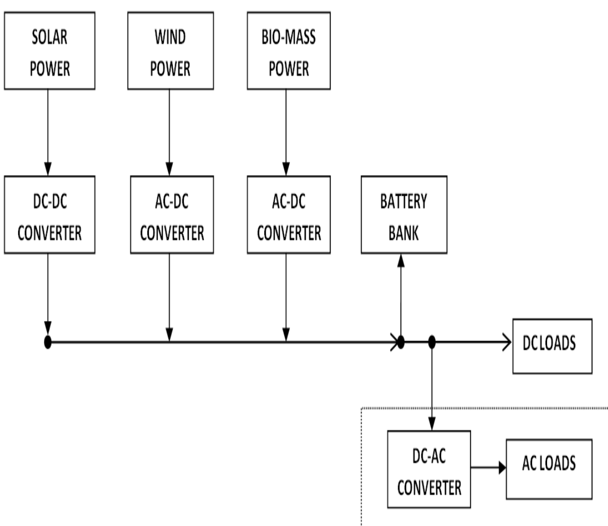

Figure 5: Electricity generation coupled at DC bus line

5.2 Electricity generation coupled at AC bus line

All electricity generating components are connected to an AC bus line as shown in figure 6. AC generating components may be directly connected to the AC bus line or may need an AC/AC converter to enable stable coupling of the components. In both options, a bidirectional master inverter controls the energy supply for the AC loads and the battery charging. DC loads can be optionally supplied by the battery.

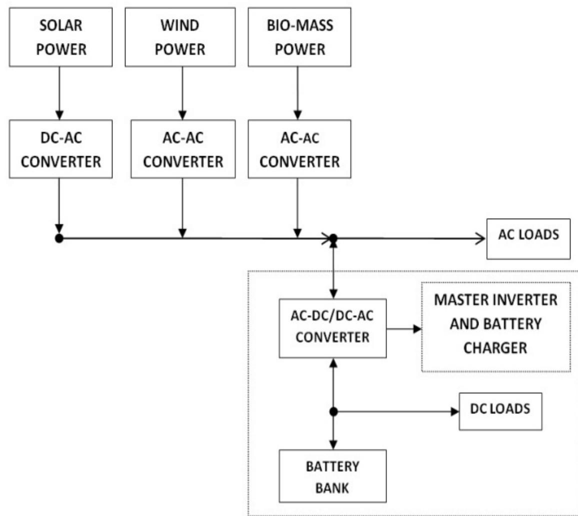

Figure 6: Electricity generation at AC bus line

Herein after, estimation of loads and components ratings parameters for establishment of PV-wind hybrid unit of a DC bus line has been described.

6. HYBRID SYSTEM DESIGN PARAMETERS

One has to determine the configuration of hybrid system in which components (PV panels, load, battery, controllers, wind generator, etc.) are to be connected in power supply line to provide continuous and sufficient power to the consumer. The configuration and design of the system will change depending on:

1. The type of the load (AC or DC, light or heavy, etc.),
2. The load requirement (critical/non-critical, reliability, cost, etc.)
3. Its geographical location (wind resources, solar resources, proximity with grid, etc.).

A hybrid system configuration can be very simple, incorporating only three components (load, PV panel and wind generator), or it can be very complex, containing several power sources, sophisticated controllers and multiple energy storage units to meet stringent load requirements. The establishment or household owner has to choose from these configurations while keeping in mind the following parameters:

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- ✓ Load requirements.
- ✓ Resource availability.
- ✓ Performance of the system.
- ✓ Reliability of the system
- ✓ Cost of the system.

6.1 Rating Calculation for Hybrid Integrated System components

A solar PV cells and wind generator system is to be designed wherein the load consists of a CFL, TV, fan, and small domestic loads. The system should be able to run the load in cloudy days or when there is no wind. The process is explained with considering basic domestic loads below.

6.1.1 Load estimation

In this step the energy required for the operation of the load is determined. While estimating the load the following parameters are considered:

- Type of load, DC or AC (most of the appliances use AC power);
- Number of loads (e.g. Lighting, cooling, TV etc.)
- Power voltage and current ratings of each load
- Hours of load operation per day
- Energy required per day by the load and
- Efficiency of the power converter

The power rating (W) is to be multiplied with the no. of hours of operation of all the loads and then it is all added up to find the total daily energy consumption as calculated in table 2. Separate tables can be made for AC and DC loads. In this case however we have considered a house with only AC loads.

It is important to keep in mind that the system should be designed for the worst case scenario, energy required changes from day to day and season to season basis. The system should meet the peak energy requirement or the peak load demand i.e. the highest requirement in a particular day of the year. However a reliable system design will add to the cost of the system. Thus a balance has to be struck between reliability and cost.

Wh = (Load Watt) X (Quantity) X (H/Day) ***(6.1)***

Table 2: Calculation of load in Watt-hr for individual house

LOAD	*WATT*	*QUANTITY*	*H/Day*	*WATT-HOUR*
1. CFL	*28*	*2*	*6*	*336*
2. FAN	*80*	*2*	*10*	*1600*
3. T.V	*150*	*1*	*4*	*600*
TOTAL LOAD (WATT-HOUR)				*2536*

6.1.2 Inverter rating

An inverter supplies power to AC loads and converter supplies power to DC loads. The inverter and converter should be capable of handling input current from the battery and output current to the load.

In this case, since there are only AC loads thus only inverters are used. Generally, input voltage varies from 12 - 72V and current from 1 – 10's of Amperes. The output is fixed at 220V, 50Hz. In this step the inverter rating is calculated. The sum of all the loads connected to the inverter is calculated in table 3.

VA= (Total Load (Watt)) / (Power Factor) **(6.2)**

Table 3: Illustrative Power (Watt) Use per Day

LOAD	*WATT*	*QUANTITY*	*Total WATTs*
1. CFL	*28*	*2*	*56*
2. FAN	*80*	*2*	*160*
3. T.V	*150*	*1*	*150*
TOTAL LOAD (WATT)			*366*

So, total load of 366 watt would apply to inverter. Thus inverter rating should be approx 460 VA, 12V /220V 50 Hz (366/0.8 = 457.5 VA, standard PF of consumer load is 0.8)

6.1.3 Daily energy supplied by the inverter

Load energy is supplied to the load from the battery through the inverter. The inverter is not 100% efficient it ranges from 90% – 97% [8]. Thus the energy supplied by inverter is more than the total load requirement as calculated in the first step.

Energy supplied by the inverter = (Load energy requirement) / (Efficiency of inverter) ***(6.3)***

In this case inverter with 93% efficiency is taken.
Energy supplied by inverter= 2536/0.93 = 2726.8 Wh.

6.1.4 System voltage

System voltage is defined as the input voltage to the inverter. It depends on the battery voltage, line current, allowable voltage drop, power loss in the cables, etc. Typically terminal voltage of batteries is 12V, therefore system voltage are generally multiples of 12, 24, 36, 48V etc.... High system voltage results in less power loss and voltage drop in cables. But high system voltage also means more PV panels in series and therefore high cost [8]. So system voltage should be chosen after careful considerations. In this case, a system voltage of 12V is chose.

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6.1.5 Battery capacity

As calculated earlier 2726.8 Wh of energy is required to be supplied by the battery and the terminal voltage of the battery bank should be 12V. The parameters to be considered in sizing of batteries are:

- Depth of discharge (DoD) of battery;
- Voltage and ampere-hour (Ah) capacity of the battery; and
- Number of days of autonomy.

Therefore, Usable capacity = 100 x 0.7 = 70Ah

Now, Required charge capacity = (Energy that needs to be supplied by the battery) / (system Voltage)

The energy that needs to be supplied by the battery
= 2726.8 Wh
The system voltage = 12 V
Therefore, the required charge capacity = 2726.8 /12
= 227.23 Ah

The total no. of batteries required = (Required charge capacity) / (Usable capacity) (6.5)
= 227.23 / 70 = 3.24

This can be rounded off to 4 batteries.
Now because of this round off, some extra charge capacity (280 Ah instead of 227.23 Ah required) is available to the load. These four batteries should be connected in parallel.

6.1.6 Consideration for battery autonomy

The system should be designed for some autonomy during the completely intermittent conditions. As we are using hybrid (solar and wind) system, the probability of no generation becomes very less compare to use of single renewable energy source. The autonomy is defined as the number of days the battery should be able to supply the energy to load even for those number of days when there is no power generation (assuming on completely cloudy days, or no energy is generated by wind generator). , 1 day autonomy means the battery bank should be able to supply the energy to the load where there is no generation for 1 day. Thus, depending on the number of days of autonomy, the battery bank size should be increased. If total daily Ah requirement is *X* and the number of days of autonomy is *n* days, then total Ah required including autonomy is given as:

Total Ah = X + n.X (6.6)

Therefore, total Ah = 227.23 + 1 x 227.23 = 454.46 Ah

Thus, battery bank size should be two times than what was derived previously. Now instead of 4 batteries of 12 V, 100 Ah, we would require 4 x 2 = 8 batteries of 12 V and 100 Ah.

For PV applications deep discharge batteries are used with **DoD** in the range of 60% to 80% and batteries of capacities 25Ah, 50Ah, 100Ah, and 150Ah are available [8]. ***In this case batteries of 12V 100Ah with DoD 70% are chosen.***

Usable capacity = (Rated capacity) x (Depth of Discharge) (6.4)

As the autonomy day increases, the battery bank size increases adding to the cost. Typically, the battery cost is about 30% of the overall hybrid system cost.

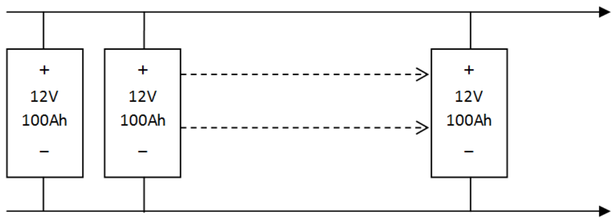

Figure 7: Parallel connection of 8 batteries to supply the required energy to the load considering 1 day autonomy.

6.1.7 Daily energy required to be generated by PV panels and wind generator

The parameters of concern for the hybrid module sizing are:

- Voltage, current and wattage of the module;
- Solar radiation at a given location and at given time;
- Efficiency of the batteries;
- Temperature of the module;
- Efficiency of the MPPT and charge controller unit; and
- Dust level in working environment.

The PV panels and wind generator are required to supply energy to battery which is consumed daily but not the total energy stored in the battery bank. The energy taken out from the battery bank is the energy required by the load on daily basis. The energy supplied by the panels will be higher because the efficiency of the charge discharge cycle of the battery is less than 100%. It is 80% to 93% [8].

An efficiency of 85% is taken in this case.
The energy supplied at the input of battery terminal = Energy supplied by the battery/ Battery efficiency (6.7)

= 2726.8/0.85
= 3208 Wh

The energy to the input terminal of the battery bank is supplied through controller electronics (charge

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controller). The efficiency of the controller circuit is generally quite high [8].

A controller circuit efficiency of 90% is assumed.

The energy that should be supplied by the system at the input of controller circuit = Energy supplied at the input of battery terminal/Controller circuit efficiency (6.8)

= 3208/0.9 = 3564.44 Wh

Thus, about 3564.44 Wh energy should be generated by hybrid generating system every day.

6.2 Establishment of PV-Wind Hybrid Unit

The hybrid unit contains two complete generating plants, a PV solar cell plant and a wind-turbine system. These sources are connected in parallel to a 12V DC line. The power is next connected to a DC to AC inverter and is then supplied from the inverter's output to a single-phase 50HZ, 220V AC load [10].
Now, the energy required to be generated by the hybrid system is 3564.44 Wh, hence the total Ah generated can be obtained as:

Total Ah generated by PV-Wind module = Energy supplied by PV-Wind module/ System voltage (6.9)

= 3564.44/12 = 297.03 Ah

During a day, from sunrise to sunset, the solar radiation intensities vary significantly. Normally, the number of daily sunshine hours equivalent to 1000 W/m^2 (equivalent peak sunshine hours) is estimated for the location at which PV system needs to be installed In India, the peak equivalent sunshine hours vary between 5 hrs and 7 hrs, corresponding to 5000 Wh/m^2 and 7000 Wh/m^2 / day and annual average wind speed is 3.2 m/s [8-9].
Thus when we combine both systems an efficient hybrid RES system is established for the above discussed load.

For this case, we are assuming *6* hours equivalent peak generations by peak sunshine and wind hours in the location where hybrid RES system needs to be installed.
Total amperes to be produced = (Total Ah generated by PV-Wind module)/(No. of peak Sunshine + wind hours) (6.10)

= 297.03/6
= 49.5 A

Thus total of 49.5A current should be generated by both PV panels and wind generator.
A schematic connection of different components of hybrid RES system is shown in figure 8.

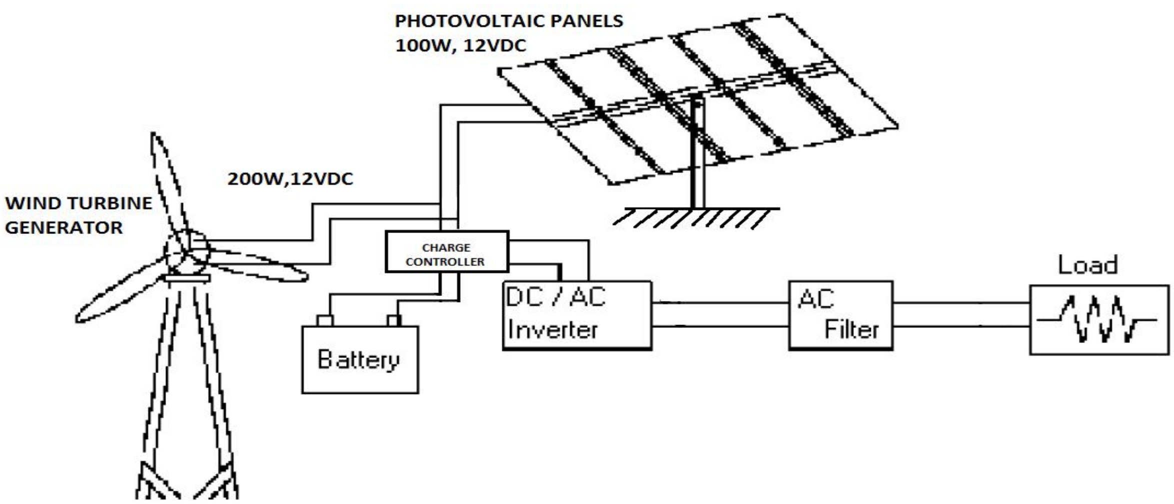

Figure 8: Hybrid RES System

7. CONCLUSION

India is a developing country and for its sustainable economic growth, the development of power structure plays a major significant role. Enhanced use of hybrid renewable source of energy reduces the dependency on fossil fuels and also provides the solution for energy crises. The use of solar and wind hybrid power generation is an especially vivid and relevant choice for rural electrification.

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