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CONTROLLER DESIGN FOR HYBRID POWER SYSTEMS

N.Prabhu*,R.Balraj, S.Ayyubh
*Assitant Professor, Dept. of Electrical and Electronics Engineering,
Shree Venkateshwara Hi-Tech Engineering College, Anna University,
Gobichettipalayam – 638455 Erode District, Tamilnadu, India
Assitant Professor, Dept. of Electrical and Electronics Engineering,
Shree Venkateshwara Hi-Tech Engineering College, Anna University,
Gobichettipalayam – 638455 Erode District, Tamilnadu, India
Assitant Professor, Dept. of Electrical and Electronics Engineering,
Shree Venkateshwara Hi-Tech Engineering College, Anna University,
Gobichettipalayam – 638455 Erode District, Tamilnadu, India

ABSTRACT

In this paper an efficient design along with modeling and simulation of a transformer-less small-scale centralized AC—bus Connected Hybrid (Wind–PV) power system for supplying electric power to a single phase load. The main components of the hybrid system are: a PV generator (PVG); and an array of horizontal-axis, fixed pitch, small-size, variable-speed wind turbines (WTs) with direct-driven permanent magnet synchronous generator (PMSG) having an embedded uncontrolled bridge rectifier. An overview of the basic theory of such systems along with their modeling and simulation via Simulink/MATLAB software package are presented. An intelligent control method is applied to the proposed configuration to simultaneously achieve three desired goals: to extract maximum power from each hybrid power system component (PVG and WTs); to guarantee DC voltage regulation/stabilization at the input of the inverter; to transfer the total produced electric power to the electric load.

KEYWORDS: Wind Energy, Solar Energy, MPPT Controller, Power electronics, loads sharing..

INTRODUCTION

A Hybrid Power System is simply one in which an electric load is served by two or more power sources. Because renewable energy sources, such as wind and solar, are inherently intermittent, they are frequently combined with dispatchable power sources, such as the utility grid, to ensure a continuous supply of power. Energy storage is often included in hybrid systems.

Hybrid WT–PV power systems with proper control may provide almost continuous electric power with better reliability than a single such power source (PVs or WTs),the Grid Connected Hybrid–PV Power Systems (GCHWPPS) based on the need for green electrical energy, the relevant economic incentives, the pertinent technical advances, and the real benefits for utilities have become very popular.

With increasing concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Other than hydro power, wind and photovoltaic energy holds the most potential to meet our energy demands. Alone, wind energy is capable of supplying large amounts of power but its presence is highly random as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc.

The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable. However, by combining these two intermittent sources and by incorporating maximum power point tracking (MPPT) algorithms, the system's power transfer efficiency and reliability can be improved significantly.

Renewable hybrid energy systems (RHESs) are the systems where the renewable energy sources as wind, solar, etc. have been utilized simultaneously. In order to avoid global warming caused by greenhouse gases, in this respect in addition to the establishment of the globally great energy stations, local and network-free residential applications have been extensively explored and hence photovoltaic panels and wind turbines have been setup in these residences.

The electrical energy produced by renewable energy systems like photovoltaic panels is in the form of the DC electrical energy. In effect, despite of the fact that the electrical energy produced by the wind turbines is in the form of Alternative Current (AC) in proportion to the wind speed, this AC energy is converted into the DC energy by the internal converters in the low-power turbines used in the residences and then the network is supplied by this DC energy, thus the DC energy produced by photovoltaic panels , turbines have to be converted into AC energy due to the fact that the consumers are all AC. Such a DC/AC conversion brings some disadvantages such as the need of a DC/AC converter, the involvement of some harmonics, the loss of energy, the increase in dimension and cost, and some degradation of the quality of the energy.

Maximum Power Point Tracking (MPPT) to be used to extract maximum power from the wind and sun when it is available. An adaptive MPPT algorithm will be used for the wind system and incremental conductance method will be used for the PV system. Operational analysis of the proposed system will be discussed in this paper. Simulation results are given to highlight the merits of the proposed circuit.

HYBRID SYSTEM ARCHITECTURE

There are many possible configurations of hybrid power

Systems, and the number keeps growing as additional wind turbine models, power converters, and energy storage options become available. One way to broadly classify system architectures is to distinguish between AC and DC bus systems. AC bus systems are those where the renewable energy components (e.g. wind turbines, PV arrays) and sometime even the backup generator feed their power to a AC bus, to which is connected an inverter that supplies the loads. All of the renewable energy must flow through the inverter to reach the loads. This architecture is typical of small hybrid systems. Village and industrial scale systems generally use an AC bus architecture, where the wind turbines are connected to the AC distribution grid and can serve the loads directly.

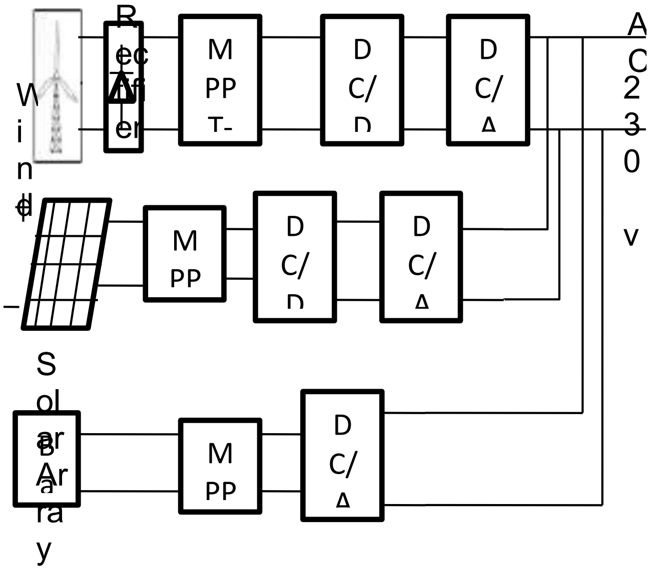

Fig.1. General Schematic of Hybrid Power System

The proposed hybrid renewable green energy scheme has four key subsystems or components to supply the required electric loads.The first subsystems include the renewable generation source from PV array, wind turbine. The second is the interface converters used to connect the renewable energy generators to boost up the voltage .The third device represents the added inverter between the added interface converters to feed all AC loads. The fourth subsystems comprise all controllers.

WIND ENERGY CONVERSION SUBSYSTEM

Wind turbines are one of the three primary energy conversion devices. The turbine’s blade rotates an alternator delivering AC power. Since the wind turbine produces AC power, a device called a rectifier (AC to DC converter) is used to convert the turbine's output current to DC. This DC power is regulated using a boost converter (DC/DC converter). This power can then be fed to the AC bus, which can be used to power DC loads (ex: battery) or AC loads (through an inverter – DC/AC converter).

A.Wind Turbine Model

The horizontal-axis, fixed-pitch, variable-speed WTs are widely used in modern small-scale WECS since: they permit high wind energy capture; have low mechanical stress; low noise emissions; and low fatigue loading throughout the structure. The wind power is proportional to the V^3 and practically only a part of this power is captured (1) describes the output mechanical power of each WT,

$P_{WT} = 0.5 \cdot \rho \cdot A \cdot Cp \cdot V^3$ (1)

Where,

ρ = the air density (kg/m^3),
A = the rotor sweep area of the WT (m^2),
V = the wind velocity (m/s),
C_p= the power coefficient.

The C_p and consequently the P_{WT} of each WT are functions of the tip-speed ratio TSR and the blade angle β This relationship is usually given by the manufacturer of the WT in the form of a set of non-dimensional curves. The value of TSR is obtained from:

$$TSR = \omega_s \cdot R / V \qquad (2)$$

Where,

R = radius of the rotor of the WT (m),
ω_s = rotational shaft speed of the WT (rad / s).

B. Permanent magnet synchronous generator

Permanent magnet synchronous generators provide an optimal solution for wind turbines, using either a gearless or a single stage gear configuration. This eliminates the need for separate base frames, gear boxes, couplings, shaft lines and reassembly of the nacelle. The output of the permanent magnet synchronous generators can be fed to the load via power converters. This provides a high overall level of efficiency while keeping the mechanical structure of the turbine simple. In PM machines, the excitation or field winding is replaced by a permanent magnet and, of course, no external source of electrical energy is required.

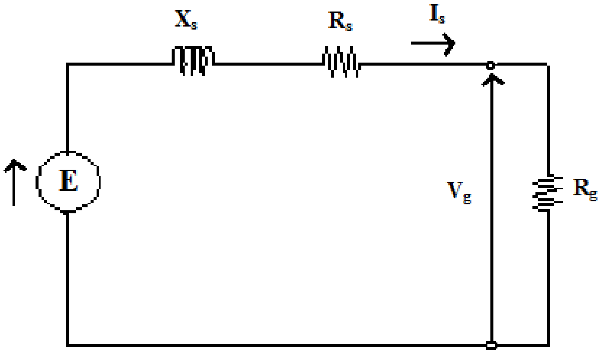

Fig.2. Equivalent Circuit of PMSG

Generated emf/phase $E= V_t+(I_a.Z_s)$

Where,

$Z_s= (R_{a2}+X_{s2})^{½}$

The rotor reference frames of the voltages are

$V_q=-(R_s+L_{qp})*(I_q-(\omega_r*L_d*I_d)+\omega_r/m)$

$V_d=-(R_s+L_{dp})*I_d+(\omega_r*L_q*I_q)$

The expression for the electromagnetic (EM) torque in the rotor is the relationship between the angular frequency of the stator voltage (r) and the mechanical angular velocity of the rotor (m) may be expressed as

$T_e = (3/2)*(P_n/2)*((L_q-L_d)*(I_qI_d-\boldsymbol{\lambda}_mI_q))$

$\omega_r = (P_n/2)*(\omega_mG)$

$P.\omega_r = (P_n/2I_g)*(T_m-T_g)$

$P_\theta = \omega_r$

Torque developed by the turbine T_t and the input to the generator is expressed as

$T_m = T_t/G$

C. Rectifier

A three- phase diode bridge rectifier converts the AC output voltage from the generator terminal, which is variable in magnitude and also in frequency, in to DC. The average output voltage of the three-phase diode rectifier is

$V_{d\,c}= (3*V_m)/ \pi$

The average load current of the three-phase diode rectifier is

$I_{dc}=V_{dc}/R_L$

The RMS value of load current of the three-phase diode rectifier is

$I_{rms} = V_{rms}/R_L$

D. Inverter model

A forced-commutated, transformer-less, full-bridge, singlephase, IGBTs voltage source inverter (VSI) is proposed for interfacing these HWPVS with the LV grid via a coupling inductor (L_k). The main purpose of this inverter is to convert DC to AC power. The use of high-frequency semiconductors with fast gate turn-off capability (i.e. IGBTs) and modern control techniques makes the inverter a suitable device with the capabilities to: ensure that the load connection of the HWPVS will not affect adversely the power quality and safety of operation of the load achieve MPP Tracking, and provide reactive power compensation. It is common practice for small-scale single phase load connected inverters to inject power into the load with a PF close to unity. This way the inverter does not perform any local compensation for PF correction. The proposed centralized AC—bus HWPVS is a small-scale one and the only task of its inverter is to transfer the maximum power of the HWPVS to the load in AC form, with zero reactive power and in compliance with all applicable power quality interconnection rules.

E. MPPT Control strategy for wind turbine system

For small-scale wind generator system the synchronous generator is used. According to the operation theory of wind turbine, the maximum output power of wind generator depends on the

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optimal tip speed ratio λ $_{opt}$. In terms of this, the MPPT1 block shown in Fig. 1 is controlled to track the maximum power of wind turbine and the battery charging voltage in such a way taking the technique parameters of wind turbine given by the manufacturer to calculate the optimum tip speed of the wind turbine λ_{opt} and the maximum power coefficient Cpmax related to the optimum tip speed λ_{opt}. The maximum power is divided by the amplitude of the output voltage of the load side which is obtained by measure module, obtaining a reference current of the boost converter of MPPT 1. By comparing the measured current with the reference current of the converter, the PWM signals are acquired. When the measured value is greater than the reference value, the switch is turned off, so the output voltage will get down and the current will also get down to track the reference current. Contrarily, the switch is turned on. The control diagram is showed in Fig 3.

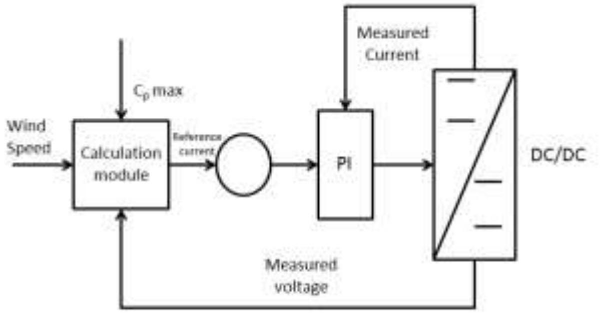

Fig.3. Control Diagram

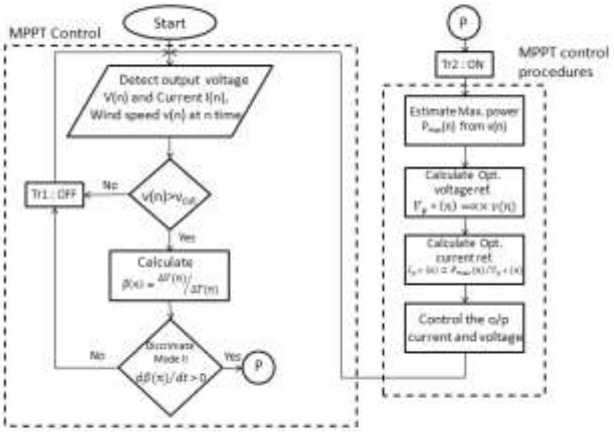

Fig.4. MPPT Control flowchart for wind turbine system

SOLAR ENERGY CONVERSION SUBSYSTEM

Solar panels produce direct current (DC) electricity. This DC power is regulated using a DC/DC converter, which can be used to feed power to a AC bus, which can be used to power DC loads (i.e. battery) or AC loads (through an inverter – DC/AC converter).

A. Solar Cell

Solar cells consist of a p-n junction fabricated in a thin wafer or layer of semiconductor (usually silicon). In the dark, the I-Voutput characteristic of a solar cell has an exponential characteristic similar to that of a diode. When solar energy (photons) hits the solar cell, with energy greater than band gap energy of the semiconductor, electrons are knocked loose from the atoms in the material, creating electron-hole pairs. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. The characteristics of this diode therefore set the open circuit voltage characteristics of the cell.

B.Modeling the Solar Cell

Thus the simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell (photocurrent I_{ph}). During darkness, the solar cell is not an active device; it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. However, if it is connected to an external supply (large voltage) it generates a current I_D, called diode (D) current or dark current. The diode determines the I-V characteristics of the cell.

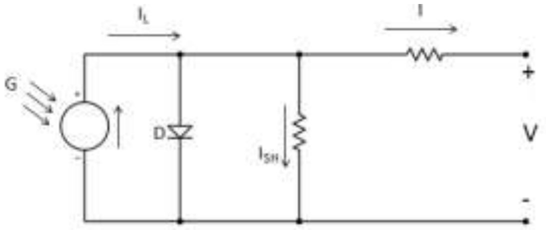

Fig. 5. Circuit diagram of the PV model

The current produced by the solar cell is given by the following equation,

$I = I_L - I_D - I_{SH}$

Where,

I = Output Current (A)
I_L = Photo Generated Current (A)
I_D = Diode Current (A)
I_{SH} = Shunt Current (A)

The current through these elements is governed by the voltage across them:

$V_j = V + IR_S$

Where,

V_j = Voltage across Both Diode And Resistor R_{SH} (V)
V = Voltage across the Output Terminal
I = Output Current (A)
R = Series Resistance (Ω)

Equation of a solar cell, which relates solar cell parameters to the output current and voltage:

$$I_L - I_O \{exp\left[\left(q * \frac{(V+IR_s)}{nkT}\right)\right] - 1\} - \left[\frac{V+IR_s}{R_{SH}}\right]$$

Where,

I_0 = Reverse Saturation Current (A),
I_L = Photo generated Current (A)
n = Diode Ideality Factor (1 for an ideal diode)
q = Elementary Charge
k = Boltzmann's Constant
T = Absolute Temperature
R_{SH} = Shunt Resistance (Ω)

C.MPPT Control strategy for PV array system

C.1 Principle of the incremental conductance

This method consists in using the slope of the derivative of the current with respect to the voltage in order to reach the maximum power point. To obtain this point, dI/dV must be equal to –I/V In fact, applying a variation on the voltage toward the biggest or the smallest value, its influence appears on the power value. If the power increases, one continues varying the voltage in the same direction, if not, one continues in the inverse direction. The simplified flow chart of this method is given in figure. In addition, by using the power formula, P=V.I, its derivative becomes: dP = V.dI + I.dV In general, the duty cycle (αn) of the used chopper (dc-dc converter) .

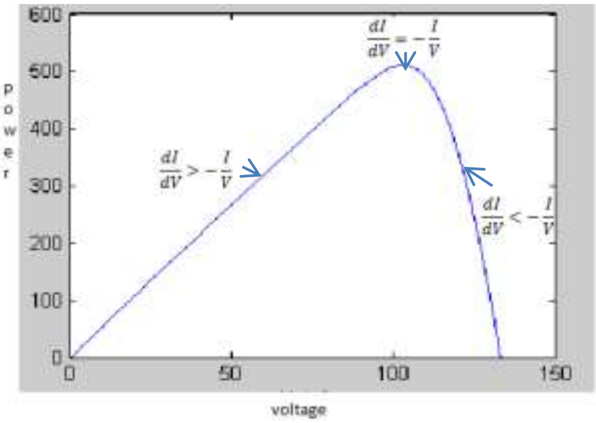

Fig 6. Output power using Incremental Conductance MPPT method

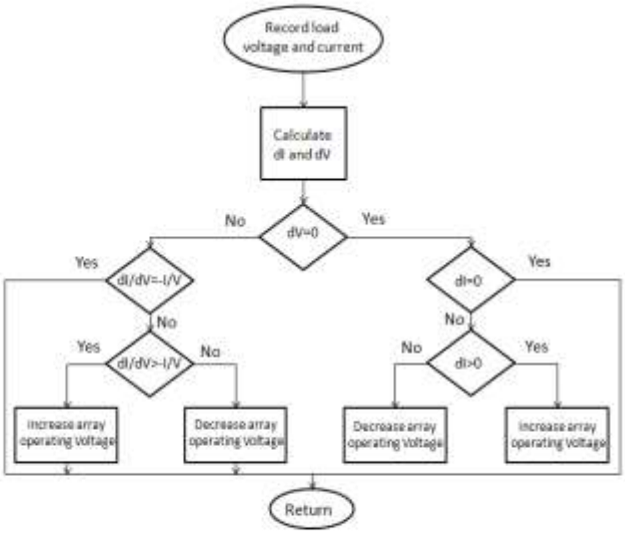

Fig 7. Incremental Conductance (MPPT) Flow Chart For Solar System

SIMULATION

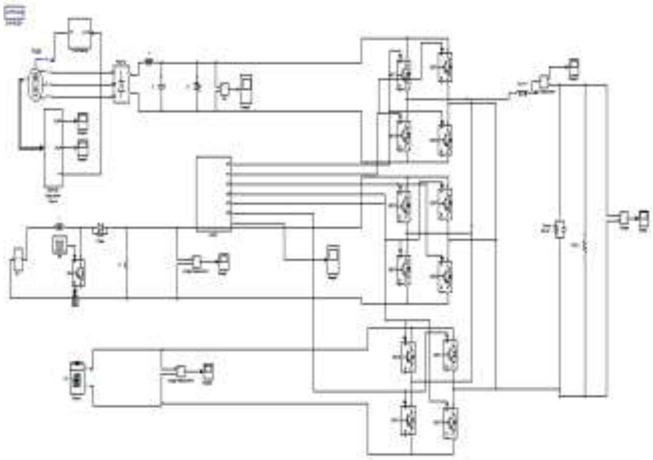

Fig.8.Simulink model of PV&Wind Hybrid Power System

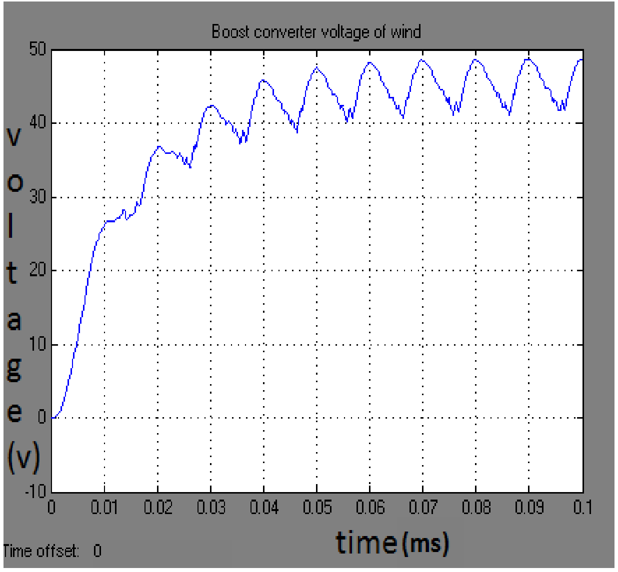

Fig.9.Output voltage of Rectifier (Wind)

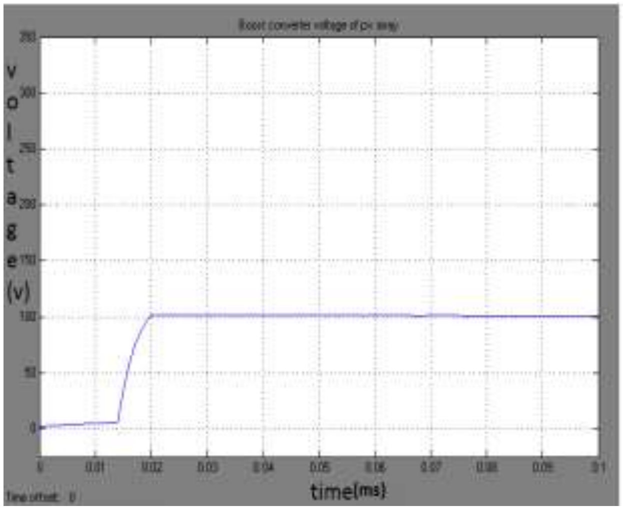

Fig.10.Output voltage of boost converter (PV array)

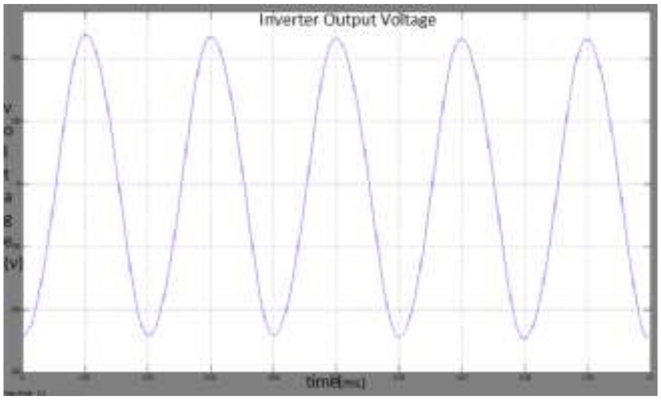

Fig.11.Inverter output voltage

CONCLUSION

The implemented Hybrid Power System consists of a wind energy conversion system, PV array and a battery module which is used to supply a total load of 1KW.In the proposed PV system, boost converter is used to boost the output voltage from the array. To obtain the maximum power from the PV array at all conditions incremental conductance algorithm is used to track maximum power point. Wind energy conversion system is designed using permanent magnet synchronous generator. The excess power from the Wind/PV system is used to charge the battery. The designed hybrid power system model is simulated using MATLAB Simulink environment. The simulation results show the possibility of producing efficient power from the sources. In this model, two sources are integrated along with battery backup to provide reliable supply to the load. This system is used to extract maximum power from the renewable resources. This scheme is very much advantageous for rural electrification. It also results in lower environmental pollution.

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