

Experimental study on hybrid power combining solar energy and animal energy for home lighting system

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ABSTRACT: *In this paper a hybrid power system combining solar energy and animal energy is experimentally studied to supply continuous power to home lighting applications. The solar system is used as main energy source while the animal system is used as secondary or back-up energy source. This invention provides animal powered mechanical device for prime mover to electric generator. Animal energy in form of high-torque low-speed can be converted into low-torque high-speed through speed increaser to energize the electric generator. A simple and cost effective charge control with dc–dc converters is used for maximum power point tracking and hence maximum power extracting from the solar system. The results show that even when the sun is not available; the system is reliable and available and it can supply high-quality power to the home lighting applications by the animal powered system.*

Keywords: *Animal power, electric generation, hybrid system, solar power, speed increaser.*

I. INTRODUCTION

Over 1.5 billion people rely on kerosene for light. Lack of suitable home lighting is directly linked to illiteracy, poverty and health problems. The current widespread burning of kerosene also results in environmental pollution. It is very difficult and very costly to available grid power everywhere specially at remote isolated communities in developing countries but it is necessary of continuing energy supply. To achieve this goal consists of using renewable energy sources, not only for large-scale energy production, but also for stand-alone systems [1-3]. Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources till date. The current–voltage (I-V) characteristic of a solar photovoltaic is given by Eq.(1). The output characteristics of a solar PV are non-linear and are crucially influenced by the solar radiation, temperature and load condition therefore it must be ensured that it operates at all time to provide maximum power output. In this paper the voltage-based MPPT (dc–dc converter) technique have been used to track the maximum power point of the PV array used [4 – 7].

$$I_{PV} = n_p I_{sc} - n_p I_0 \left\{ \exp \left[\frac{q(V_{PV} + R_s I_{PV})}{A k T n_s} \right] - 1 \right\} - n_p \frac{(V_{PV} + R_s I_{PV})}{n_s R_{sh}} \quad (1)$$

where V_{PV} and I_{PV} represent the output voltage and current of the solar cell, respectively; R_s and R_{sh} are the series and shunt resistance of the cell; q is the electron charge ($1.6e^{-19}$ C); I_{sc} is the light-generated current; I_0 is the reverse saturation current; A is a dimensionless junction material factor; k is the Boltzmann constant ($1.38e^{-23}$ J/K); T is the temperature (K); n_p and n_s are the number of cells connected in parallel and in series, respectively.

In this paper authors introducing the animal power and human power as other forms of hybrid energy system. The force exerted by a working animal is approximately equal to 10-12% of its live weight, and this means for example, that a buffalo has a power output of about 300 W, or 5.4 MJ/d, if it is assumed that the animal works for 5 h per day[8-10]. The methodology of animal power system is very simple. The device called belan pulled by animal comprises of a mechanical link means provided with an extended pipe to transmit animal power in form of high-torque low-speed to a speed increaser; a speed increaser provided with an input shaft mounted with 68 teeth gear and an output shaft mounted with 15 teeth gear for converting human power received from a mechanical link in the form of a high-torque low-speed to low-torque high-speed in four stages; a belt and pulley system which is connected to the output shaft of the speed increaser for transmitting mechanical energy in form of low -torque high- speed received from the speed increaser to generator; generator to convert mechanical energy into electrical energy; and a storage system.

II. EXPERIMENT DETAILS

2.1 Solar Power system: The solar power of size 1000 Watt which has four solar panels of 250 Watt in series was used in experiment which has been using by author for last two years. Solar panel is manufactured by Sova Power Ltd. It has efficiency of more than 85%. Rated voltage is 34.85 V, Rated current is 7.19A, Open circuit voltage (V_{oc}) is 42.91V, Short circuit current (I_{sc}) is 7.85A.

2.2 Battery system: Inverter Tubular Battery of 12V 180 AH is used. The maximum charging current should not exceed 40 Amps. The system cut off voltage shall be at 14.4V and discharge cut off voltage 10.8V.

2.3 Inverter: MRO-TEK’s DSP based Sine wave Solar PCU with state of the art technology is used:

Inverter Model	NS 1024S+	MPPT Model	NS 1024S+
Output voltage (VAC)	230±10%	Battery charging current	40 A
Output power (VA/Watt)	1000/1000	Max solar input power	1000 Watt
Output frequency (Hz)	49-51	Peak charge efficiency	95%
Output current (Amps)	15A	Max solar open circuit volt	85
Efficiency (%)	85%		
Battery voltage (V)	24		

2.4 Draught animal: The authors’ main object is to use the animal power for generating electricity for domestic and agriculture use. For this experimental study authors used the pair of bullocks. The weights of bullocks are 456 kg and 478 kg. The mechanical link is fitted with a device pulled by pair of bullocks called bellan which is made of wood and has the weight of 105 kg.

2.5 Speed increaser: Speed increaser is a four set of spur gears housed in a frame of mild steel angles having 690 mm × 690 mm at the top and 780 mm × 780 mm at bottom. It is having 4 numbers of stages with gear ratio of 1:4.5. Input shaft of the speed increaser having 50 mm diameter and 600 mm length of mild steel material is in vertical position whereas output shaft having 50 mm diameter and 450 mm length of mild steel material of the same is also in vertical position. The shafts are supported with taper roller bearings at top and bottom. Bearings are fastened on tie-bars which are welded on frame. Speed increaser is specially used for transmitting and converting low-speed high torque to high-speed low-torque.

2.6 Belt and Pulley transmission unit: The final speed increasing is done by using belt and pulley system. One pulley of 228.6mm (9 inch) was mounted on the output shaft of the speed riser and counter pulley was mounted on car alternator having 76.2mm(3 inch) thereby stepping up the speed in the ratio 1: 3 when connected with toothed belt. According to Indian Standard Code (IS: 2494-1974), the A type of belt is selected which has power ranges 0.7kW – 3.5 KW.

2.7 Generator: In this experimental study authors select the car alternator to generate electricity. Lucas-TVS car alternator of 12V 95AH and 12V 75AH were used.

2.8 Home lighting system: This inventions main object is to produce power for home lighting at rural and isolated remote areas where population rely on kerosene for lighting. This system consisting following home appliance with power required.

Home Appliance	load per unit	Quantity	Min Time	Max Time	Min Total Load	Max Total Load
CFL Bulb	25×4=100W	4	4 hr	8 hr	400W	800W
Ceiling fan	75W	1	4 hr	8 hr	300W	600W
Plasma TV	125W	1	2 hr	4 hr	250W	500W
Computer	150W	1	2 hr	4 hr	300W	600W
Mobile Charger	40W	1	5 hr	10 hr	200W	400W
Radio	50W	1	1hr	2hr	50W	100W
Total Power	540W				1500W	3000W

2.9 Gears: Four sets of spur gears transmits the power among parallel shafts. The spur gears are made of cast iron having module 5 mm. the spur gears has 68 teeth while the spur pinions has 15 teeth. The pressure angle is 20 degree and outside diameters are 350mm and 85mm respectively. The speed ratio of 1:4.5 is obtained in single stage. The geometric detailed and strength calculation for cast iron spur gear.

Geometric details of desired spur gear [11]	Strength calculation for spur gear [11]
<ul style="list-style-type: none"> • Module (m) = 5 mm, Addendum = 1 module, Dedendum = 1.157*module Pressure angle (α) = 20 degrees Tooth thickness (t) = 1.571 * module = 1.571*5 = 7.855mm 	Using Lewis equation [11] Tangential load $F = \sigma_b * y * P_c * b$ Where ‘σ _b ’ is the allowable stress, ‘y’ is the Lewis form factor $y=0.1034$, ‘P _c ’ (Circular pitch) = $\pi * \text{module}$, ‘b’ is the face width of the gears,

<p>Whole depth = 2.25 * module • Face width (b) = 5.4 * module = b = 5.4*5 = 27mm. • Fillet radius = 3.9 * module • No of teeth (z) = 68 and 15 Pitch circle diameter (pcd) = z*m = 68*5 = 340mm and 15*5 = 75mm Outside diameter = (z+2)*m = 350mm and 85mm</p>	<p>'d' is the pitch circle diameter of the gear. F = 2*500 = 1000N putting in Lewis equation 1000 = $\sigma_b * 0.1034 * (\pi * 5) * 27$ $\sigma_b = 22.81 \text{ N/mm}^2$ σ_{all} of Cast iron (high grade) = $\sigma_{\text{ut}}/3$ = 320/3 = 106.67 $\text{ N/mm}^2 > 22.8 \text{ N/mm}^2$</p>
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According to [8-10] an animal (bullock) can applied the tangential force of 500N (F=2*500=1000N). and ultimate strength of cast iron is 320 N/mm^2 [11].

III. FABRICATION AND PROCEDURE

The fabrication of speed increaser was done very carefully because there are five vertical shafts which are supported by taper roller bearing. The bearing covers were fitted with the help of nut and bolt on the mild steel ties, which are welded on the frame at top and bottom. Collars are provided at bottoms of shaft to support the load on bearings. Gears are fitted by means of nuts by drilling two holes on the shafts and on gear houses. There are four step gear transmission system. The first gear of 68 teeth was mounted on first shaft at 20mm from the collar which meshes with the second gear having 15 teeth mounted on second shaft at 20mm above from the collar. The third having 68 teeth was mounted on second shaft 50mm above the second gear and meshes with the fourth gear having 15 teeth which was mounted on third shaft at the same height. The fifth gear having 68 teeth was mounted on third shaft 50mm above the fourth gear and meshes with the sixth gear having 15 teeth which was mounted on the fourth shaft at the same height. The seventh gear having 68 teeth was mounted on fourth shaft 50mm above the sixth gear and meshes with the eighth gear having 15 teeth which was mounted on fifth shaft at same height. The pulley of 228.6mm was mounted on fifth shaft at 200mm from the bottom which drive the another pulley of 76.2mm mounted on alternator and alternator was fabricated on the frame with the help of mechanical linkage.

If bullock rotates at radial distance (r) of 2.5 m from the main shaft (first gear) then the distance at one revolution is 15.7 m ($2 \times \pi \times 2.5$). And the distance cover in one minute by bullock is $1 \times 60 = 60$ m. Hence the initial rpm is 3.82(60/15.7). Due to compactibility and resources available author select the gears used in sugarcane juice machine of speed ratio 4.5. Four stage gear system is used. Output rpm is increased by using pulley and belt which has speed ratio 3. So that the rpm of output gear according to S S Ratan[12].

$$\frac{N_8}{N_1} = \frac{Z_1}{Z_2} \times \frac{Z_3}{Z_4} \times \frac{Z_5}{Z_6} \times \frac{Z_7}{Z_8} \tag{2}$$

$$(N_f)_g = 3.82 * 4.5 * 4.5 * 4.5 * 4.5 * 4.5 \approx 1567 \text{ rpm.}$$

The mechanical link GI pipe was fitted with the first shaft of speed increaser by means of elbo and nut-bolt at one end and another end was coupled on belan with the help of GI wire such that the center of belan coincide at 2500mm of mechanical link. The speed increaser was fixed in the pit of 780mm×780mm×300mm. The bullock pair was harnessed with traditional means. The shepherd applied the force the bullocks started moving into the circular path and also the belan along with mechanical link rotate the first shaft of the speed increaser. At the starting the rpm was very low hence the alternator was not responding but as well as speed was increasing the alternator start to generating power. Bullocks were need to applied force time to time to maintain average speed. The rpm and generated volt & current were taken after every four minutes. The batteries were 50% charged and it took approximate 2 hours to charge fully(multimeter indicate 12.6V). In first two experiments the automotive battery of 12V 150AH was charged with animal power system and connected in series to the 1000VA inverter and 540W load subjected to inverter. Next two experiment the tubular battery of 12V 180AH was charged with animal power system and connected in series to the inverter. Same time the solar system charged the tubular battery using MPPT technology (also dc-dc convertor) and 540W load connected with this tubular batteries through inverter.



Fig 3: Bullocks powered mechanical device for generating electric power.



Fig 4: Parallel combination of animal power and solar power of 250W.

IV. RESULTS AND DISCUSSION

The animals' effort and speed depend on the load subjected and force applied by shepherd. Animal speed is change very quickly and abruptly. It is very difficult to taking speed reading continuously because animals got puzzled. The readings were taken after every four minutes within one hour. Speed vs. Current shows that at low rpm at starting of animal motion it is not generating current by both alternator, but as well as rpm is increasing and reaches to ideal working rang alternators producing high value of currents. Alternator generates constant voltage of 12V as specified after reaching ideal speed. Fully charged battery shows 12.6V. The time taken by solar system to charge the battery is depend on atmosphere temperature. Since MPPT technology is used to charge controlle battery get the constant valtage. Normaly 12V 180Amps tubular battery is charged in 7–10 hours because temperatue is vary from morning to evening. But when tubular battery was charged using animal powered alternator of TVS-Lucas 12V 75AH which generate 36Amps it took 2 hour to fully charge from 50% state of charge. Tubular battery can not be charged using alternator of 12V 95Amps because of high charging current but 12V 150Amps automotive battery took 2 hours to charge. When 540W load subjected with automotive battery through inverter it delivers power very efficiently and worked for 4 hours 30 minutes. Same time tubular battery worked for 5 hour 25 minutes. Finally charged tubular batteries by solar power and animal power were connected in series individually after then connected parallel to the inverter and delivered power to 540W load for 9 hours 36 minutes(average). Authors also done combine experiment during charging batteries by animal power and solar power of 250W and found that fan of 1 hp is running efficiently. Hence solar power and animal power are good combination for home lighting system.

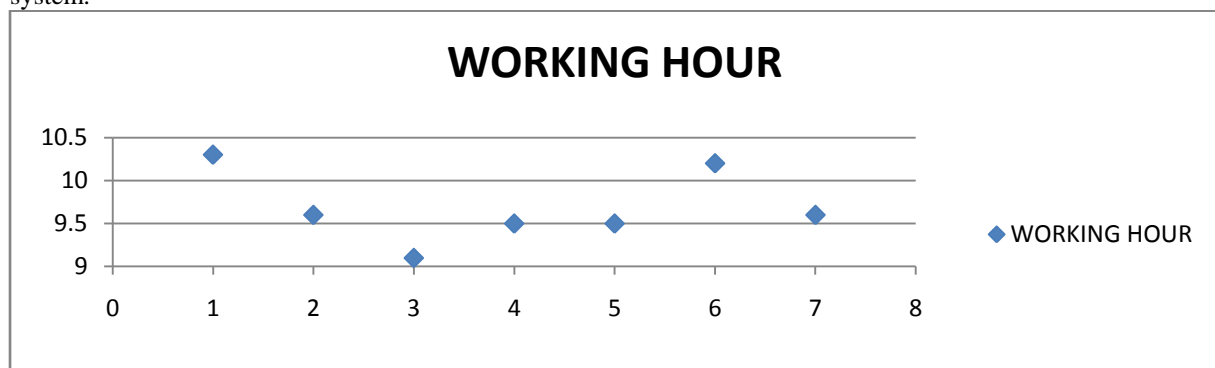


Fig 5: Working hours when 540W load subjected to hybrid power system.

V. CONCLUSION

The present work provides a system and method for producing electricity for home lighting system using the biological energy of the muscles of animals like bullock by means of a mechanical device. The project goal was to combining the solar power and animal power for home lighting which can work when even sun is not available. This goal had to be met within the constraints of a low production cost and high safety. The project has to offer a durable product with relatively good efficiency and emission free system. This is also concluded that animals are the great energy source for generating power even having low speed.

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