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RESEARCH ARTICLE

Integration of solar photovoltaic power for wet tanning process application in leather industry

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Abstract

The potential to use solar photovoltaic system for industrial processes reduces the environmental impact of burning fossil fuels. Geographically, India is in tropical region placed in Asian continent and receives solar energy equivalent to 5000 TkWh/year, which is more than the current total energy consumption of the country. However, the awareness to exploit the solar energy for industrial uses is very limited. Leather making is an energy intensive process. The electrical input used in wet tanning process is about 15-20% of total energy consumption for the production of wet finished leather. In this context, harnessing solar energy for tanning operation is the best option. The objective of this study is to run a rotating tanning drum continuously using SPV power for wet processing. A prototype Solar Photovoltaic (SPV) power plant was set up along with tubular lead acid battery as energy storage to run the tanning drum with geared motor assembly. Several tests were carried out effectively and efficiently using SPV energy with 50-100% solar fraction throughout the year. The specific energy and CO_2 saving were also calculated. The quality of the leather is in par with the leather processed by conventional method. The results obtained from the prototype are promising, and has a scope for the implementation of solar energy in industrial application, particularly in leather industry in India. Thus, this research, indicates promising technical and economical feasibility of using solar PV energy for industrial processes and provides an important step towards sustainable zero emission production in leather industry.

Keywords: Solar photovoltaic system, leather processing, tanning drum, solar charge controller, tubular lead acid battery.

Introduction

Production of electricity from renewable sources has become an inevitable task due to environmental pollution and global warming. Reduction in greenhouse gas emissions can only be achieved by following methods using renewable energy sources and by simultaneously increasing the energy efficiency. Enormous research and development activities on renewable energy, particularly on solar energy (for electricity, heat, H_2 fuel, etc.) are being carried out all-over the world, since energy demand is increasing day by day due to more population and growth of industries, especially in India and China. India's commercial energy consumption has been growing fast in recent years keeping pace with high economic growth rate. India depends mainly on coal and oil for its energy demands. As these are polluting fuels and are the biggest source of greenhouse gas emissions, their use needs to be curtailed for reducing emission of both greenhouse gases and local air pollutants.

Nomenclature

SPV: Solar Photo voltaic; PMDC: Permanent Magnet DC motor; CO_2: Carbon Dioxide, H_2: Hydrogen; MPPT: Maximum power point tracker; BLDC: Brush Less DC motor; SCC: Solar charge controller; DC: Direct current; SS: Stainless steel; Re-Chro: Re-Chroming; Neut: Neutralization; SO_2: Sulphur dioxide; CO: Carbon monoxide; NOx: Oxides of nitrogen; D: Drum.

Solar PV systems has been used with PMDC motors with water pumps and circulation fans for the applications of drinking water purposes, irrigations, green house water supply management and drying of grains (Putta Swamy *et al.,* 1995; Mumb, 1996; Smulders *et al.,* 1997; Badescu, 2003).

Photovoltaic systems with MPPT controller and digital signal processor was implemented and tested in remote areas with 3 phase BLDC motor drive and increase of power up to 25.35% was reported by Akkaya *et al.* (2007). Another major achievement was done by the installation and use of a 3-kWp photovoltaic (PV) plant in Tanzania to provide power supply for a village school, health center, school staff quarters, and mosques (Kivaisi, 2000). Effective studies have been done on larger lead acid battery banks with solar PV stand-alone systems for life cycle improvements, frequency regulation, load leveling and effective energy storage in various locations ((Wagner *et al*., 1997; Kaushika *et al*., 2005; Lemaire-Potteau *et al*., 2006; Ali Muhtaroglu *et al*., 2008). Introduction and integration of Solar PV systems in industries, hotels and residential building have been done effectively and confirmed its importance for energy production as well as to reduce CO_2 (Andreia *et al*., 2007; Li *et al*., 2007; Michalena *et al*., 2010; Al-Salaymeh *et al*., 2010).

Fig. 1. (a) The schematic of experimental photovoltaic tanning drum system; (b) Solar power plant; (c) Measuring and control devices with lead acid battery.

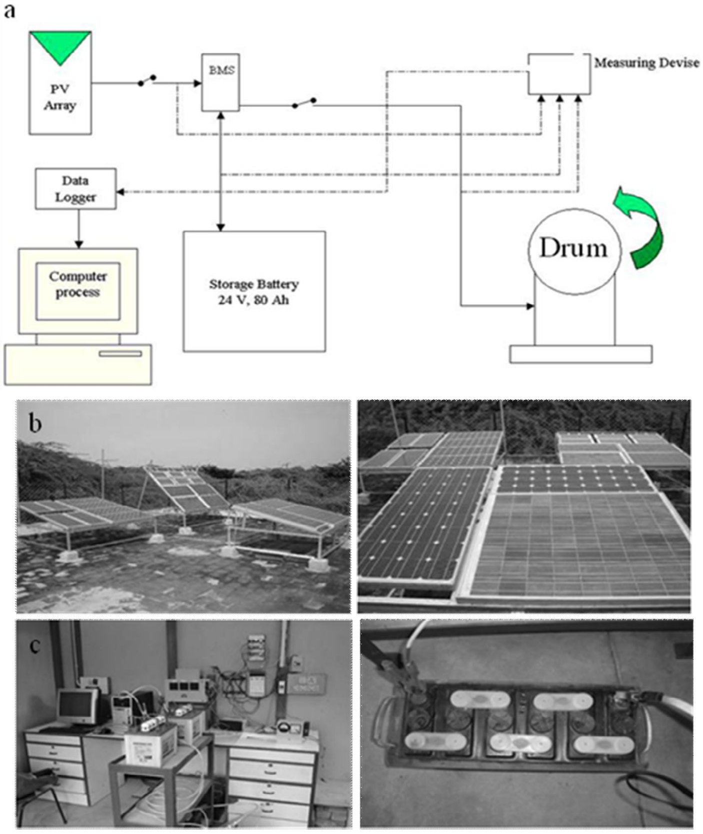
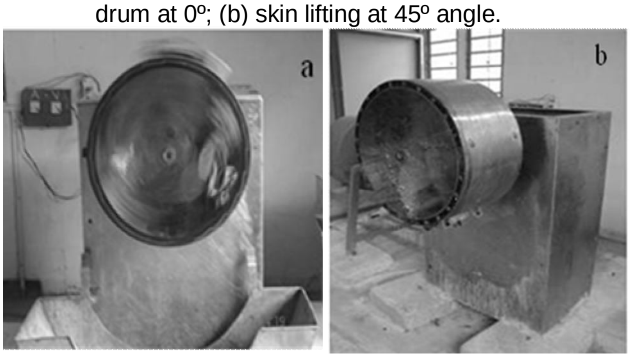


Fig. 2. Tanning drum; (a) Skin at bottom of the drum at 0º; (b) skin lifting at 45º angle.



Hybrid systems such as wind/solar-Diesel, PV-Diesel with battery as back up are being used in urban and remote area for uninterrupted power generation and to meet the energy demands in summer (Thomachan *et al.,* 1996; Martins *et al*., 2008; Ernest *et al*., 2009; Campoccia *et al*., 2009; Liu and Wang, 2009; Nema *et al*., 2009). India depends heavily on coal and oil for meeting its energy demand, which is highly problematic for the country. India has made significant progress in renewable energy and the status and potential of different renewable have high growth with new technologies like solar PV, solar thermal, wind and geothermal power plants etc. (Bhattacharya and Jana, 2009; Pillai and Banerjee, 2009). In this paper, an attempt has been made on introducing SPV system in wet tanning operation for leather industry.

Materials and methods

Study location

Chennai (Madras) is located at a latitude angle 13.04°N and longitudinal angle 80.17 E and has the annual average solar irradiation of 4.7 kWh-8.2 kWh/m^2/d with sun shining days of about 300-320 d/annum. The annual average temperature was measured as 30-32°C.

System configuration

A SPV power plant with a peak power of 1kWp has been installed and commissioned with a rearrange combination of 10-150 Wp panels (each one is crystalline type with 36 cells) 12 VDC and the power efficiency of 14% fixed at an angle of 13.04° facing south. Depending on the specific application in leather industry such as skin/hide tanning process, effluent treatment, SPV ozone generation etc., and this integrated SPV system is being used at different system voltages such as 12 V, 24 V and 48 V DC etc. A 400 W solar PV power system has been tapped to operate one prototype rotating tanning drum with a PMDC geared motor assembly through BMS/solar charge controller (SCC), DC shunts with isolation transformer and positive tubular plate lead acid battery as back-up to operate the tanning drum day and night time, since the complete leather process consumes energy of about 18-20 h. Data logger supports the entire system for logging all data such as solar insulation, current and voltage during charge and discharge period at an interval of 1 min.

Fig. 3. Flow chart of complete sequence leather tanning operation. The D indicates tanning drum where the complete leather processing is carried out.

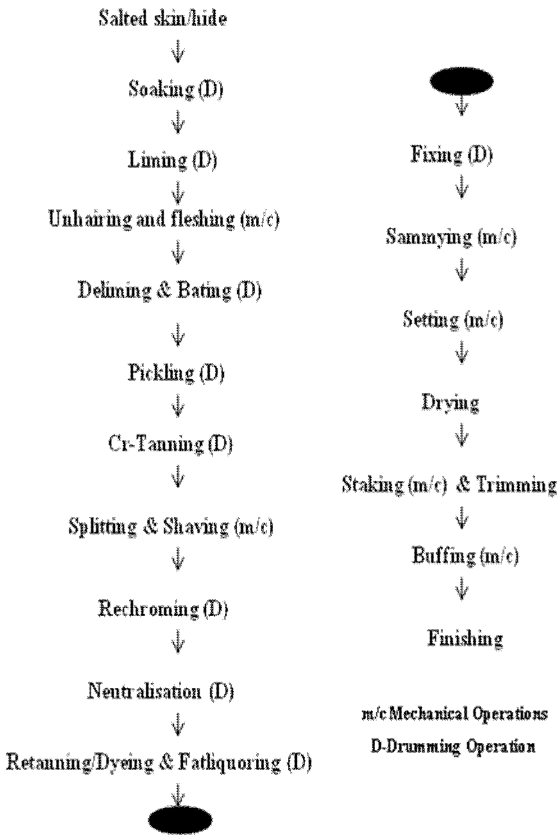


Table 1. Specification of the system components.

Name of the component	Specification
Solar PV system Make: Maharishi solar products, India	Max.Power: 400 W_p OCV: 57 V System voltage: 24 V, I_{max}: 16 A.
Tubular Lead Acid Battery: Prepared in CLRI, with electrically conductive carbon black.	System voltage: 24 V; Capacity: 80 Ah, (two string of 12V, 40 Ah, C10 rate connected in series and parallel)
3-Stage PWM Solar charge controller, Xantrex, Model: C 40, USA.	Voltage: 12/24/48 VDC and I_{max}: 40 A
Pyranometer, Kipps and Zonen, Holland.	Model CM-11B, 0-1000 W/m^2
PMDC Motor with reduction Gear box, India	Power: 375 W, 24 V and Current: 15 A, Motor Speed:1400 rpm, Tanning Drum speed:12-14 rpm, Gear Reduction ratio-100:1
Tanning drum, Ronald, India	50 cm dia. and 30 cm width and Weight: 30 Kgs

Schematic representation of the entire SPV stand-alone system is shown in Figure 1. The specification of the system components are given in Table 1.

Rotating tanning drum

The tanning drum is a cylindrical one, made up of SS 316, where the raw goat skin is processed from soaking to finished operation as shown in the Figure 2. The dissolved chemicals in water are penetrated inside the skin by agitation of the drum by carry-over the skin from bottom to top (0-50°) along with 2 or 4 baffles plates, provided on the inner circumferential area of the tanning drum to complete the tanning process. Once the skin reaches the maximum level, the motor develops maximum torque and the skin falls down inside the drum with minimum torque. This process is repeated till the tanning process is complete which is shown in Figure 3.

Experimental procedure

In this method, total wet tanning operation was carried out in the Tanning Drum indicated by (D) from soaking to wet finishing leather process to minimize the water quantity. A total weight of 10 Kg (1:1 ratio of skin and water) was taken with rotation of the drum at a speed of 12-14 rpm, which was suitable for the wet tanning process. Suitable chemicals for leather processing were added as given in the Figure 4. The tanning operation was carried out successfully with a total period of about 20 h.

Results and discussion

A typical solar irradiation profile is shown in Figure 4. A maximum solar irradiation of 900 W/m^2 on 27.04.11 was received on this day at Chemical Engineering Department, CLRI, Chennai. Solar energy harnessed on this day was more than sufficient for our day-to-day leather process operation. The SCC was switched-on by charge control mode with a bulk charge voltage of 28 V_{max} to charge the batteries effectively in one day as shown in the Figure 5.

Fig. 4. Solar irradiation during test day on 27.04.08.

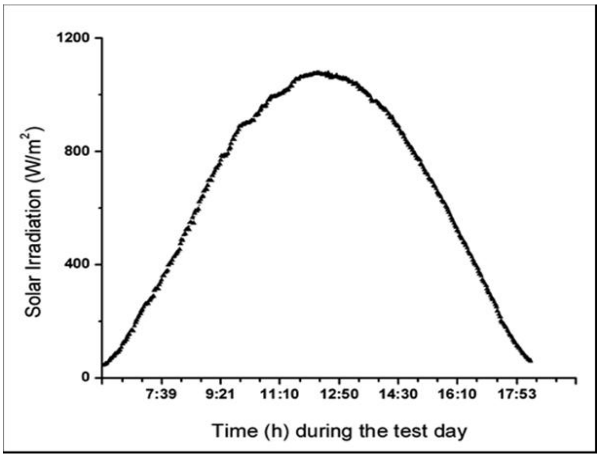


Fig. 5. Current and voltage of the battery during charge using SPV power.

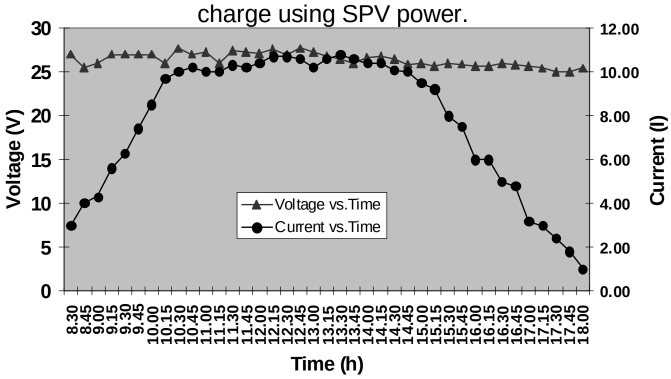


Fig. 6. Profile of battery discharge current.

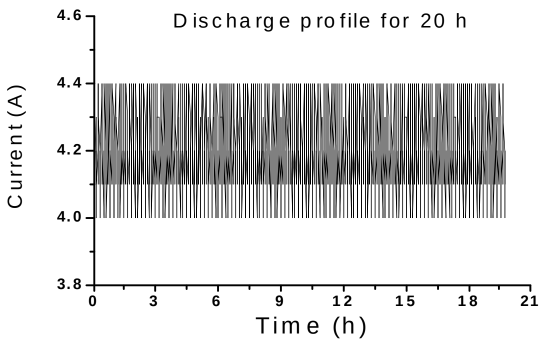
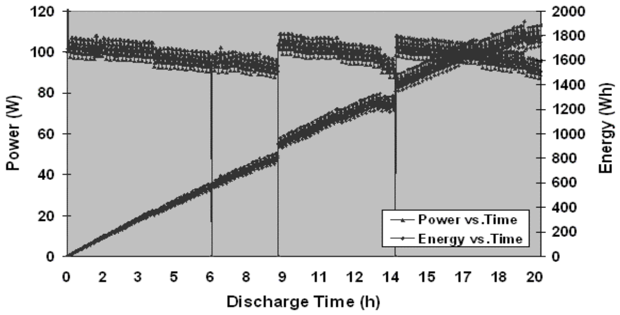


Fig. 7. Power and energy during discharge of the battery.



Battery charging method

The effective charge was performed from 10.00 AM to 3.00 PM at a charge current of about 10 A controlled by PWM controller to protect the battery from high surge current. But, the charge voltage was maintained between 25-27 V, as seen in Figure 5. The 80 Ah tubular batteries were charged full by indicating a solid green light on the SCC. The measurement was taken manually at every 15 min interval.

Battery discharge method

The SCC was switched-over to discharge/load control mode with a lower set voltage limit of 21.6 $V_{min.}$ The tanning drum was started for the wet tanning process and the DC motor was found to draw a starting current of 6.8 A and normal operating current of 4-4.4 A, because of the variation in the torque by the up and down movement of skins inside the tanning drum. Initially, 80% of the rated capacity of this battery was discharged and charged again in the next day to complete the tanning process. The total discharge current profile of this battery for 20 h process is shown in the Figure 6. From the entire test, we could be able to use 80% of the rated capacity effectively for this wet tanning process. The average current and voltage were calculated as 4.2 A and 22.8 V respectively. This profile with up and down motion explains the corresponding motion of skins inside the tanning drum during the skin processing. In addition, it was observed that the performance of the tubular lead acid battery is viable for industrial leather processing application with variable torque/loads.

Table 3. Chemical analysis of processed leather.

Test	Method adopted	Experimental	Control
Insoluble ash	IUC 7:1965	4.93	4.95
Solvent soluble	IUC 4:1965	4.99	5.3
Chrome	IUC 8:1965	2.38	2.35

Table 4. Physical observation.

Test parameters	Experimental	Control
Color	7	7
Tightness	7	8
Softness	8	8
Smoothness	8	7
Fullness	6	6
General appearance	7	7

This test was carried out by hand evaluation by three experts in our laboratory. Assessed on a scale of 1-10, with 1 as the poorest and 10 as the best.

Table 5. Physical property.

Test parameters	Method adopted	Experimental	Control
Tensile strength (N/mm^2)	ISO 3376	16	16
Tear strength (N)	ISO 3377	49	49
Grain crack strength Load (kg)	ISO 3378	23	23
Grain crack strength (Distance)	ISO 3379	8	8

Table 6. Color Fastness test.

Parameters	Experimental	Control
Penetration rating	5	5
Exhaustion rating	4	4
Levelness	Good	Good
Intensity of shade	Good	Good
Wet Rub Fastness	4-5	4-5
Dry Rub Fastness	4-5	4-5
Perspiration Fastness	4-5	4-5
Color Staining	4-5	4-5

Assessed on a scale of 1-5, with 1 as the poorest and 5 as the best.

Table 2. Energy consumption of three main processes.

Discharge cycle	Process	Wt. of Skin, water and chemicals (Kg)	Process time (h)	Capacity (Ah)	Total energy consumed (Wh)	Eq.CO_2 savings (gm)
Pre-tanning C1	Soaking, Liming, reliming, Deliming and pickling	10	5	32	652	638.9
Tanning C2	Chrome tanning	7	6	25.25	517	506.6
Post tanning C3	Re-chro,Neut, Re-tanning, dyeing and Fat liquoring	3	9	37	716	701.60
Total			20		1885	1847. 3

Discharge power and energy

Figure 7 shows the power and energy consumed to process 5 kg of goat skins from pre-tanning, tanning to post tanning process. The energy and power profile was similar to the profile of discharged current by agitation of skins with up and down motion during the tanning process. From the measured data, the average power and average energy was calculated as 94 W and 1885 Wh respectively.

Analysis of energy and CO_2 saving data

Table 2 shows the details of energy consumption of three main processes during the wet tanning process namely pre-tanning, tanning, and post-tanning operations. From this table, it could be observed that the post-tanning process consumed a maximum energy of 716 Wh with 9 h process time. Specific energy was also calculated as 377 Wh/kg of goat skin based on the raw goat skin weight of 5 kg and equivalent CO_2 saved was 370 gms/kg of goat skin, based on equivalent CO_2 0.98 kg/kWh (US Energy Information Agency's report, 1999) of electrical energy generation. Based on this data, specific energy 377 kWh/ton of goat skin was calculated and equivalent CO_2 370 kg/ton of goat skin was estimated. Leather industries in Tamil Nadu process raw skins/hides of about 350,000 ton per year (Hans *et al*., 2007), which can save an electrical energy of 131.95×10^6 kWh and the Eq. CO_2 of 129.5×10^3 tons per year, if this system is adopted (170 tons to 218 tons of CO_2 per year was reduced) (Schnitzer *et al.,* 2007).

Quality of wet processed leather

The quality of the leather is in par with the leather processed by conventional method, because, the wet leather process was not changed. Only, conventional energy was switched over to SPV energy. The test results obtained are given in Tables 3, 4, 5 and 6.

Conclusion

Several tests were carried out effectively and efficiently using integration of solar PV system for goat skin wet tanning operation in our laboratory. All tanning process were carried out successfully using clean energy and achieved better result as mentioned in Tables 3-6. The quality of the leather is in par with the leather processed by conventional method. The total energy of 1885 Wh could be made use of processing the leather of 5.25 sq.ft or 1 kg dry weight. The process could be run even in night also because of the SPV energy storage reliability. This method could be operated even during power cut so that the quality of the leather could be maintained without putrefaction. This method could be more beneficial for such areas if, solar PV systems with stand-alone systems would be implemented in medium and large-scale capacity. In rural and remote areas, many carcasses are not processed into leather because of lack of transportation from the villages to the areas where the tanneries are situated. This method could also be used in such places, hence environment can be protected. This method has completely eliminated the conventional electrical energy consumption. Hence, this method is very eco-friendly by eliminating CO_2. Also, this complete system protects the environment and global warming, since renewable energy was used as a prime power source. This system not only eliminates the CO_2 emission to the atmosphere effects, but also eliminates methane, SO_2, NOx, CO etc. Also, this SPV system completely eliminates the fossil fuels such as coal, oil and natural gas since India depends heavily on these fuels for meeting its energy demand.

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