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Investigation and Analysis of A PV Stand-Alone System for Industrial Leather Processing

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ABSTRACT: In this study, solar photovoltaic (SPV) power has been used to conduct leather process using experimental drum with a motor power of 746 W. A conventional stainless steel (SS) leather tanning drum was chosen for this purpose and power supply system was redesigned using improved tubular lead acid battery bank, DC-AC inverter, solar charge controller (SCC) powered by SPV panels. Experiment studies have been made with different loads (skin and process liquor) to evaluate the performance of the system were carried-out by applying the load. Experiment results shows that the specific energy consumption was found to be 321 Wh/kg (321 kWh/ton) of skin/hide processing and specific CO₂ reduction was calculated as 298 gm CO₂/Wh (298 Kg CO₂/MWh).

KEYWORDS: CO₂ reduction, Inverter, Leather tannin drum, Single-phase induction motor, Solar charge controller, Solar PV, Tubular lead acid battery.

I. INTRODUCTION

In rural and remote areas, many carcasses are not processed into leather, because of lack of electricity and transportation from the villages to the areas where the tanneries are situated. India's commercial energy consumption has been growing fast in recent years keeping pace with high economic growth rate. One such process, the most widely used and generally the most energy consuming, is industrial wet tanning process in leather industry.

India depends mostly on coal and oil to meet its energy demand, which is a highly challenging task for the country. Bhattacharya et al. conducted wide literature survey and reported that India has made significant progress in different renewable, which have high growth with new technological development [1]. Saidura et al. has carried out a complete literature review on various solar energy systems for energy analysis and highlighting the importance of renewable energy, since it is a green energy and available easily with abundant amount [2]. Research, development and implementation on solar energy use in industries as a substitute of fossil fuels over a decade's for numerous applications reviewed by Mekhilef et al. [3]. A comprehensive literature survey have been carried out on renewable energy systems and highlighting the state of the art in designing renewable energy systems with major achievements [4]. The performance characteristics and dynamic modeling behavior of water pump has been studied using SPV system and reported the vital role of battery in SPV system for day to day usage [5-7]. Kattakayam et al. has investigated the performance study of solar refrigeration with an uninterrupted supply system, powered by hybrid system (SPV and petrol generator) for autonomous power supply [8, 9]. Kaplanis et al. explained the effective design and development study to convert a domestic refrigerator into a solar powered one, where they explained the various factors affecting the sizing of the system, the method of sizing and the various modifications made to diminish the heat losses [10]. The same concept was also used and tested the performance of domestic refrigerators with solar PV system and with battery for vaccine and medicine storages application in rural area described by Anish Modi et al. [11].

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Different performance characteristics of the water pump were studied and analyzed the SPV systems, simulations and reported that both results are substantiated to validate the superiority of the SPV system with better efficiency [12-14]. Saravana Ilango et al. investigated voltage/frequency (v/f) control technique in order to analyze the characteristics of single-phase AC induction motor using SPV and improved energy saving [15]. Kapila Bandaraa et al. has introduced and described a novel multi-level DC-AC inverter technology using solar PV and battery for off-grid electrification and proved its better performance with less standby losses than other inverter [16].

Lead acid batteries are suitable for a large number of utility applications and used in most PV systems to perform power buffer between the array and loads and energy storage bank. In addition, batteries provide a more stable system voltage to system appliance [17, 18]. Kattakayam et al., characterized the tubular lead acid battery as a energy storage component of the solar refrigeration system and the calculation method for the battery bank capacity [19].

In this paper, an attempt has been made to introduce a SPV system in tanning operation for leather industry. Though SPV system was used widespread for many applications as mentioned above, there is no report on the use of SPV power on leather processing application so far. Hence, this study was performed to evaluate the possibility of using SPV power to run leather processing tanning drum so as to develop an independent system, which is both environment-friendly and free from the dependency on usage of grid electricity and fossil fuels.

II. MATERIALS AND METHODS

For this investigation, a rotating tanning drum made up of SS was used for tanning process. This cylindrical drum has the diameter of 800 mm, width of 420 mm and a thickness of 3 mm. This rotating drum is coupled directly with an AC induction motor and reduction gear assembly by means of chain and sprocket drive mechanism. Three numbers of baffles and three numbers of SS pegs were fastened on the inner circumferential area of this drum to carry-over the skins inside for agitation during the tanning process. The rated power of the single phase AC induction motor is 746 W and variable frequency (v/f) controller of 0-50 Hz electricity in order to vary the motor speed up to 1385 revolution per minute (rpm). In addition, a constant mesh reduction gear is assembled to step down the drum speed from 2-30 rpm as required for the tanning process. This drum assembly contains variable. The acceptable voltage range for the compressor is 180-240 V and maximum current is 3.4 A. A single phase MOSFET-PWM inverter having the rated power of 2500 VA was used to provide the continuous AC power to the induction motor. Schematic view of the leather tanning drum is shown in the Fig.1a.

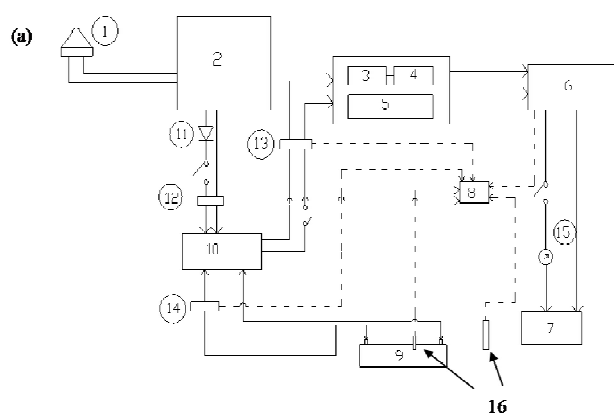


Fig.1a: Schematic views of the industrial leather tanning drum.

Fig 1b. shows the schematic representation of the major components of the tanning drum used in the experimental study.

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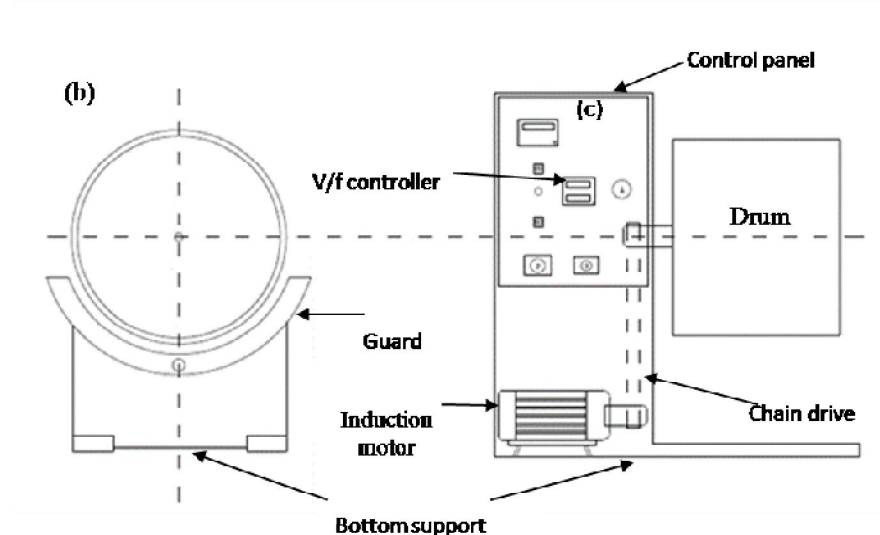


Fig.1b: Schematic representation showing the major components of the tanning drum used in the experimental study.

Nine 37 Watt power (W_p) SPV panels were used to generate electrical energy from solar power. The specifications of the SPV panels are mentioned in the Appendix A. The panels were arranged in such a method that a set of three panels in series-in-parallel with another set of three panels in series as reported in literature [11]. Schematic view arrangement of SPV panels is shown in Fig.2.

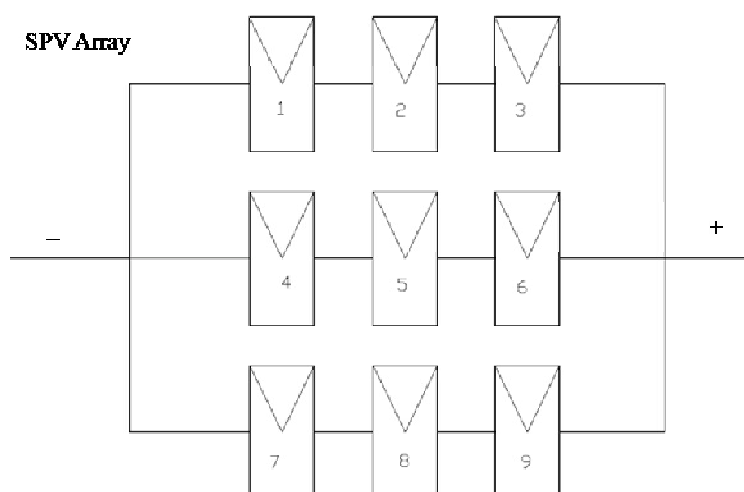


Fig.2: Schematic view arrangement of SPV panels. 1-9: Mono-crystalline SPV panel

The purpose of this arrangement was to get sufficient potential difference across the 36 V battery bank systems in order to get properly charged. An Open Circuit Voltage (OCV) of 21 V, as maximum potential could be obtained from one

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panel and hence three panels were connected in series to get higher potential. In the same way, additional set was added in parallel to gain sufficient charging current to the battery. The panels were kept at angle of 13° from the horizontal, facing south direction. To provide back-up power in the period of low or zero solar irradiation, a battery bank was used. Three 12 V-100 Ah tubular lead-acid batteries connected in series in the battery bank. This tailor made battery to improve storage capacity and increased the life cycle has prepared by the following procedure, as given in Appendix-B [20].

The battery bank was connected to the AC induction motor of the tanning drum through DC-AC inverter system assembly which was used to convert the DC current from the SPV system or from the battery bank to AC current at a required frequency and voltage to run this motor of tanning drum. A SCC, having six terminals, three positive terminals and three negative terminals was used. One pair of positive and negative terminal for connection to SPV panels and one pair for load and another pair for battery bank were used. The SPV panels and the battery bank are directly connected to the SCC. Also, the SCC step down and support in regulating the surge voltage from the SPV panel to an appropriate range to charge the tubular lead acid battery bank. From the solar charge controller, the load is connected through inverter, in order to protect the solar charge controller from the initial surge current during the start-up of the tanning drum.

A battery protection circuit is also used to regulate the flow of charge and to protect the battery bank from getting overcharged or getting deep discharged. This protection circuit has two sub-circuits: first one is, the battery overcharging protection sub-circuit or the High Volt Disconnect (HVD) sub-circuit, and the second one is battery deep-discharging protection circuit or the Low Volt Disconnect (LVD) sub-circuit. Both the sub-circuits obtain the battery terminal voltage as their cut-off reference and their values for cut-off can be set independently using the adjustable provision incorporated in the SCC.

A. Load cut and reconnection

These are set at 32.4 V for LVD protection (Cut-off voltage for tubular lead acid battery is 1.8 V/cell) and 42 V for HVD protection. The charging was performed after reaching the reconnection voltage of 36.6 V (the battery would gain the reconnection voltage within 1-2 h, after the LVD cut-off). The float voltage was set to 38 V. The voltage difference between the fully charged battery (38 V) and LVD (32.4 V) was 5.6 V. The difference in set-point was maintained at 3.6 V in 36 V systems.

High starting current was avoided by introducing soft-start system or controlling variable frequency of AC induction motor, thus enable to reduce the cable size. The cabling between the loads to the battery, 10 mm² wires were used as reported in literature [11], because of the high starting current of nearly 32 A DC from the battery [11]. Similarly, 1.5 mm² cables were connected between the SPV panel and the charge controller for reducing the losses. The increase in the diameter is only limited by the economics of the system. Fig. 1(a) shows the block diagram for arrangement of the complete system, Fig. 1(b) shows the tanning drum schematic with location of the major components and Fig. 2 illustrates the arrangement of the SPV panels. Experiments were carried out to analyze the performance of the designed/converted system by measuring various parameters such as solar radiation, voltage, current, etc., under different operating conditions.

B. Experimental conditions

The following experimental conditions were maintained during the course of the tests: 1. The solar panels were kept over the roof of the single storied building, at a place where there was no shade throughout the day, at an angle of 13° to the horizontal facing south direction. 2. The tanning drum and other instruments and equipments were kept inside the building. 3. The panels were always kept dust free to take advantage of maximum possible solar insolation that can be harvested by the panels. 4. Test was conducted at no load and suitable load conditions (skin and water at the ratio of 1:50 to 1:300) for the tanning experimentation. 5. The tanning drum speed was set to 12-14 rpm throughout the process. 6. The load inside the drum was not constant throughout the process. 7. This entire experiment was carried out at a room temperature. 8. All parameters were measured using a data-logger at every minute interval for the entire process duration.

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C. Experiments performed

This experiment was performed using the SPV, connected to the systems and current drawn from the SPV consumed by the load, either by battery or by AC motor. In this study, experiments were conducted with load and without load (Skin, water and chemicals). These tests were conducted to validate the performance of tanning drum using direct solar power as well as the battery bank's back-up power in better ambient conditions. In this experiment, 100 Ah tubular positive plate lead batteries were charged and discharged by the SCC, on daily basis to carry-out the day to day tanning process. The solar irradiation, current, voltage and State-Of-Charge (SOC) of the battery during charge/discharge and SPV, battery temperature were also measured during charge/discharge process.

Leather processing consists of static and dynamic process, where static process is carried out in the pits and dynamic process is carried out using the tanning drums. Suitable load and chemical were charged into the drum for processing the skin. The tanning drum was run at a speed of 12-14 rpm with suitable duration to process the skin. Suitable chemicals for leather processing were added. The complete skin tanning process was carried out successfully with a total period of about 19 h by the mechanical agitation of skin provided by the baffles and pegs inside the drum.

III. RESULTS AND DISCUSSION

The following plots of the various observed and calculated parameters give us an idea about the technical performance of the system.

A. Solar radiation and charge current

The variation of solar radiation intensity and charge current with time for two consecutive days was shown in Fig. 3. The values of solar radiation intensity when plotted against time in Fig. 3 (a) strongly follow a clear sine curve. It helps us in relating the charging DC current to the system with the solar radiation intensity available. This is in accordance with the known fact that during a day variation of solar radiation intensity with time is a sinusoidal function.

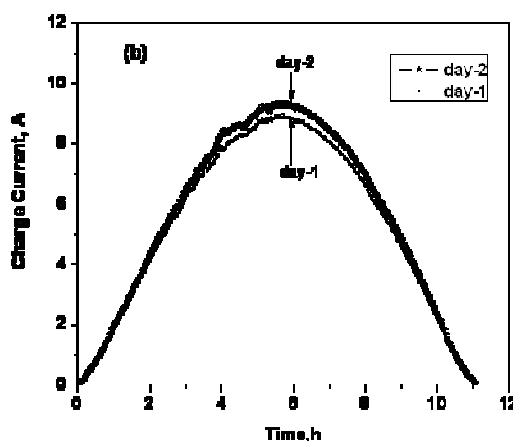


Fig. 3a: Variation in intensity of solar radiation (W/m^2) with time

The corresponding charge current was also plotted against time in Fig. 3 (b), which was also increasing trend for the current with the solar radiation as a sinusoidal function. Further, it was observed from this figure that the solar radiation and current generated from the SPV increases gradually till mid-day and decreases gradually till the sun set. But, about 5 % of variations were observed during the mid-day from both radiation and charging current curve and the charging performance was not affected by this variation. The weather was pretty good with clear sun shining day and the SPV generated sufficient power to charge the battery bank. The maximum average charging current was attained from the

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SPV panels during the experiment period is 9.2 A at 1144 W/m^2 of average solar radiation for the experimental duration of two days.

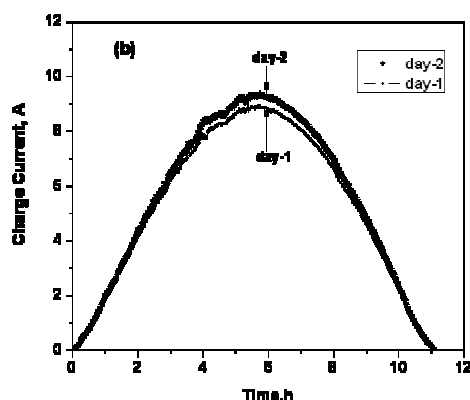


Fig. 3b: Variation in charge current (A) with time.

Fig. 4 shows the drop in the average value of charging current in the charge controller for the two days. It could be observed that the current curve matches the solar intensity curve very much closely. The drop in current in the charge controller is almost equal and vary between 0.03 to 0.13 A in comparison with 0.08A, which is in align with results throughout period reported by other researchers [14]. The constant gap between the two curves causes the constant energy loss in the charge controller.

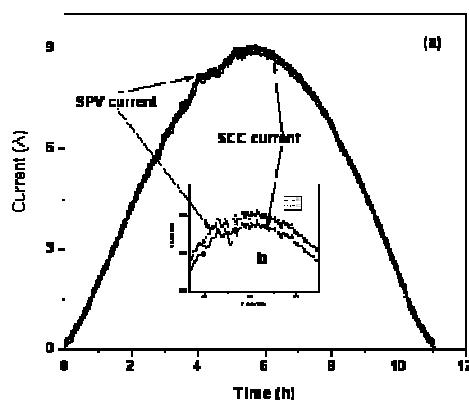


Fig.4: Variation of charging current (A) with time (h). SPV-Current from SPV panels and SCC-Current from solar charge controller

The average voltage curve across the battery terminals shows a rising tendency with the solar radiation and similar gap could be observed in Fig.5, like Fig.3 (a) and (b). The drop in voltages of two terminals was attained between 1.3 to 1.5

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V throughout the charge. The maximum average charging voltage was obtained from the SPV panels during the two days experiment period was 39.3 V at 1144 W/m^2 of solar intensity.

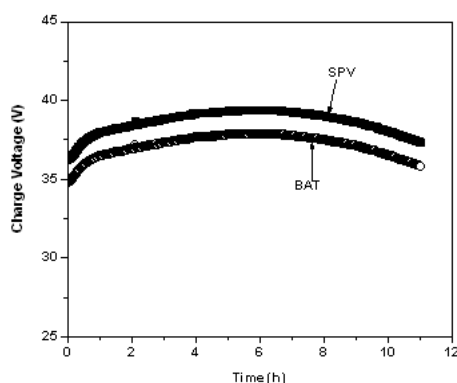


Fig.5: Variation of charge voltages (V) at various terminals with time (h)

Fig. 6, represents the relation between the average charging current and charge controller efficiency with respect to time. This value of charge controller efficiency keep on increasing as it approaches the noon and maintain at constant level. A maximum average charge efficiency value of 98.5 % was observed with effective charge duration of 6.5 h during the charge period.

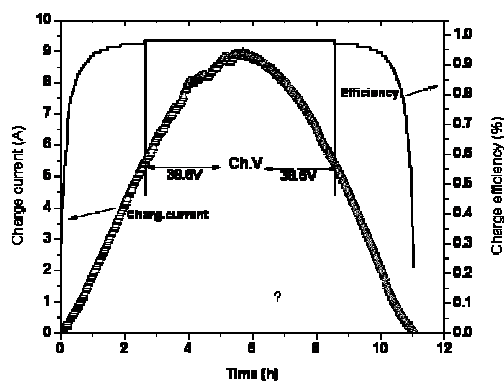


Fig.6: Variation of charging current (A) and charge controller efficiency (%) with time (h).

The discharge behavior of the tubular lead acid battery during tanning process was observed that the discharge current and voltages of battery and load were fluctuating throughout the process due to agitation with up and down movement of skins. Difference of this discharge voltages and current of both battery and load terminal was not high and were observed throughout this process more or less as 0.62 V and 0.15 A respectively. The variation in gap between the two curves of battery and load causes the constant energy loss in this system as mentioned in Fig.7.

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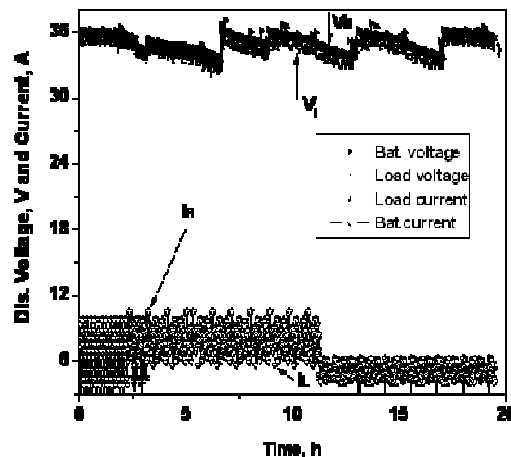


Fig. 7: Variation of battery discharge voltages (V) and currents (A) with time (h).

Discharge power profile of the tubular lead acid battery during the tanning process is represented in Fig.8. The average discharge power was obtained as 245 W and this power is adequate to carry-over the skins inside the drum during the tanning process.

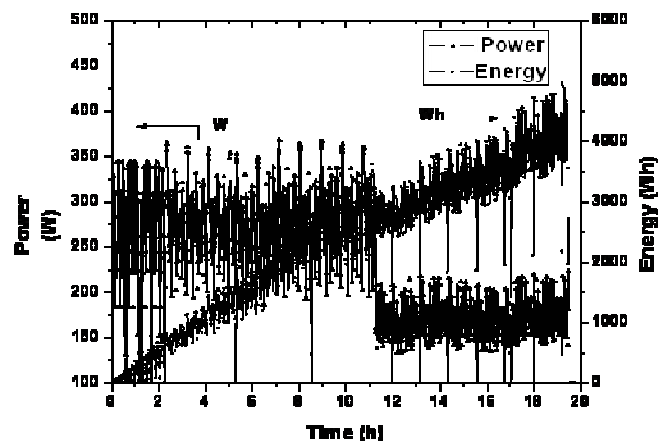


Fig. 8: Variation of battery discharge power (W) and energy (Wh) with time (h).

It was observed from Fig.9, that both DC and AC current were similar trend, but not constant throughout process. The high starting current of this system was minimized by means of soft-start system (v/f controller), which was incorporated in the motor of the tanning drum, which was also minimized the voltage drop of battery terminal voltage during starting time of the drum in Fig.7.

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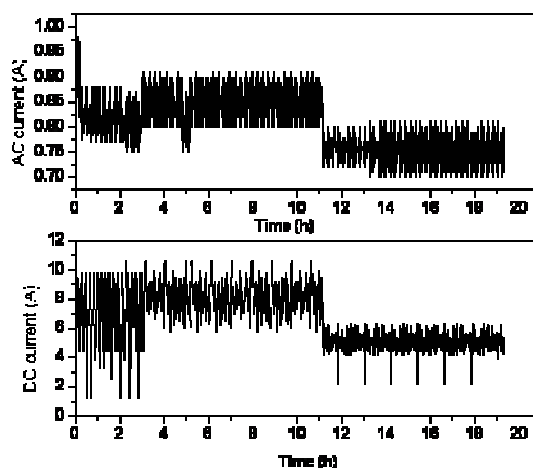


Fig.9: Comparison of DC and AC current (A) with time (h.)

Further, it was observed that, DC and corresponding AC current were decreased after 11h process than previous to due to the reduction of load in the tanning drum by one third of the initial load. The average current of DC and AC were measured as 6 A and 0.8 A respectively. However, the starting current did not raise-up to as high as 36 A in DC and corresponding 4.2 A in AC mentioned in [11]. However, the running current of DC and AC are very less as compared to the starting current of both DC and AC.

Fig.10 represents the current and power factor performance of the system with a single-stage DC-AC inverter. The power factor (PF) of the motor of the tannin drum was observed as low value (average PF 0.67) during the first 11 h and this was rapidly increased (average PF 0.85) due to variation in current and ultimately by loads after 11 h till end of this process, because after chrome tanning the thickness of the skin was adjusted according to the requirement by a mechanical process, called shaving, where as substantial amount of solid is removed from the tanned leather. Hence, accordingly other materials such as water and chemicals were taken for subsequent process. Therefore a significant reduction in load/weight during subsequent process steps was observed.



Fig. 10: Relation between AC current and power factor (PF) with time.

The presence of capacitor in the auxiliary winding with conventional method degrades the system performance when operated at lower frequencies (supply frequency 20 Hz was used to maintain 12 rpm in this experiment), as its value

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strongly depends on load condition as reported for a single phase induction motor [15]. However, this PF could be improved using a booster capacitor, which provides PF more than 0.97 throughout the process. Insignificance changes in motor supply voltage were observed and maintained about 227 V at a supply frequency of 50 Hz. Inverter average efficiency was calculated as 75 % and it was quite reasonable and because of low DC voltage system. Other total losses were calculated as 25 %, which includes all switching losses and inverter standby losses. Kapila Bandara et al. reported as, an off-grid PV system with battery energy storage, which employs a cascaded DC-AC inverter without a transformer and provided lower switching losses [16]. The standby losses were specified by the manufacturer as 32 %, which used for this study.

The variations of total process energy of DC and subsequent AC systems and both are almost linear and similar tendency. Much variation was observed in the energy value throughout the process and both profiles were observed as irregular with fluctuation as shown in Fig. 11. Total average energy from DC and AC energy were obtained as 4530 Wh and 2501 Wh respectively. This time, entire energy was consumed only from the tubular battery with better ambient operating conditions. The leather process in the tanning drum performed well with its normal behavior and with constant rpm of the drum.

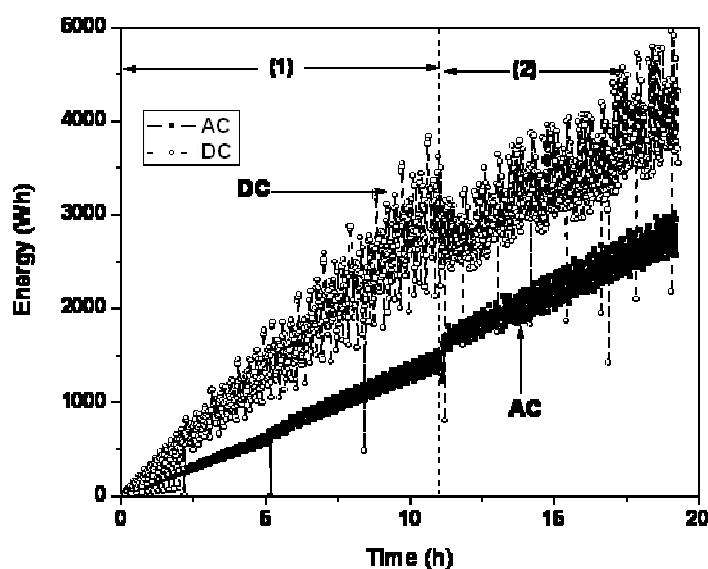


Fig. 11: Variation in energy of DC and AC (Wh) with time (h).

The specific energy consumption and specific CO₂ emission reduction were calculated as 321 Wh/kg (321 kWh/ton) of skin/hide processing and 298 gm of CO₂/Wh (298 Kg CO₂/MWh) respectively, since the Green House Gas emission factor is 0.927 as reported data for Indian power generation [11]. Leather industries in Tamil Nadu process raw skins/hides of about 350,000 ton per year [21], which consumes enormous energy from grid power. This leads to generation of large amount of CO₂. The present investigated SPV system, if employed for the leather sector of Tamil Nadu, will be substitute for grid power, in addition this will also reduce CO₂ emission nearly 33.376×10^3 ton/year.

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B. Energy consumption of three similar experiments

Table1

Energy consumption of three experiments

Sl.No	Experiment	Weight (Kg)	DC Energy (Wh)	AC Energy (W)
1	Skin processing	14.11	4530	2505
2	Skin processing	14.2	4550	2502
3	Skin processing	14.1	4560	2508
	Average	14.14	4546	2505

Table-1 shows the total energy consumption of tanning process for three similar batches of skins and observed that the variations in the energy consumption of DC source in the three experiments was 20-30 Wh and variation was not observed in the AC energy consumption.

IV. CONCLUSIONS

Tanning drum with a motor power of 746 W was operated using SPV system and used for skin tanning process. A maximum average charge current was obtained as 9 A at 1144 W/m² peak solar radiation and the charge performance was very effective with an efficiency of 98.5 %. The average DC power consumption was found to be 245 W during the tanning process. The maximum PF and inverter efficiency were 0.85 and 75 % respectively. The variation in total energy consumption among three similar batch of leathers processed was very low. Experiment results shows that the specific energy consumption and specific CO₂ reduction were calculated as 321 Wh/kg (321 kWh/ton) of skin/hide processing and 298 gm CO₂/Wh (298 Kg CO₂/MWh) respectively. Under the experimental conditions, the modified tannin drum performed similar to a conventional tanning drum that is working on grid electricity. This type of SPV Stand-alone system could be implemented on large scale for industrial purpose for the rural areas, thereby a substantial industrial growth can be achieved even in rural area thereby, overcrowding of cities for employment can be minimized.

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