Designs of Some Low Power Renewable Energies Installations

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Abstract

This work describes the designs of some low power renewable energies installations as combined photo-voltaic-thermal (PVT) collector system, solar biogas digester (SBD) and micro-hydropower plant MHPP. The PVT-collector system consists of a support, standard PV module, semi cylindrical concentrator-collector heater (SCCH). The SCCH concentrate light to module and store heated water. To improve concentrating properties the SCCH has variable curvature that is less in the centre with respect to the edges. Heating of sludge in biogas digester increases biogas production and decreases the retention time. The SBD consists of methane tank with built-in solar reverse absorber heater to utilize solar energy for the heating of the slurry prepared from the different organic wastes (dung, sewage, food wastes etc). MHPP for free water flow operation provide unique chance to use hydropower of canals and small rivers where there are no waterfalls or sufficient large water heads. Catamaran and battery based micro-hydropower plant's design is presented.

Keywords
Design, installation, renewable energy, combined PV-collector, solar biogas digester, micro-hydro power plant.

1. Introduction

Utilization of renewable energies, and especially solar energy, which is environment-friendly, is very important for the sustainable development. Development of solar energy technologies include, firstly, improvement of the electric parameters of solar cells, and secondly, of photovoltaic (PV) systems. Recently a number of researches were done in these areas. In [1] anti reflection coatings (ARC), made from silicon-rich-nitride (SRN) films embedded with silicon nanocrystals that were integrated into monocrystalline silicon solar cells were studied. During the fabrication of silicon solar cells, two types of ARC layers were deposited by plasma enhanced chemical vapor deposition (PECVD): one with single layer SRN film and other with double layer SiO_x/SRN, and thermally annealed to precipitate silicon nanocrystals. It was observed that the power conversion efficiency increased upto 15.6% for single layer nanocrystals-embedded-ARC and 22.8% for double layer nanocrystals-embedded-ARC. It was found that the solution processed thin film solar cells based CdTe and Cu(In,Ga)Se_{2-x}S have relatively low cost in comparison with tradition Si-based solar cell [2]. It was observed that CdTe and Cu(In,Ga)Se_2 thin-film solar cells efficiencies are equal to 16.5% and 20%, respectively [3] that are the highest value achieved for thin-film solar cells. At present production cost of CdTe thin-film modules is almost $0.76 per peak watt. In [4] recent research in Building Integrated Photovoltaics (BIPV) was discussed that lead to improved solar energy conversion efficiency and/or economic viability. This system includes the following elements as invertors, concentrators and thermal management systems. In [5], PV power station remote monitoring system data acquisition device is discussed, namely, the photovoltaic power generation system, voltage, current and temperature sensing circuits, remote communication diagram of PC are presented. The monitoring and low cost data acquisition systems applied to decentralized renewable energy plants were discussed in [6]. It was shown that the use of such systems contributes to disseminate these plants, recognizing in real time local energy resources and monitoring energy conversion efficiency.

It is known that one of the limiting factors of solar modules and collectors applications in especially urban area is the availability of the required sufficient land [7,8], therefore during the last years, combined photo-voltaic-thermal collectors' designs were implemented and investigated in practice [9-19]. It was found that the main advantage of the PV-collector system observed is more electrical and thermal energy produced with respect to the conventional PV modules and collectors that partially cover the same area. Basically four groups of water type PVT-collectors

[18-20], namely: sheet-and-tube PVT-collectors, channel PVT-collectors, free flow PVT-collectors and two-absorber PVT-collectors were evaluated. Optical and thermal efficiencies of the PVT-collectors were analyzed. Except uncovered PVT-collector, all discussed designs with additional glass sheet, provide more reflection losses, hence lower electrical efficiency of the system. It was stated in [18] that the uncovered PVT-collector for low temperature applications is the most promising design. As uncovered PVT-collector shows lower thermal efficiency with respect to the covered by glass sheet PVT-collectors, it would be reasonable to design the uncovered PVT-collector system where at high electrical efficiency the thermal efficiency would be improved. In [21] we presented the design of uncovered PVT-collector system with built-in storage water heater. It was shown that the average thermal and electrical powers of the PVT-collector system at the tracking mode of operation observed were 39W and 21W, with efficiencies of 15% and 8% respectively at the input power of 260 W.

Biogas as a source of renewable energy is produced by biotechnology and is used widely in some countries for domestic applications [7, 22-32]. Earlier we have designed and fabricated one of the solar biogas digester as discussed in [32].

The battery-based micro-hydropower systems with storage of electric energy in the electrochemical batteries are economically advantageous to use if the peak load is considerably larger than the hydropower [33-42]. In this case the hydro power is converted into the electric power using micro-hydropower system and stored in the batteries and is used during shorter time at peak/maximum load.

In this paper we are presenting the designs of the combined photo-voltaic-thermal (PVT) collector system that consists basically of a standard PV module and semi cylindrical concentrator-collector heater (SCCH) with variable curvature, solar biogas digesters with built-in reverse absorber heater and of battery-based micro-hydropower plant on catamaran for free water flow operation.

2. Combined photo-voltaic-thermal (PVT) collector system

Fig.1 shows views of combined photo-voltaic-thermal collector system. The PVT-collector system consists basically of standard PV module and glass semi cylindrical concentrator-collector heater (SCCH) (in Fig. 1 it is lens). As transmittance of water for visible light is the maximum (accordingly absorption is minimum, Fig. 2) with respect to the UV and IR spectra. The lens is filled with water that is heated mostly by IR solar irradiation. Visible light will be converted by module into electric power. This system has the following advantages that the module will not be overheated by IR radiation that usually decrease its efficiency (the temperature coefficient for the open-circuit voltage of silicon solar cells is approximately equal to -2.3 mV/^{o}C, whereas, short-circuit current is not dependent of temperature [8]), but concentration of light by the lens can increase the efficiency of the module [8]:

$$\eta(X) = V_{OC}(X)\, I_{SC}(X)\, FF / G(X) = \eta(1)\, (1 + (kT/q)\, \ln X / V_{OC}(1)) \qquad (1)$$

where $\eta(X)$ and $\eta(1)$ are efficiencies of the cells under concentrated and non-concentrated lights, $V_{OC}(X)$ and $V_{OC}(1)$ are open-circuit voltages of cells under concentrated and non-concentrated lights, $I_{SC}(X)$ is short-circuit current under concentrated light, FF is fill factor, $G(X)$ is global irradiance under concentrated light, k and T are Boltzmann coefficient and absolute temperature, q is charge of electron and X is concentration ratio . From Eq.1 it is seen that if $X > 1$, $\eta(X) > \eta(1)$.

To improve the concentrating properties the SCCH has variable curvature that is less in the centre with respect to the edges (Fig.1). In result, in the morning and in the evening where usually the solar irradiance is less than in the noon time, the module will be illuminated by light better. This in principle can avoid utilization of mechanical tracking system in this PVT collector system.

The dimensions of the PV module were 122cm x 30.5cm with a total area of 0.37m^2. The electric properties of the modules were investigated earlier in [40]. The volume of lens is 60 liters. The radius of the lens decreases in radial direction from 30 cm in centre to 4 cm in the edge. Fig. 3 shows variation of the lens curvature in radial direction: for simplicity, linear variation of the lens curvature along of radial direction is selected. The inclination angle of the PVT-collector system to horizontal surface is made variable as in [40]: in summer, winter, fall and spring seasons which is, 23, 45, 34 and 34^o (34^o is the latitude of the location of the PVT-system). The change of the inclination angle from 34^o to 23^o or 45^o seasonally increase the efficiency of electric power generation by the system potentially on 15 % in summer and winter times with respect to the spring and fall [43].

Previously our simple combined photo-voltaic-thermal (PVT) collector system, designed, manufactured, investigated and realized [21]. The PVT-collector system consisted of standard PV module, sheet-and-tube water collector and storage tank-heater. Average thermal and electrical powers of the PVT-collector system at the tracking mode of operation observed were 39W and 21W, with efficiencies of 15 % and 8 % respectively at the input power of 260 W. The maximum temperature of the water obtained was 42^{o}C. In the case of combined photo-voltaic-thermal collector system, an expected electric power will be above of 21 W due to the concentration of energy. Accordingly, thermal power will be above 39 W due to the direct absorption of IR radiation by water in the concentrator-collector heater.

It is considered that concentration ratio (X) is equal to 1.5. Taking into account that the lens (Fig.1) has variable curvature and incident light's angle in the morning and in the afternoon is less in comparison with uniform curvature lens, moreover the PV module's temperature is not increase much as IR radiation mostly will be absorbed by water that is in lens, it is assumed that effective concentration ratio is equal to 2. By use of the Eq.(1) where $k= 1.38\ 10^{-23}$ J/K , T= 300 K , $q= 1.6\ 10^{-19}$ C, $V_{OC}(1) = 0.6$ V, $\eta(1)= 15\%$ it was found that $\eta(X)= 15.5\%$,i.e. it is increased on 3 %. Electric power of this PVT collector system is above of power of uncovered PVT system. It can be expected that thermal efficiency of the system will be no less than of free flow PVT-collector system [20].

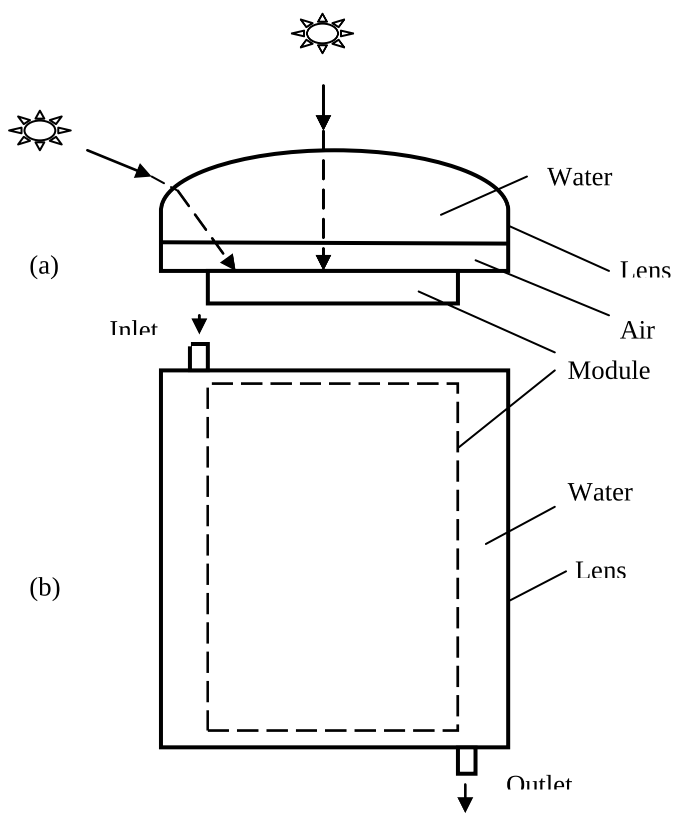

Figure 1: Cross-section (a) and top (b) views of combined photo-voltaic-thermal collector system

3. Solar biogas digesters with built-in reverse absorber heater

It is well-known that the heating of sludge in a biogas digester increases biogas production and decreases the retention time. Fig. 4 and Fig. 5 show schematic diagram and picture of the solar biogas digester. The biogas digester consists of methane tank with built-in solar reverse absorber heater to utilize solar energy for the heating of the slurry prepared from the different organic wastes (dung, sewage, food wastes etc). The digester is a laboratory (or domestic) type and consists of horizontal axes cylindrical metallic methane tank of size 0.8m in diameter; 2m in length and 1 m^3 in volume with a solar reverse absorber heater installed under the methane tank. The absorber was blackened to increase absorption of solar irradiation. The solar reverse absorber heater consists of horizontal axes cylindrical reflecting mirror and horizontal glass cover. A horizontal absorber is a common element of the methane tank and solar reverse heater. The cylindrical reflector was used with radius of 0.7 m and glazing size of $1.9x0.7m^2$. Outer surface of the digester was covered by thermo insulated material, aluminum foil and polymer film. The methane tank was filled up to 70% of volume by organic wastes of the GIK institute sewage (70%) and cow dung (30%) as well. During three months (January-March, 2011) the digester was investigated. The solar irradiance incident to the absorber, slurry's temperature and ambient temperature were measured. Fig. 6 shows sludge and ambient temperatures during 11 days in March 2011.

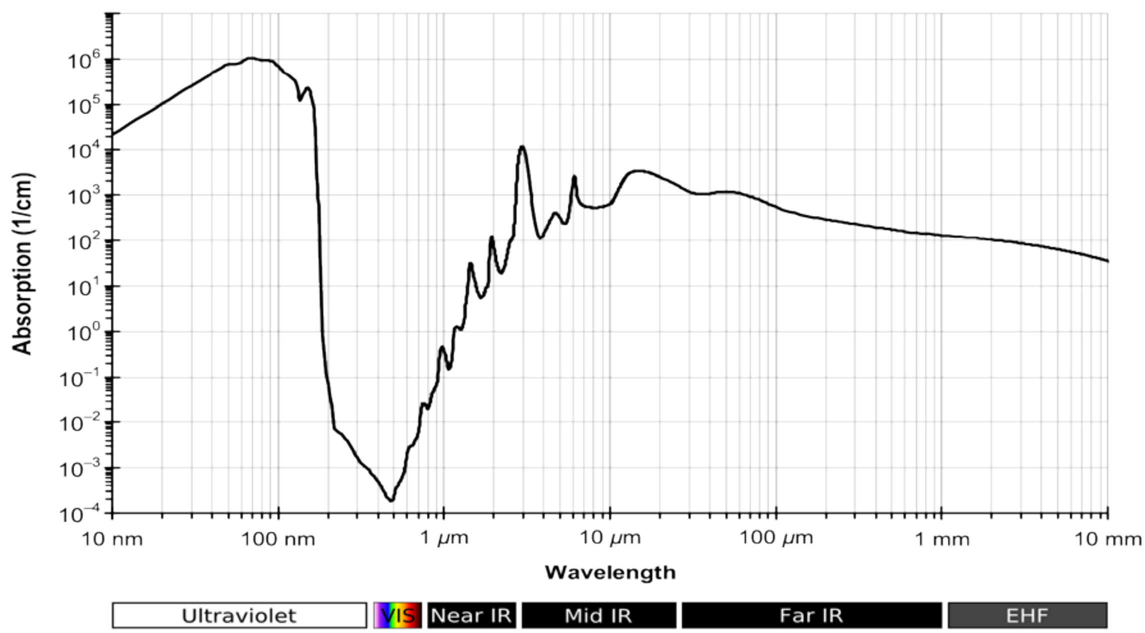

Figure 2: Absorption of ultraviolet, visible and infrared radiations by water

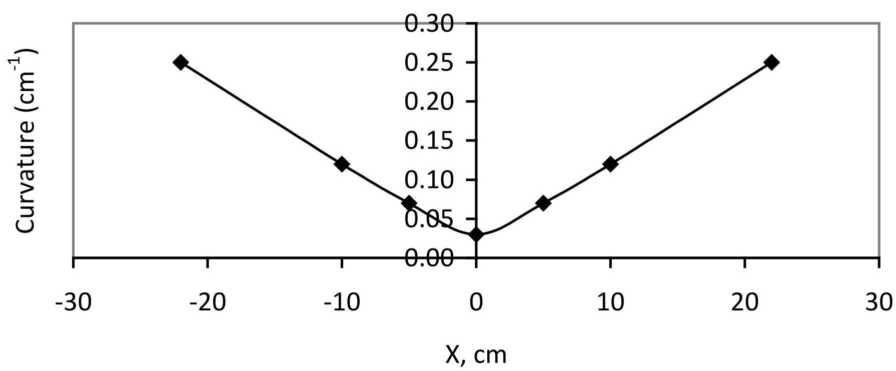

Figure 3: Variation of lens curvature in radial direction

It is shown that the sludge temperature is more than the ambient temperature. It was found that using sewage and cow dung the retention time was almost 2 weeks and almost 0.8-1.0 m^3 of biogas was produced daily. Concentration of methane in biogas in average was almost 74%. The biogas extracted from the gas holder was burned, electric power generator was driven and electric power was produced successfully. Presently, up gradation of the biogas by removal of carbon dioxide, hydrogen sulphide and water vapor is in process. The scrubbing tower for removal of carbon dioxide from biogas is manufactured.

The total biogas output may be increased by increasing the number of units of the biogas digesters. This biogas digester may be used domestically as well as for the demonstrative and teaching purposes. In addition based on the results achieved it can be used for the construction of larger volume solar biogas digesters for use in the farms, especially located in the remote and mountain areas where the climate in the winter period is cold.

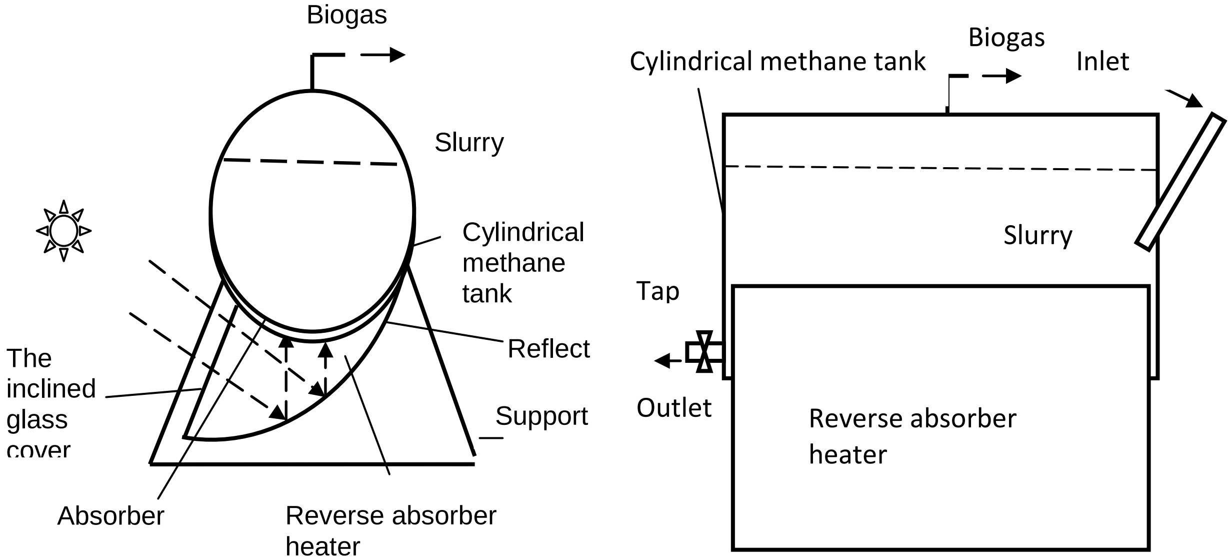

Figure 4: Schematic diagram of solar biogas digester

Figure 5: Solar biogas digester

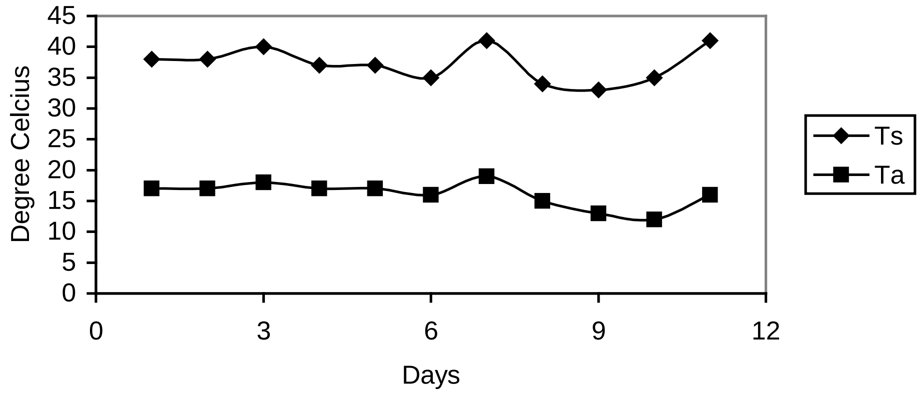

Figure 6: Sludge (T_S) and ambient (T_a) temperatures during 11 days in March 2011

4. Battery-Based Micro-Hydropower Plant on Catamaran for Free Water Flow Operation

Micro-hydropower plants for free water flow operation provide unique chance to use hydropower of canals and small rivers where no waterfalls or sufficient large water heads. In this case only kinetic energy of water flow can be converted into electric power. Calculations of the water power show that at the water velocity of 1 m/s and turbine's blades area of 0.75 m^2 the electric power generated will be 187 W. As battery based micro-hydropower systems can operate and store energy continuously, almost 24 hours per day, electric energy produced daily will be almost 6 kWh that is sufficient for the main electric and electronic appliances of the average family. For the last few years, the micro-hydropower systems are becoming more and more popular: some people and organizations are aspired to have their own source of energy that would be more reliable than grid [33-42]. Moreover non-renewable energy sources (petrol and natural gas) are becoming costly and hydropower is now more competitive. The most important thing is that the hydropower is renewed and in the case of small power systems, practically there is no negative impact on the environment.

The battery-based micro-hydropower systems with storage of electric energy in the electrochemical batteries are economically advantageous to use if the peak load is considerably larger than the hydropower [33]. In this case the hydro power is converted into electric power by the use of the micro-hydropower system and stored in the batteries and is used during shorter time at peak/maximum load. The batteries in this case undergo deep discharge of up to 50% of their total capacity and after that these are charged. The battery-based micro-hydropower systems belong to the systems that are not connected with the grid and can work jointly with photo-voltaic and wind power plants on common load, so called hybrid system. The battery-based micro-hydropower systems with respect to AC-direct micro-hydropower systems have the advantage as they can work at relatively low water flow rates but at the same time being able to provide the necessary peak power in the load when it is required [33]. It is assumed to use DC generator. The battery-based micro-hydropower systems can feed DC loads directly from batteries and AC loads through the inverter.

Fig. 7 shows schematic diagram (top view) of the battery-based micro-hydropower plant (MHPP) on catamaran for free water flow operation. The MHPP consist of the following basic parts: two barges, turbines, shaft, gear box, generator, battery and DC-AC converter. The most important parts of the MHP is the barges and turbines. Efficiency of the barge depends much on its shape. The velocity of the water flow in the level of turbines blades in the first approximation can be estimated by use of continuity equation for steady incompressible flow [7]:

$$\rho Q_1 = \rho Q_2 \qquad (2)$$

or

$$v_1 A_1 = v_2 A_2 \qquad (3)$$

where ρ represent the fluid density, Q_1 and Q_2, v_1 and v_2 are the volume flow rates and velocities in the entrance of catamaran and exactly on the level of vertical position of the turbines' blades (Fig.7). Assuming that v_1 is equal to 1 m s^{-1}, and A_1 and A_2 are equal to 1 m^2 and 0.5 m^2 accordingly, the v_2 can be found from the equation:

$$v_2 = v_1 A_1 / A_2 \qquad (4)$$

as v_2 = 2 m s^{-1}. It means that the shape of the barges of the catamaran allows increasing the water velocity in the level of the turbines blades and accordingly to increase of the angular velocity of the turbine that is very important to increase finally the efficiency of the MHPP.

Total number of blades in one turbine is 8. Three turbines blades installed with a phase shift of 15^o that make rotation of the shaft uniform. The shaft has variable length and angle with respect of the horizontal plane that allow to install gear box, generator, battery and DC-AC converter on the bank of the river in order to avoid overloading of the catamaran. The blades of the turbines are made in the form of semi cylinders in order to provide higher efficiency and solidity. The size of one blade was 0.5x0.5 m^2. As there are three turbines the total area of the active blades is equal approximately to 0.75 m^2 and expected generated electric power will be 187 W at velocity of water of 1 m/s.

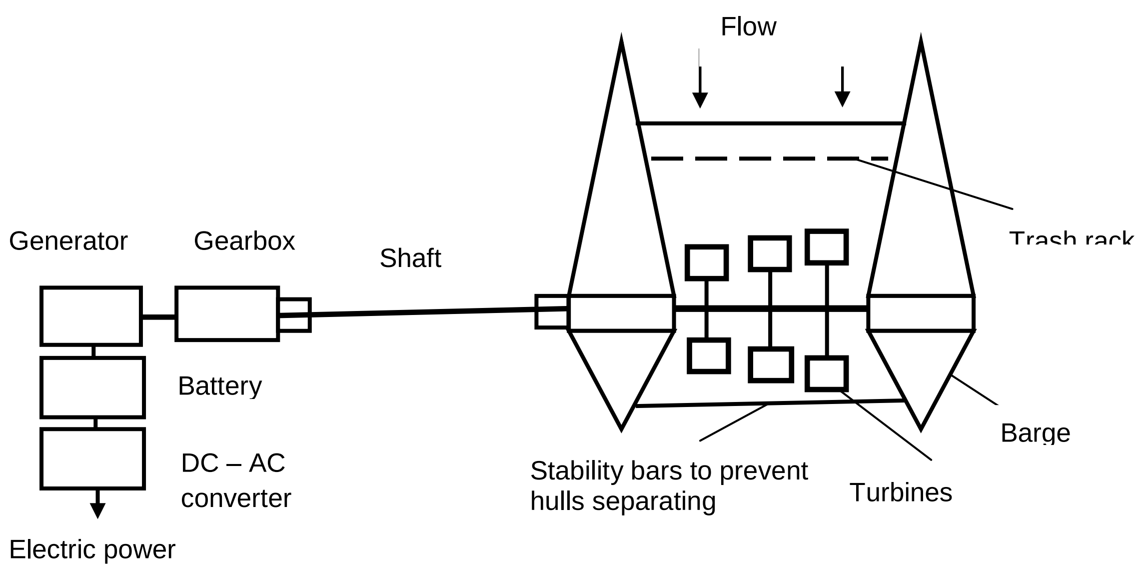

Figure 7: Schematic diagram (top view projection on horizontal plane) of battery-based micro-hydropower plant (MHP) on catamaran for free water flow operation

5. Conclusions

In this work the designs of combined photo-voltaic-thermal (PVT) collector system, the solar biogas digester with built-in reverse absorber heater and micro-hydropower plants for free water flow operation based on catamaran and battery for storage of electric energy are presented. The solar biogas digester is manufactured and experimentally investigated. It was found that the solar energy increases the temperature of sludge that actually decreases the retention time and increases daily production of biogas. The preparative work is done for the manufacturing of combined photo-voltaic-thermal (PVT) collector system. The micro-hydropower plants for free water flow operation have been constructed at present. After laboratory tests, these devices can be recommended for domestic utilization.

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