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Solar Water Heater

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Abstract

Now-a-days, plenty of hot water are used for domestic, commercial and industrial purposes. Various resources i.e. coal, diesel, gas etc., are used to heat water. Solar energy is the main alternative to replace the conventional energy sources. The solar water heating system is the technology to harness the plenty amount of free available solar energy. The solar system is designed to meet the energy demands. The size of the systems depends on availability of solar radiation, temperature requirement of customer, geographical condition and arrangement of the solar system, etc. Therefore, it is necessary to design the solar water heating system as per above parameters. The available literature is reviewed to understand the construction, arrangement, applications and sizing of the solar thermal system.

Keywords: *Renewable, Fossil fuel, Active system, Passive system, photovoltaic.*

INTRODUCTION

We are blessed with Solar Energy in abundance at no cost. The solar radiation incident on the surface of the earth can be conveniently utilized for the benefit of human society. One of the popular devices that harness the solar energy is solar water heater systems.

The solar energy is the most capable of the alternative energy sources. Due to increasing Demand for energy and rising cost of fossil type fuels (i.e., gas or oil) solar energy is considered an attractive source of renewable energy that can be used for water heating in both homes and industry. Heating water consumes nearly 20% of total energy consumption for an

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average family. Solar water heating systems are the cheapest and most easily affordable clean energy available to homeowners that may provide most of hot water required by a family.

Solar heater is a device which is used for heating the water, for producing the steam for domestic and industrial purposes by utilizing the solar energy. Solar energy is the energy which is coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on absorbing surface, then they get converted into the heat, this heat is used for heating the water.

TYPES:

Solar water heating systems are generally very simple using only sunlight to heat water. A working fluid is brought into contact with a dark surface exposed to sunlight which causes the temperature of the fluid to rise. This fluid may be the water being heated directly, also called a direct system, or it may be a heat transfer fluid such as a glycol/water mixture that is passed through some form of heat exchanger called an indirect system. These systems can be classified into three main categories: [13]

Active Systems: Active systems use electric pumps, valves, and controllers to circulate water or other heat-transfer fluids through the collectors. So, the Active systems are also called forced circulation systems and can be direct or indirect. The active system is further divided into two categories:

• Open-loop (Direct) Active System
• Closed-loop (Indirect) Active System

(i)Open-Loop Active Systems: Open-loop active systems use pumps to circulate water through the collectors. This design is efficient and lowers operating costs but is not appropriate if the water is hard or acidic because scale and corrosion quickly disable the system. These open-loop systems are popular in non-freezing climates.

(ii) Closed-Loop Active Systems: These systems pump heat-transfer fluids (usually a glycol-water antifreeze mixture) through collectors. Heat exchangers transfer the heat from the fluid to the household water stored in the tanks. Closed-loop glycol systems are popular in areas subject to extended freezing temperatures because they offer good freeze protection.

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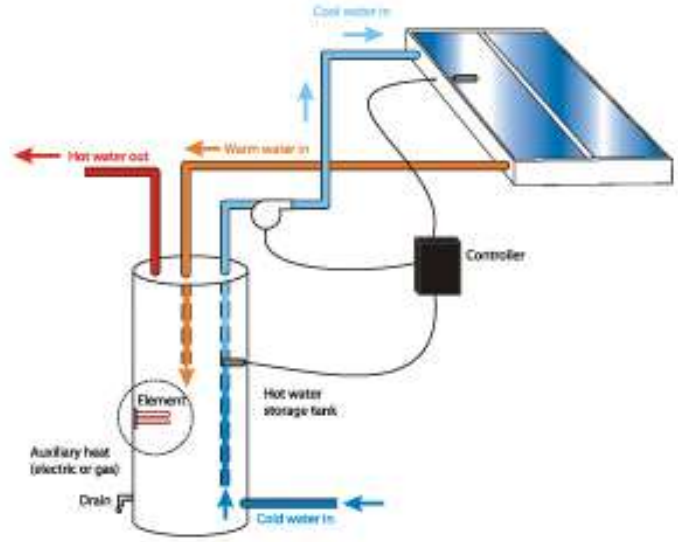

Fig.1Open Loop Active System [16]

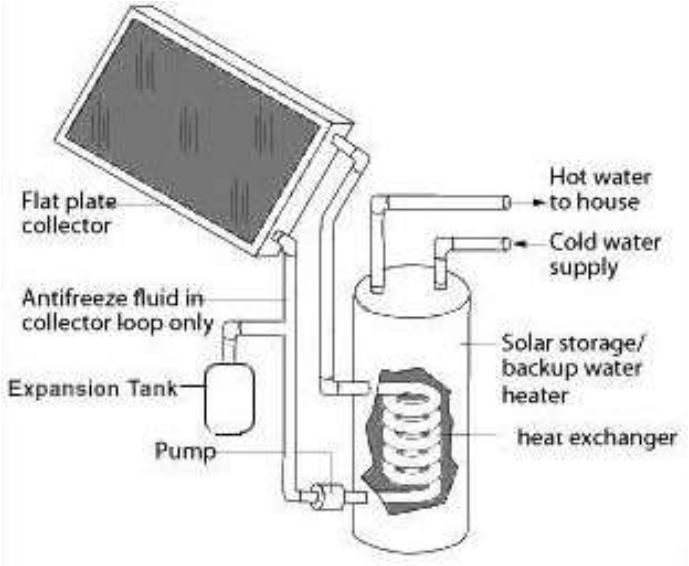

Figure:-2 Close Loop Active System [17]

Passive Systems:

Passive systems simply circulate water or a heat transfer fluid by natural convection between a collector and an elevated storage tank (above the collector). The principle is simple, as the fluid heats up its density decreases. The fluid becomes lighter and rises to the top of the collector where it is drawn to the storage tank. The fluid which has cooled down at the foot of the storage tank then flows back to the collector. Passive systems can be less expensive than active systems, but they can also be less efficient. Thermosiphon system is the best example of passive systems. [13]

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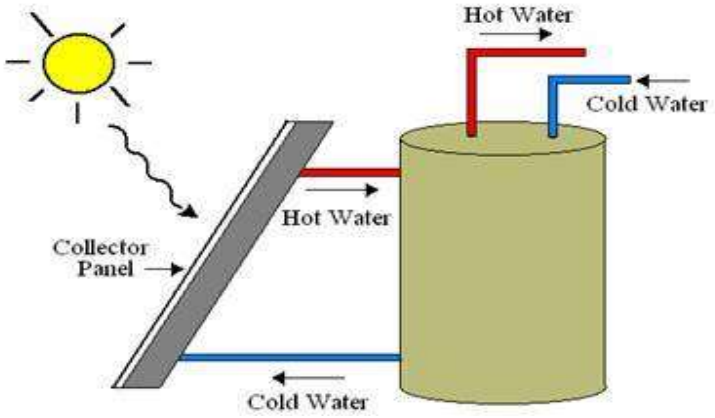

Figure:-3. Passive System [18]

Thermosiphon Systems is the system where water comes from the overhead tank to bottom of solar collector by natural circulation and water circulates from the collector to storage tank as long as the absorber keeps absorbing heat from the sun and water gets heated in the collector. The cold water at the bottom of storage tank run into the collector and replaces the hot water, which is then forced inside the insulated hot water storage tank. The process of the circulation stops when, there is no solar radiation on the collector. Thermosiphon system is simple and requires less maintenance due to absence of controls and instrumentation. Efficiency of a collector depends on the difference between collector temperature and ambient temperature and inversely proportional to the intensity of solar radiation.

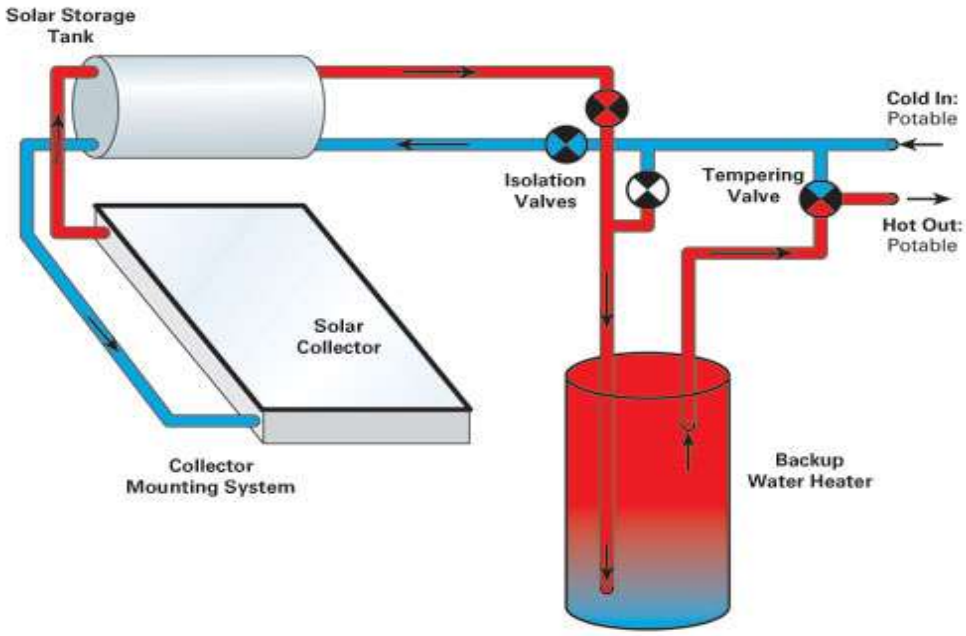

Figure 4: Thermosiphon Systems [19]

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Batch systems: Batch System (also known as integral collector storage systems) are simple passive systems consisting of one or more storage tanks placed in an insulated box that has a glazed side facing the sun. Batch systems have combined collection and storage functions. Depending on the system, there is no requirement for pumps or moving parts, so they are inexpensive and have few components in other words, less maintenance and fewer failures.

ADVANTAGES AND DISADVAN--TAGES:

Advantages:

i. Solar energy is free, renewable source of energy.
ii. By using solar energy, they help our dependence on fossil fuels.
iii. Low maintenance cost.
iv. In sunny and warm places with high insolation values solar water heating systems are very cost effective.

Disadvantages:

i. Relatively high upfront cost
ii. They required excellent overheating and freeze protection.
iii. Highly weather dependent
iv. In most areas they will require electrical or gas or other fuel backup during the winter period.

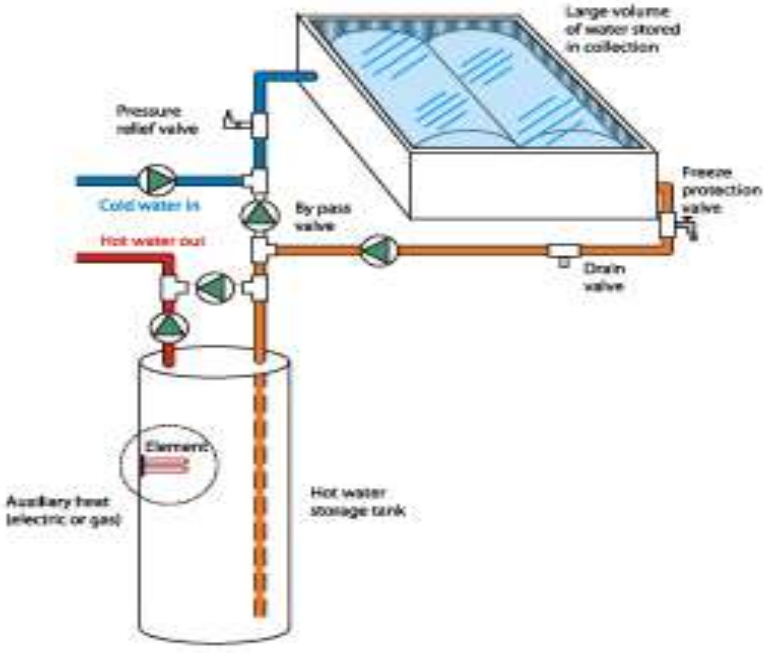

Figure:-5 Batch system [20]

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LITERATURE REVIEW

In the present review paper, the existing solar water heating systems are studied with their applications. Solar energy is free, environmentally clean, and therefore it is accepted as one of the most promising alternative energy sources. The effective use of solar energy is hindered by the intermittent nature of its availability, limiting its use and effectiveness in domestic and industrial applications especially in water heating. Now a day, plenty of hot water is used for domestic, commercial and industrial purposes. Various resources i.e. coal, diesel, gas etc., are used to heat water and sometimes for steam production. Solar energy is the main alternative to replace the conventional energy sources. The size of the systems depends on availability of solar radiation, temperature requirement of customer, geographical condition and arrangement of the solar system, etc. Therefore, it is necessary to design the solar water heating system as per above parameters. The available literature is reviewed to understand the construction, arrangement, applications and sizing of the solar thermal system. [12]

There is a survey that presents the various types of solar thermal collectors and applications. All the solar systems which utilize the solar energy and its application depends upon the solar collector such as flat plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors which are used in these system. The solar collectors are used for domestic, commercial and industrial purposes. These include solar water heating, which comprise thermosiphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling, which comprise, space heating and service hot water, air and water systems and heat pumps, refrigeration, industrial process heat, which comprise air and water systems and steam generation systems, desalination, thermal power systems, which comprise the parabolic trough, power tower and dish systems, solar furnaces, and chemistry applications. [1]

There is a method of solar water heating system. This automated system would allow the user to get hot water from the solar water heater as long as the solar water heater can supply hot water above a set temperature. If the solar water heater is unable to supply water above the set temperature, then only will the electric water heater come into action. It is efficient because our controller ensures

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that the solar water heater is used to supply hot water 80% of the time, and the rest 20% will be supplied by the electric water heater. It is cheap because, our system runs on solar energy which is abundant and free. It uses very small amount of electricity and therefore, reduces the expenses for the user. [2]

The previous works on solar water heating systems with various heat transfer enhancement techniques include collector design, collector tilt angle, coating of pipes, fluid flow rate, thermal insulation, integrated collector storage, thermal energy storage, use of phase change materials, and insertion of twisted tapes. This paper also discussed the methods to optimize and simulate the solar water heating systems to understand flow and thermal behavior in solar collectors that would lead to the improvement of the thermal performance of solar collectors. The enhancement of heat transfer in the solar collector with twisted tape is found to be better than the conventional plain tube collector. In solar water heating systems twisted tape has been used as one of the passive techniques to augment the heat transfer. Twisted tape has been used in heat exchangers but their applications are limited in solar water heating systems. [3]

Table 1: Comparison of the Collectors

Motion	**Collector Type**	**Absorber Type**	**Concentration Ratio**	**Temperature Range (°C)**
Stationary	FPC	Flat	1	30-80
Single Axis-Tracking	ETC	Flat	1	50-200
Two Axis-Tracking	CPC	Tabular	1-5	60-240
	LFR	Tabular	15-45	60-250
	PTC	Tabular	15-45	60-300
	CTC	Tabular	10-50	60-300
	PDR	Point	100-1000	100-500
	HFC	Point	100-1500	150-2000

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PROJECT METHODOLOGY

Solar Panel:

A panel designed to absorb the sun's rays as a source of energy for generating electricity or heating. A photovoltaic module is a packaged, connected assembly of typically 6×10 solar cells. Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications.

Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel or an array of solar modules, a solar inverter, and sometimes a battery and/or solar tracker and interconnection wiring. [4]



Fig.6 Solar Panel

The Specifications of the solar panel we are using in this particular project is given below with all its parameters and ratings:

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Table 2: Solar Panel Operating Parameters

Parameters	Ratings
Maximum Power (Pmax)	20 W
Voltage of Maximum Power (Vmax)	17 V
Current of Maximum Power (Imax)	1.18 A
Open Circuit Voltage (Voc)	21 V
Short Circuit Current (Isc)	1.20 A
Tolerance	±5%
Temperature	26ºC
Power Measured	1000 W/m²
Temperature Coefficients of Power	-0.47% / ºK
Temperature Coefficients of Voltage	-0.123V / ºK
Temperature Coefficients of Current	+4.4mA / ºK
Operation Temperature	-40ºC to 85ºC
Maximum System Voltage	600 V
Nominal Operating Cell Temperature	47 ± 2ºC

The working of a solar panel can be explained as a p-n junction is formed by placing p-type and n-type semiconductors next to one another. The p-type, with one less electron, attracts the surplus electron from the n-type to stabilize itself. Thus the electricity is displaced and generates a flow of electrons, otherwise known as electricity.

When sunlight hits the semiconductor, an electron springs up and is attracted toward the n-type semiconductor. This causes more negatives in the n-type semiconductors and more positives in the p-type, thus generating a higher flow of electricity. This is the photovoltaic effect. [5]

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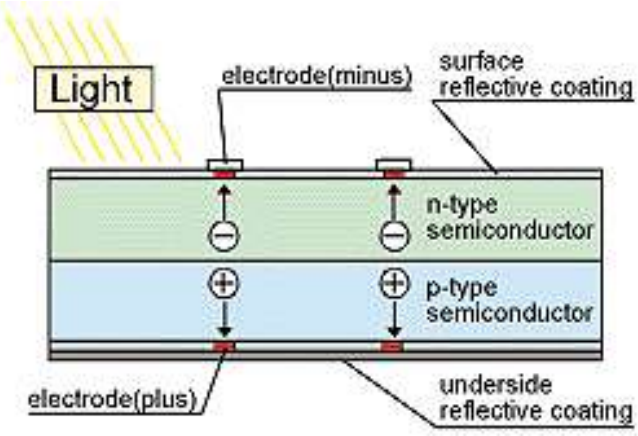

Fig.7. Photovoltaic Effect

Solar Charge Controller:

A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifespan, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life. The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery charger. [6]

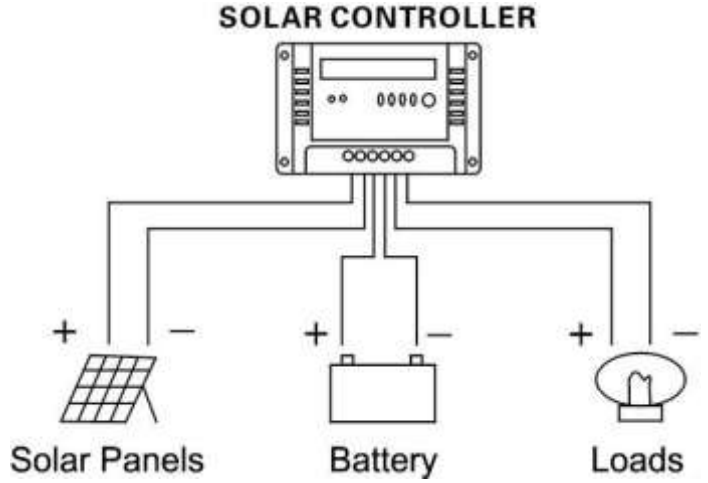

Fig. 8: Solar Charge Controller Connection Diagram [21]

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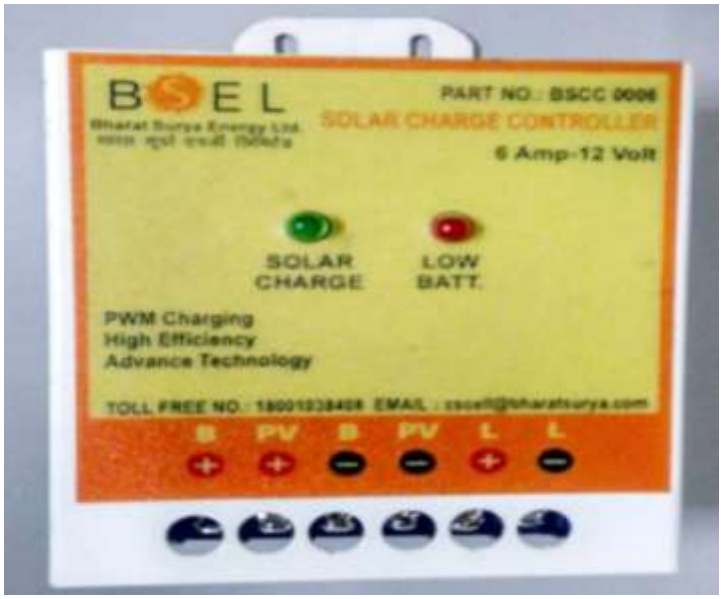

Fig.9: Solar Charge Controller

The PWM controller is in essence a switch that connects a solar array to a battery. The result is that the voltage of the array will be pulled down to near that of the battery. The PWM charge controller is a good low cost solution for small systems only, when solar cell temperature is moderate to high (between 45°C and 75°C). The PWM Solar Charge Collector we are using is of rating 6 Amp-12 Volt with high efficiency. The different specifications of a PWM controller is given below: [14]

Battery:

An electric battery is a device consisting of one or more electrochemical cells with external connections provided to power electrical devices. A discharging battery has a positive terminal, or cathode, and a negative terminal, or anode. The terminal marked negative is the source of electrons that when connected to an external circuit will flow and deliver energy to an external device. When a battery is connected to an external circuit, electrolytes are able to move as ions within, allowing the chemical reactions to be completed at the separate terminals and so deliver energy to the external circuit. It is the movement of those ions within the battery which allows current to flow out of the battery to perform work.

In our project we are using a 12V, 7.2 AH DC Lead Acid Battery. The cycle use is 14.1-14.4V at temperature 27ºC. The standby use of the battery is 13.5-13.8 V at temperature of 27ºC. The maximum initial current is 1.44 A.

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Table.3 Specifications of PWM Solar Collector

Array Voltage	**PV array & battery voltages should match**
Battery Voltage	Operates at battery voltage so it performs well in warm temperatures and when the battery is almost full
System Size	Typically recommended for use in smaller systems where MPPT benefits are minimal
Off-Grid or Grid-Tie	Must use off-grid PV modules typically with Vmp ≈ 17 to 18 Volts for every 12V nominal battery voltage
Array Sizing Method	PV array sized in Amps (based on current produced when PV array is operating at battery voltage)



Figure: 10 Battery

Batteries convert chemical energy directly to electrical energy. A battery consists of some number of voltaic cells. Each cell consists of two half-cells connected in series by a conductive electrolyte containing anions and cations. One half-cell includes electrolyte and the negative electrode, the electrode to which anions (negatively charged ions) migrate; the other half-cell includes electrolyte and the positive electrode to which cations (positively charged ions) migrate. Redox reactions power the battery. Cations are reduced (electrons are added) at the cathode during charging, while anions are oxidized (electrons are removed) at the anode during charging. During discharge, the process is reversed. The electrodes do not touch each other, but are electrically connected by the electrolyte. Some cells use different electrolytes for each half-cell. A separator allows ions to flow between half-cells, but prevents mixing of the electrolytes. [7]

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Batteries are classified into primary and secondary forms:

- Primary batteries irreversibly transform chemical energy to electrical energy. When the supply of reactants is exhausted, energy cannot be readily restored to the battery. Common examples are the alkaline battery used for flashlights and a multitude of portable devices.

- Secondary batteries are not indefinitely rechargeable due to dissipation of the active materials, loss of electrolyte and internal corrosion. Examples include the lead-acid batteries used in vehicles and lithium-ion batteries used for portable electronics.

Pump:

A solar-powered pump is a pump running on electricity generated by photovoltaic panels or the radiated thermal energy available from collected sunlight as opposed to grid electricity or diesel run water pumps. The operation of solar powered pumps is more economical mainly due to the lower operation and maintenance costs and has less environmental impact than pumps powered by an internal combustion engine (ICE). Solar pumps are useful where grid electricity is unavailable and alternative sources (in particular wind) do not provide sufficient energy.

The controller matches the output power that the pump receives with the input power available from the solar panels. Then a controller usually provides a low voltage protection, whereby the system is switched off, if the voltage is too low or too high for the operating voltage range of the pump. This increases the lifetime of the pump thus reducing the need for maintenance.



Fig.11: Submersible DC Water Pump

Voltage of the solar pump motors can be AC (alternating current) or DC (direct current). Direct current motors are used for small to medium applications up to about 3 kW rating, and are suitable for applications such as garden fountains, landscaping, drinking water for livestock, or small irrigation projects. Since DC systems tend to have overall higher efficiency levels than AC pumps of a similar size, the costs

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are reduced as smaller solar panels can be used.

Finally, if an alternating current solar pump is used, an inverter is necessary that changes the direct current from the solar panels into alternating current for the pump. The supported power range of inverters extends from 0.15 to 55 kW and can be used for larger irrigation systems. However, the panel and inverters must be sized accordingly to accommodate the inrush characteristic of an AC motor.

Solar powered water pumps can deliver drinking water as well as water for livestock or irrigation purposes. Solar water pumps may be especially useful in small scale or community based irrigation, as large scale irrigation requires large volumes of water that in turn require a large solar PV array. As the water may only be required during some parts of the year, a large PV array would provide excess energy that is not necessarily required, thus making the system inefficient. [8]

Solar Collector:

A solar collector collects heat by absorbing sunlight. A collector is a device for capturing solar radiation. Solar radiation is energy in the form of electromagnetic radiation from the infrared (long) to the ultraviolet (short) wavelengths.

In order to heat water using sunlight, a solar thermal collector heats the water that is pumped through it. As the water is pumped through the collector, the water becomes heated. The now heated water then is pumped out of the collector to the thermal storage tank.

Heat exchangers are usually comprised of copper, and are normally found inside a solar storage tank. This allows the heat in the fluid to be transmitted – or exchanged, hence the name - into the water in the storage tank. The storage tank is an essential element of any solar thermal system, as it allows all the heat being generated by the solar thermal collector to be stored for use whenever it is needed. [9]
The solar collector we have made required the following items:

- Plywood
- Black Paint
- Copper Tube
- Convex Lenses
- Plastic Level Pipe
- Glue / Fevicol

The Convex lens of the Magnifying Glass available easily in local markets of

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diameter 5cm was chosen. The focal length of this lens was found out to be 15cms and the maximum temperature attended at the focal point is found out to be 1950^{0}C by placing copper filament under direct solar radiations. The Solar Collector is a Rectangular box of size 45cms x 30cms x 18cms made of plywood of 5mm thickness. At the top of the box, twelve circular holes of 4.7cms dia. are cut where convex lens were fixed. The lenses used were the simple Convex Lens from Magnifying glass which is available easily in local markets. [15]



Fig.12. (a) Inside of the Solar Collector



Fig.12 (b) Outside of the Solar Collector

The lenses are fixed in the holes of the receiver box fevicol as it provides easily removal of the lens for further adjustments. The Receiver is made of a Copper tube 4mm (3/16th inch) in dia. and 1 mm thickness. The length of the tube is 180cms and is fitted in spiral form in the Panel Box at its focal length. The incident solar rays on the twelve lens area are concentrated at the focal point where the receiver tube is placed. The Sun is tracked from East to West with axis of the receiver tube along North-South directions and the collector is inclined. The inclination of the collector can be adjusted such that the incident radiations are normal to the collector surface. [10]

Thermal Water Storage:

A hot water storage tank (also called a hot water tank, thermal storage tank, hot water thermal storage unit, heat storage tank and hot water cylinder) is a water tank used for storing hot water for space heating or domestic use. Water is a convenient heat storage medium because it has a high specific heat capacity. This means, compared to other substances, it can store more heat per unit of weight (and volume). An efficiently insulated tank can retain stored heat for days, reducing fuel costs. Largely due to the move towards smaller households in developed countries, along

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with high density housing and high levels of private home ownership, the trend has been increasingly away from maintaining any hot water storage tanks, opting instead for integrated central heating systems supplied by combination boilers that can supply mains pressure hot water on demand. Water heaters for washing, bathing, or laundry have thermostat controls to regulate the temperature, in the range of 40 to 60 °C (104 to 140 °F), and are connected to the domestic cold water supply. Typically, hot water storage tanks are wrapped in heat insulation to reduce energy consumption, speed up the heating process, and maintain the desired operating temperature. [11]

In this project we have made a thermal water storage to keep the water at a minimum temperature for using the water on demand. This hot water preserver is made by combining two plastic buckets, one is comparatively bigger than the other one (5 Ltr and 3 Ltr respectively). The smaller bucket is placed inside the larger bucket. The gap between these two buckets is filled with thermocol, cotton and aluminum sheet with the help of glue to preserve the heat for longer period of time inside the bucket. The covers of the bucket are also filled with thermocol and a 2 diameter hole is made in the covers at equidistance for the inlet of the hot water coming from the solar charge collector through a plastic level pipe as shown in the figure below.

Heating Coil:

A heating coil converts electricity into heat through the process of resistive or Joule heating. Electric current passing through the element encounters resistance, resulting in heating of the element.

Metal Heating Elements:

1. Nichrome: Most heating elements use Nichrome 80/20 (80% nickel, 20% chromium) wire, ribbon, or strip. Nichrome 80/20 is an ideal material, because it has relatively high resistance and forms an adherent layer of chromium oxide when it is heated for the first time. Material beneath this layer will not oxidize, preventing the wire from breaking or burning out.

2. Resistance wire: Metallic resistance heating elements may be wire or ribbon, straight or coiled. They are used in common heating devices like toasters and hair dryers, furnaces for industrial heating, floor heating, roof heating, pathway heating to melt snow, dryers, etc. The most common classes of materials used include:

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Fig.13: Thermal Water Storage

i. Kanthal (FeCrAl) wires.
ii. Nichrome 80/20 wire and strip.
iii. Cupronickel (CuNi) alloys for low temperature heating.

Etched foil: Etched foil elements are generally made from the same alloys as resistance wire elements, but are produced with a subtractive photo-etching process that starts with a continuous sheet of metal foil and ends with a complex resistance pattern. These elements are commonly found in precision heating applications like medical diagnostics and aerospace. [22]

We have use a small part of the heating coil to outrun the limitation of generating hot water after sunset. So we've provided a heating element to the hot water storage system. Using of heating coil is a secondary way of getting hot water. The heating coil is fitted inside the hot water storage tank in two heatsinks as shown in the above figure 3.8. The two ends of the heating coil are connected with wire for the supply of the current from the source.

Digital Thermometer:

Digital Thermometers are temperature sensing instruments that are easily portable, have permanent probes and a convenient digital display. The way a digital thermometer works depends upon its type of sensor. Sensor types include resistance temperature detector (RTD), thermocouple and thermistor. [23]

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Fig.14. Heating Coil



Fig.15. Digital Thermometer [24]

We are using a digital thermometer to measure the temperature of water at the thermal water storage.

CONSTRUCTION AND WORKING

Connections:

- The positive and negative terminals from the solar panel is connected to the positive and negative terminals in the PV port of the solar charge controller.
- The positive and negative terminals of the battery port in the solar charge controller is connected to the positive and negative of the DC battery.
- The positive terminal from the L (load) of the solar charge controller is connected to the positive of both the switches (Switch 1 and Switch 2) as shown above.
- Similarly, the negative terminal from the L (load) of the solar charge controller is connected to the negative of both the switches (Switch 1 and Switch 2) as shown above.
- Now, the positive and negative from the other end of the Switch 1 is connected to the positive and negative of the DC pump respectively.
- Similarly, the positive and negative from the other end of the Switch 2 is connected to the positive and negative od the heating coil.
- Make sure the connections are properly tight and clean.

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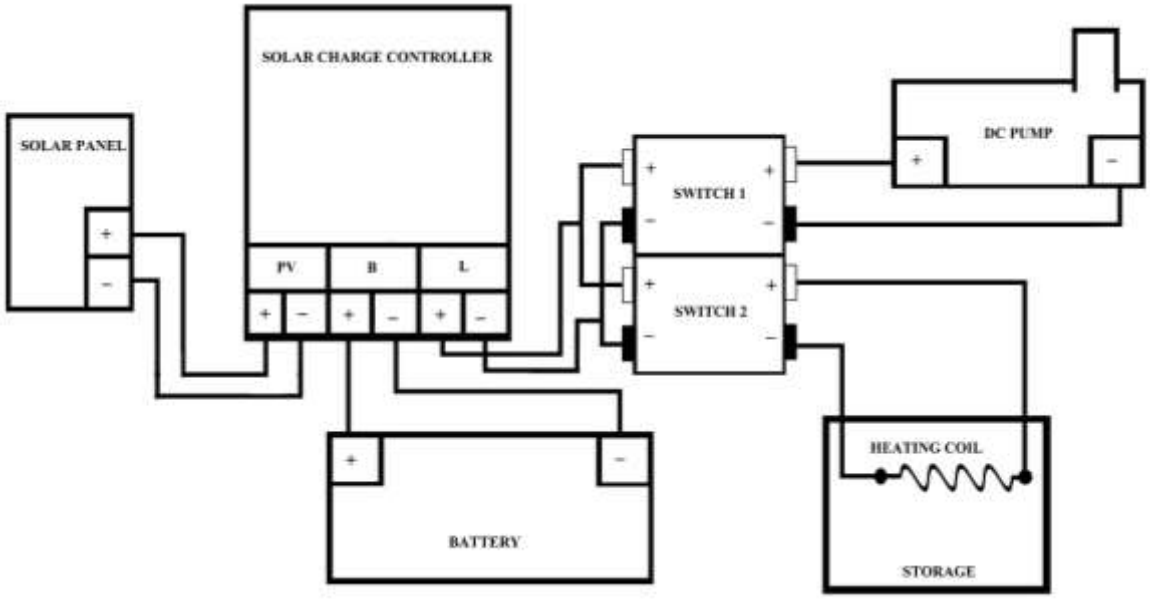

Fig.16. Circuit Diagram

WORKING PRINCIPLE

The working of the model can be simply explained as the solar radiations are converted into DC current by the solar panel and fed it to the solar charge controller. The solar charge controller then is connected to the battery where the charge will store for the various operations to perform accordingly. The submersible DC water pump and the heating coil are acting as various loads in the model. There are two switches which are used in the model where one of them is for the pump to run and other one is for the heating coil to run respectively. When a particular switch is turned on, the respective operation will perform. When the switch for DC pump is turned on the water from the cold water storage will flow to the solar collector through a level a where the water will get heat through the process of heat exchange. Then through the water outlet of the solar collector the hot water will stored at the thermal water storage. Now, the heating coil that is used in the model is for secondary purpose for heating the water in the thermal storage itself. This heating coil is used mainly for bad weather conditions and during night. When the switch for heating coil is turned on then the temperature of the coil placed inside the thermal storage will get high and due to which the temperature of the water inside the coil will become high. Hence, with the help of the solar power we will be able to heat the water and use it for domestic, commercial and industrial purposes.

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Final Model and Output



Fig.17: Final Model

Hence, the experiment is performed and the output is achieved. The temperature of the water will vary according to the temperature of that particular day.

CONCLUSION AND FUTURE SCOPE

At Present, Solar water heating systems are installed with different configurations and arrangements. The basic technology concrete of these systems are studied and it is found that there is a need to work on the generated design procedure to select, install and monitor the solar water heating system as per the availability of solar radiation and local geographical condition. The solar heating device has achieved some level of success. It is able to heat water a substantial amount above the ambient temperature in only half an hour. However, the success of the device is limited in that it was unable to accomplish the goal of reaching a boiling point. Continue experimentation, redesign and reimplementation of different containers will lead to an even better device to heat water.

India has tremendous scope of generating solar energy. The geographical location of the country stands to its benefit for generating solar energy. The reason being India is a tropical country and it receives solar radiation almost throughout the year, which amounts to 3,000 hours of sunshine. This is equal to more than 5,000 trillion kWh. Almost all parts of India receive 4-7 kWh of solar radiation per square meters. This is equivalent to 2,300–3,200 sunshine hours per year. States like Andhra Pradesh, Bihar, Gujarat, Haryana, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan,

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and West Bengal have great potential for tapping solar energy due to their location. Since majority of the population lives in rural areas, there is much scope for solar energy being promoted in these areas. Use of solar energy can reduce the use of firewood and dung cakes by rural household.

Solar water heaters, also known as solar domestic hot water system are very efficient and less expansive way to generate the supply of hot water at domestic places. The solar water heater can be used in any climate and the fuel which they use for heat generation is sun rays which is available free of cost. Now a day most of the people are showing lot of interest to buy the solar based products and these products are very useful in saving electricity, even engineering students are also showing lot of interest to build new solar energy projects which will helpful for next generation.

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