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Modeling of Solar Photovoltaic System Assisted Water Cooling System

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Abstract

The main objective of this paper is to cool a definite amount of water pumped from underground to a definite temperature throughout the day in Guwahati city, Assam,India. 5 kg/s of water present at a depth of 10m, 18^{o}C is pumped to earth's surface by centrifugal pump and passed through evaporator of vapour compression refrigeration system with R-134a as refrigerant to obtain water of 4^{o}C. The study is made for January having lowest temperature, lowest solar radiation and May having highest temperature, highest solar radiation because if the system performs well in lowest and highest conditions, it will perform well throughout the year. Evaporator temperature for both January and May is maintained at 8^{o}C, condenser temperature at 22^o C, 30^{o}C in January and May respectively. The power requirement for centrifugal pump and compression refrigeration's compressor are supplied by 315 SW280 photovoltaic modules combined in parallel and 2 SW280 photovoltaic modules combined in series with 4117.015 Ah capacity battery as backup during non sunshine hours and night time.

1. Introduction

There are various utilities of chilled/cold water. Cold water can be used for DNA(deoxyribonucleic acid) extraction, shortcrust pastry, rinsing tools, sterilizing tools and equipments, washing face, making coffee, providing cooling to buildings, in heat exchangers and many more applications. Cold water is produced in many ways both by using conventional and non conventional sources. If chilled water is produced by using non conventional sources it gives an added advantage. The present paper is based on producing cold water by using solar photovoltaic system.

Many researchers have designed/applied solar technologies for producing cold water. In (Grossman) author stated a novel open-cycle (dehumidifier evaporator regenerator) DER system aided by usage of the solar heat at relatively low temperatures, for production of both chilled water and cold, dehumidified air in quantities which are variable, as per load requirements. In (Z Hassan) author made an introduction of a novel hybrid solar chimney power plant with integration of a solar-driven adsorption water chiller. With possible investigation and modifications of a gas turbine trigeneration plant via integration it with a parabolic trough collector (PTC) technology 45461 m^3/day of freshwater and 2300 kg/s of chilled water along with 360 MWe of electricity was produced in (Dabwan et al.).In (Agyenim, Knight, and Rhodes) authors made an experimental domestic-scale prototype solar cooling system which was based on a LiBr/H_2O absorption system having a vacuum tube solar collector of 12m^2, LiBr/H_2O absorption chiller of 4.5 kW , a cold storage tank of 1000l and a fan coil of 6 kW. Like that there are many researchers working on production of chilled water by solar applications.

The aim of this paper is to produce a definite amount of cold/chilled water at 4^o C pumped from underground after passing through evaporator of vapour compression refrigeration system using R-134a as refrigerant.

2. System Layout

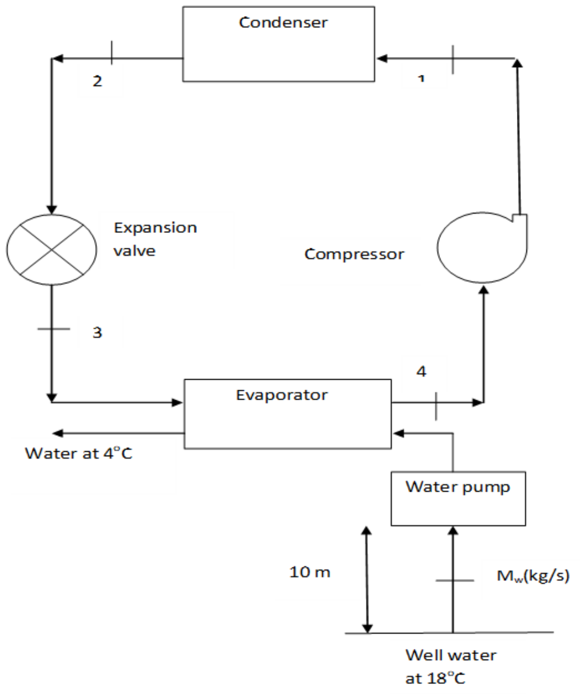

FIGURE 1. Layout of water cooling system by vapour compression refrigeration system

Fig.1 depicts a schematic view of combined water cooling system with vapour compression system with 134-a as refrigerant. Mass of water (M_w)(5 kg/s) is pumped by water pump from a depth of 10m (Well) having temperature of 18^oC (A)and passed through evaporator maintained at 8^oC(T_E) both in January and May and at exit from evaporator cold water at 4^oC is obtained. The condenser temperature(T_C) is maintained at 22^o C, 30^oC in January and May respectively. Since, M_w is constant throughout the day, cooling load of evaporator, pumping work of water pump, and compressor will be same throughout the day.

Fig.2 depicts a schematic view of system which is solar photovoltaic for running compressor and water pump in day hours. Solar photovoltaic modules generate current I_{PV} after solar radiation falls on modules. The current requirement for compressor (I_C) and water pump (I_p) is obtained after current generated by photovoltaic modules passes by charge controller and inverter. The surplus current besides meeting compressor and pump current(I_{PV}-(I_c+I_p)) is sent to rechargeable battery for storage.

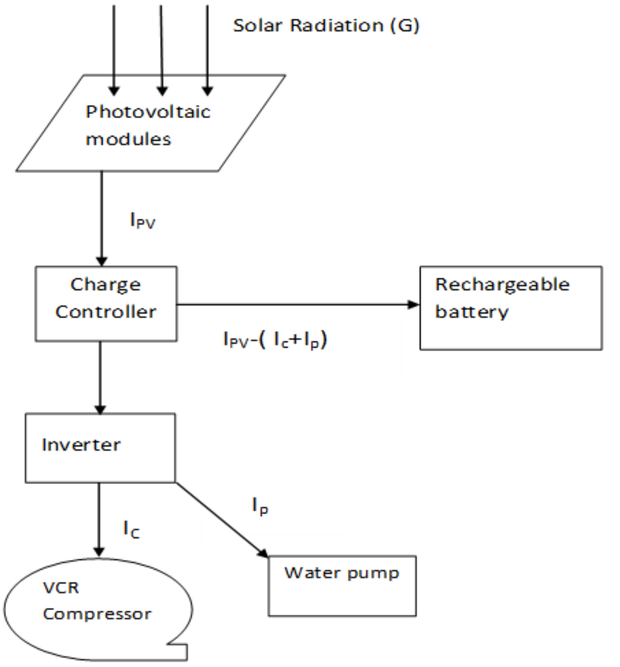

FIGURE 2. Layout of system which is solar photovoltaic for powering compressor and water pump during day time

Fig.3 shows a layout of solar photovoltaic system for powering compressor and water pump during night time/deficient solar radiation. The required current for powering compressor and water pump is managed from battery which are rechargeable (I_c+I_p -I_{PV}) after passing by charge controller and inverter.

3. Modeling of combined system

The water's mass flow rate(M_w)(kg/s) is considered 5kg/s. The water pump efficiency is considered to be 90% (Evans).

The ideal pumping power of water pump(W_{p1}) is:

$$W_{p1} = M_w \times H \times 9.81 \qquad (1)$$

Where, M_w-water's mass flow rate for pumping being 5 kg/s, H-piezometric height being 10m (Well),9.81- average gravity in m/s^2.

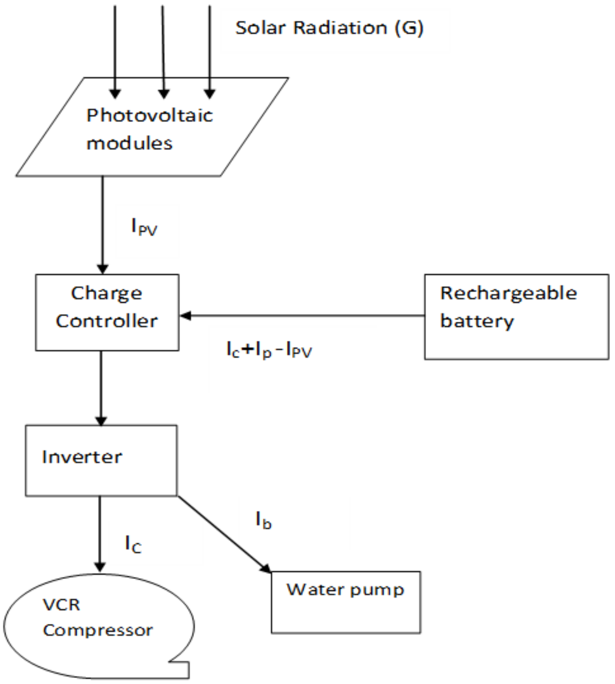

FIGURE 3. Layout of system which is solar photovoltaic for running compressor and water pump during night time.

After putting the values in eq.1, W_{p1} is found to be 0.490 kW.

Actual pumping power of water pump (W_p) is given by:

$$W_p = W_{p1}/0.9 \tag{2}$$

Where, 0.9- centrifugal pump efficiency (Evans).

Actual pumping power of water pump (W_p) is found to be 0.544 kW.

The amount of heat to be rejected to evaporator by water pumped by centrifugal pump is found to be:

$$Q_e = M_w \times C_p \times (18 - 4) \tag{3}$$

Where,C_p-4.2 k J/kg. K,18-entry temperature of water to evaporator from pump in ^{o} C, 4-exit temperature of water from evaporator in ^{o}C.

By putting the required values Q_e is found to be 314 kW.

The COP of refrigerator of figure 1 is :

$$COP_R = T_E/(T_c - T_E) \tag{4}$$

Where, T_E- temperature of evaporator, T_C- temperature of condenser.

Compressor load (W_{c2}) of figure 1 is :

$$W_{c2} = Q_e/COP_R \tag{5}$$

Or,

$$W_{c2} = m_r \times (h_1 - h_4) \tag{6}$$

Where, m_r- refrigerant 134-a mass flow rate(kg/s), h_1- refrigerant 134-a's enthalpy in superheated state at saturation pressure corresponding to condenser temperature and at exit from compressor(kJ/kg), h_4- enthalpy of refrigerant 134-a at saturation vapour state corresponding to temperature of evaporator(kJ/kg).

Refrigerant's mass flow rate (m_r) (in kg/s) is:

$$m_r = Q_e/(h_4 - h_3) \tag{7}$$

Where, h_4-enthalpy of refrigerant 134-a at saturated vapour corresponding to evaporator temperature(kJ/kg), h_3- enthalpy of refrigerant 134-a at exit from expansion valve(kJ/kg).

Actual compressor load(W_c) (in W)of figure 1 is:

$$W_c = W_{c2}/0.85 \tag{8}$$

Where, 0.85- centrifugal compressor's isentropic efficiency (Das).

The required calculations of solar photovoltaic modules along with specifications are available in (Chenni et al.) and (Beaudet) respectively. From solar radiation and wind speed data are obtained.

Series number of photovoltaic modules (N_s) is given by:

$$N_s = 48/V_{mod} \tag{9}$$

Where, 48- voltage of the system and V_{mod}- module's maximum voltage .

Current requirement from photovoltaic modules(I_{spv}) is given by:

$$I_{spv} = (W_b + W_c) \times 1.25/(48 \times 0.85 \times 7 \times 0.85) \tag{10}$$

Where, W_c-total compressor work(in W) required in a day, 1.25-derating factor of photovoltaic module , 48-voltage of the system, 0.85-power factor, 0.85-efficiency of inverter,7- Guwahati's mean sunshine hours in , 0.85-efficiency of charge controller.

Parallel number of photovoltaic modules(N_p) is given by:

Where, I_{mod}- module's maximum current .

4. Results and Discussion

Table 1 depicts the cooling load (Q_e), water pumping power(W_p) and compressor power(W_c) for January. It is seen that all the three parameters are constant as water pumping power is constant throughout the day. Based on the water pumping power(W_p) (Eq. 2), Q_e is calculated by using equation 3. Based on Q_e compressor power is calculated by using equations from 4 to 8.

TABLE 1. Temperature, cooling load, water pump work and compressor pumping power for January

Time in hours	$T_{amb,Jan}$(	Q_e (kW)	Water Pump Work((kW)	Compressor Work (W_c) (kW)
12:30 AM	13.33			
3:30 AM	16.111			
5:30 AM	20			
8:30 AM	21.111			
11:30 AM	18.888	314	0.544	18.395
2:30 PM	17.777			
5:30 PM	15.556			
8:30 PM	15			

Table 3 shows the cooling load (Q_e), water pumping power(W_p) and compressor power(W_c) for May. It is seen that all the three parameters are constant as water pumping power is constant throughout the day. Same equations are used for calculating Q_e, W_c.

Table 4 shows battery's discharging and charging pattern in May. From 6:00AM to 6:00PM extra current after fulfilling the pump's and compressor's current goes to rechargeable battery for storage. The solar radiation's intensity increases from 6:00 AM to 12:00PM and intensity decreases from 12:00PM to 6:00PM As a result current stored shows increasing pattern from 8:30 AM to 11:30 AM and again shows decreasing pattern from 11:30 AM to 2:30 PM. At 5:30 PM current is discharged from battery although solar radiation was available. The current requirement during rest hours/night time are obtained from battery which was stored during 6:00AM to 6:00PM.

TABLE 2. Electric energy discharge and charged in January

Time in hours	Discharged current from battery(Ah)	Charged current to battery(Ah)
12:30 AM	134.974	0
3:30 AM	134.974	0
5:30 AM	134.974	0
8:30 AM	0	278.515
11:30 AM	0	582.379
2:30 PM	0	424.770
5:30 PM	0	14.609
8:30 PM	134.974	0

TABLE 3. Temperature, cooling load, water pump work and compressor pumping power for May

Time in hours	$T_{amb,May}$	Q_e (kW	Water Pump Work(W (kW)	Compressor Work (W_c) (kW)
12:30 AM	23.888			
3:30 AM	25			
5:30 AM	26.667			
8:30 AM	27.777			
11:30 AM	27.222	314	0.544	28.90
2:30 PM	25.555			
5:30 PM	25.555			
8:30 PM	26.111			

Charging current to battery is greater for May than January since solar radiation is greater for May than January. As a result greater current is produced

TABLE 4. Electric energy discharge and charged in May

Time in hours	Discharged current from battery(Ah)	Charged current to battery(Ah)
12:30 AM	209.887	0
3:30 AM	209.887	0
5:30 AM	209.887	0
8:30 AM	0	330.483
11:30 AM	0	717.638
2:30 PM	0	516.563
5:30 PM	9.095	0
8:30 PM	209.887	0

by photovoltaic modules resulting in greater charge storage in May than January.

The discharging charge amount and charging amount stored in the month of January and May is found to be 539.896 Ah, 1300.273 Ah; and 848.643 Ah, 1564.684 Ah respectively. The battery capacity required for operation is calculated to be 4117.015 Ah with battery capacity of 1.3, autonomy in days is 3 and battery discharge to be 0.8. From equations 10 and 11, number of SW280 modules in parallel needed to power the complete system are 315 and from equation 9 modules in series needed are 2.

5. Conclusion

After analyzing it is inferred that for maintaining a water flow rate of 5kg/s from 18^oC to 4^oC pumped from a depth of 10m, evaporator temperature 8^oC for January, May and condenser temperature 22^oC, 30^oC for January and May respectively, 315 SW280 parallel modules and 2 SW280 series modules are sufficient with 4117.015 Ah capacity battery.

If the parameters like water flow rate, exit-outlet temperature of water, water depth, evaporator-condenser temperature change the requirement of evaporator cooling load, pumping power will change.

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