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Modeling of Solar Photovoltaic Assisted Vapor Absorption Refrigeration System for Storing Different Vegetables

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Abstract:*In this paper,a detailed modeling of solar photovoltaic assisted vapor absorption refrigeration system is done for storing vegetables safely like carrots, potatoes and tomatoes in Kolkata city located in India throughout the year.The mass of each vegetable is taken to be 5 tons i.e. 5000kg and storage temperature for each vegetable is 15^{o}C. The analysis is done for month January and May due to the fact that January month has lowest solar radiation and May month has highest solar radiation. Hence a combined photovoltaic and vapor absorption refrigeration system which works well in these two months can easily operate the combined system throughout the year. It is found that 17, 13, and 12 modules in parallel each having 2 modules in series of Central Electronics Limited Make PM 150 for vegetables carrots,potatoes and tomatoes respectively can support the cooling requirement of vegetables present in godown. The power back up is provided using battery bank of rated capacity of 239 Ah.*

1.Introduction

Use of solar energy is a very demanding technology. Solar radiation is obtained on earth abundantly. If solar energy is used by different technologies the energy crisis can be mitigated. Many people have used solar technology in different ways. Tsoutsos et al[1] studied the performance and economic evaluation of a solar heating and cooling system of a hospital in Crete using the transient simulation program (TRNSYS).Rivera et al[2]presented a novel solar intermittent refrigeration system for ice production developed in the Centro de Investigacio´n en Energı´a of the Universidad Nacional Auto´noma de Me´xico. Pongtornkulpanich et al[3]designed a solar-driven 10-ton LiBr/H_2O single-effect absorption cooling system and installed at the School of Renewable Energy Technology (SERT), Phitsanulok, Thailand. Dorantes et al[4] presented a mathematical simulation for the dynamic thermal behavior of a solar ejector-compression refrigeration system with a capacity production of 100 kg of ice per day.Guo and Sen[5] proposed a lumped method combined with dynamic model for use in investigating the performance and solar fraction of a solar-driven ejector refrigeration system (SERS) using R134a, for office air conditioning application for buildings in Shanghai, China. Vidal et al[6] dealt with the hourly simulation of an ejector cooling cycle assisted by solar energy. The system was simulated using the TRNSYS program and the typical meteorological year (TMY) file that contained the weather data from Floriano´ polis, Brazil.Helm et al[7]presented the system concept and the hydraulic scheme together with an analysis of the energetic performance of the system followed by a report on the operation of a first pilot installation. Best and Ortega[8] presented a review of solar cooling and refrigeration technologies and a discussion on the main reasons why these technologies were not presently economically feasible was carried out and two installations in Mexico were analysed. Enibe [9] discussed photovoltaic (PV) powered vapour compression systems ; continuous and intermittent liquid or solid absorption systems; and adsorption systems.The author discussed technical and financial constraints which limit their widespread application and strategies for overcoming them.

In many applications excess energy generated is lost. Rechargeable battery technology can store excess energy generated to store excess energy and can be used during energy deficient period. Nair and Garimella[10] provided a modelling framework to be able to quantify the associated benefits of renewable resource integration followed by an overview of various small-scale energy storage technologies.They presented a

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simple, practical and comprehensive assessment of battery energy storage technologies for small-scale renewable applications based on their technical merit and economic feasibility. Software such as Simulink and HOMER provided the platforms for technical and economic assessments of the battery technologies respectively.Ortiz et al[11]demonstrated the feasibility of the desalination of brackish water by means of an electrodialysis system powered directly by photovoltaic solar panels,and explained theoretically the interaction between the photovoltaic generator and the electrodialysis system during the process.Urbina et al[12]investigated the reliability of a rechargeable battery acting as the energy storage component in a photovoltaic power supply system.They constructed a model that included the solar resource, the photovoltaic power supply system, the rechargeable battery and a load. The photovoltaic system and the rechargeable battery were modelled deterministically, and an artificial neural network was incorporated into the model of the rechargeable battery to simulate damage that occured during deep discharge cycles.

In the present study solar photovoltaic modules assisted vapor absorption refrigeration system is used for storing different vegetables i.e. carrots, potatoes and tomatoes. Vegetables releases heat during storing period. So if this heat is not rejected then vegetables may get spoilt. So current generated by PV modules is given to generator of vapor absorption refrigeration system (VARS) and the system continues in operation.

2.System Layout

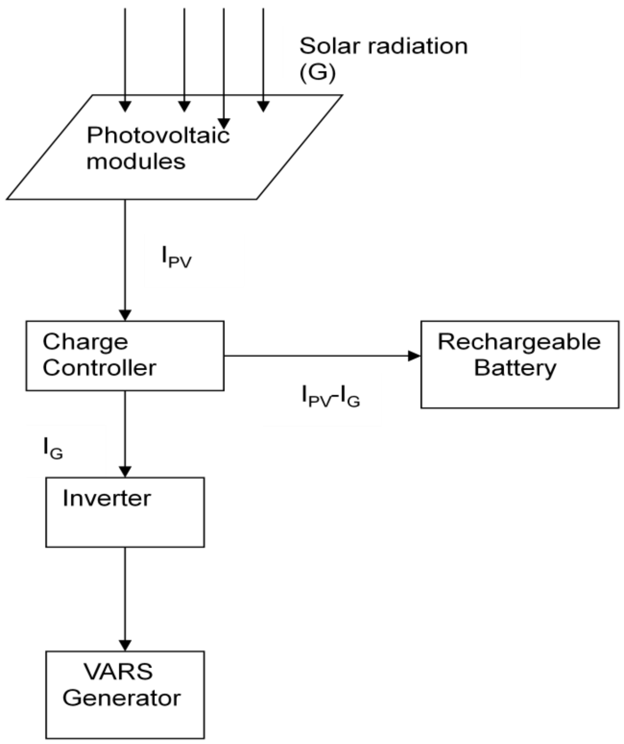

Fig.1 Schematic view of combined photovoltaic and VAR system when current produced by photovoltaic modules is more than the current required for generator.

When solar radiation is available in plenty i.e from 6:00hours to 18:00hours, solar modules generate current (I_{PV}).The excess current after meeting the requirement of vapor absorption refrigeration system(VARS) generator(I_G)goes to rechargeable battery(I_{PV} –I_G) for storing purpose. The current requirement for VARS generator (I_G) is dependent on heating load and quantity of vegetables.

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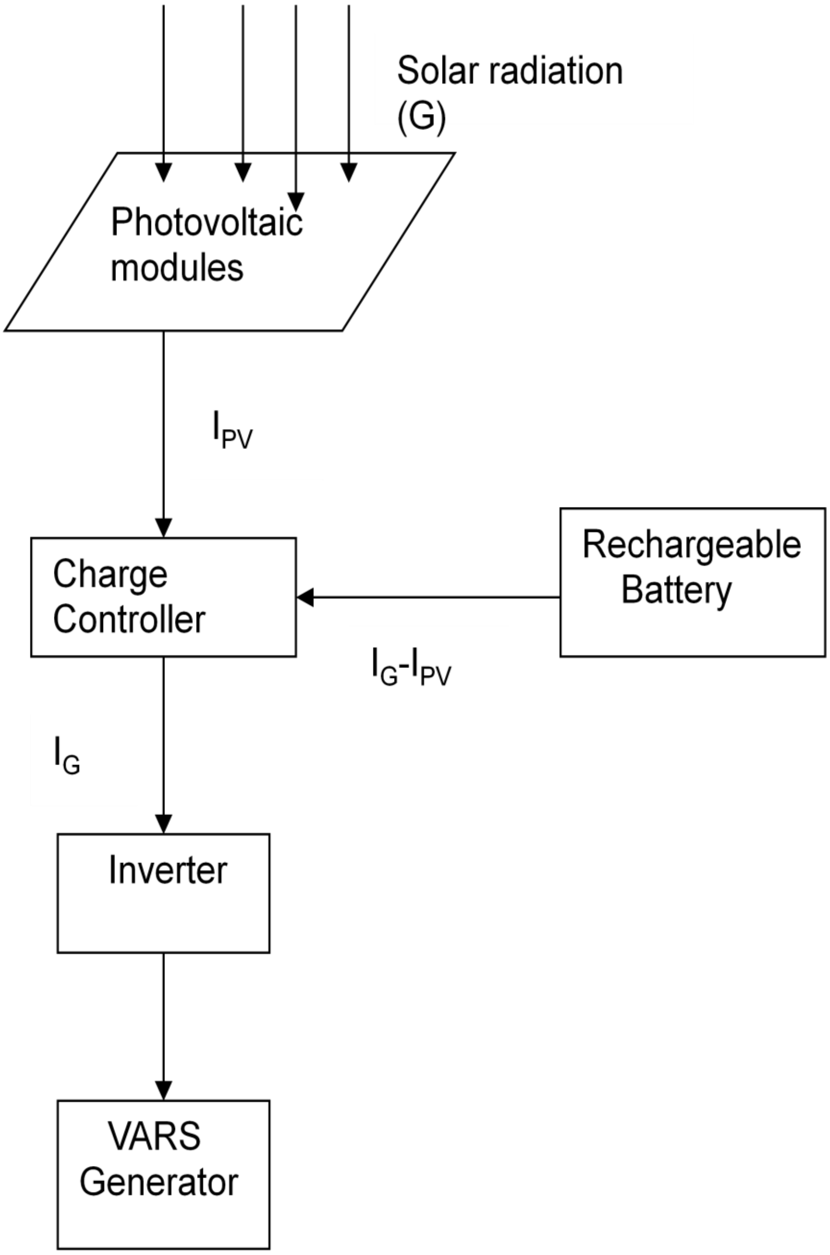

Fig.2 Schematic view of combined photovoltaic and VAR system when current produced by photovoltaic modules is less than the current required for generator.

When solar radiation is not available in plenty i.e. from 19:00hours to 5:00 hours, the current requirement (I_G) for VARS generator is obtained from rechargeable battery which stores the excess energy during sunshine hours.

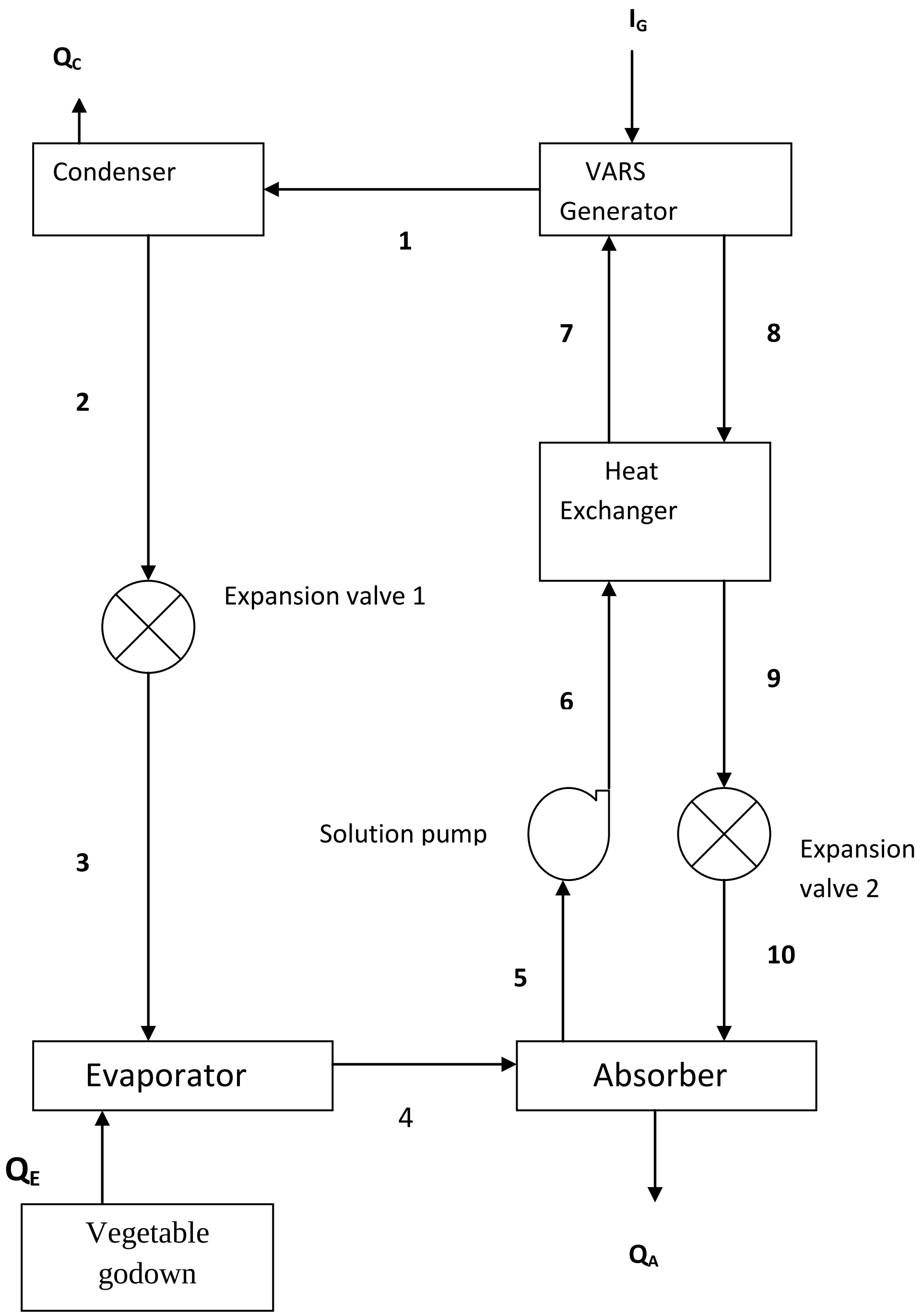

Fig.3 Schematic view of vapor absorption refrigeration system.

Table 1. Operating parameters of various components in absorption refrigeration system

Parameters	Values
Evaporator temperature	15°C
Absorber temperature	35°C
Heat exchanger effectiveness	0.8
Generator temperature	80°C
Condenser temperature	35°C

3.Modeling of solar photovoltaic modules

The electrical energy is generated by harnessing solar energy using photovoltaic modules. In the present work Central Electronics Limited Make PM-150 [13] solar photovoltaic module has been used. The single cell terminal current is given by[14]:

$$i_{PV} = i_L - i_D \quad (1)$$

Where i_L is the light current generated by a solar cell as a function of solar radiation (G) and i_D is the diode current.

The light current generated from a photovoltaic module at any given intensity of solar radiation and temperature is given by [14]:

$$i_L = \left(\frac{G}{G_{ref}}\right)\left(i_{scref} + \mu_{isc}\left(T_{module} - T_{moduleref}\right)\right) \quad (2)$$

Where, G , G_{ref} is the solar radiation at actual[15]and reference condition(1000 W/m^2)[13] respectively, i_{scref} -short circuit current at reference condition(A)[13], μ_{isc} -manufacturer supplied temperature coefficient of short circuit current(A/K)[13], T_{module} and $T_{moduleref}$ module temperature at actual and at reference condition(K)[13].

The module temperature is a function of ambient temperature ($T_{ambient}$), wind speed(v_f) and solar radiation(G) and given by[14]:

$$T_{module}(K) = (0.943 \times T_{ambient} + 0.028 \times G - 1.528 \times v_f + 4.3) + 273.15 \quad (3)$$

Where, $T_{ambient}$ is in ^{0}C[15], G in W/m^2[15], v_f wind speed in m/s[16].

The diode current in equation (1) is a function of reverse saturation current and given by[14]:

$$i_D = i_{sat}\left[\exp\left(\frac{q(V + i_{PV}R_s)}{\gamma k T_{module}}\right) - 1\right] \quad (4)$$

Where i_{sat} - reverse saturation current(A), q -electron charge(1.6 x 10^{-19}C), V -terminal voltage(V), R_S -series resistance, γ -shape factor, k -Boltzamann constant(1.38 x 10^{-23} J/K).

$$i_{sat} = i_{satref}\left(\frac{T_{module}}{T_{moduleref}}\right)^3 \exp\left[\left(\frac{q\varepsilon_G}{kA}\right)\left(\frac{1}{T_{moduleref}} - \frac{1}{T_{module}}\right)\right] \quad (5)$$

where A-completion factor, ε_G -material bandgap(1.12eV for Si),and

$$i_{satref} = i_{scref} \times \exp\left(\frac{-qV_{ocref}}{k\gamma T_{moduleref}}\right) \quad (6)$$

Where V_{ocref} -open circuit voltage at reference condition [13].

i_{sat}, i_{sarref} is taken from [14].

Shape factor (γ) which is a measure of cell imperfection is given by[14]:

$$\gamma = A \times NCS \times N_S \quad (7)$$

Where A, NCS, N_S is completion factor, number of cells connected in series in a single module(specified by manufacturer of the module) and number of modules connected in series of the entire photovoltaic array respectively.

$$N_S = \frac{V_{system}}{V_{module}} \quad (8)$$

Where V_{system} is the system voltage of the photovoltaic array(considered 48 V in present study) and V_{module} is the voltage obtained from single module.

Current requirement on hourly basis(i_g) is given by:

$$i_g = \frac{Q_G \times 1000}{V_{system} \times PF \times \eta_{inverter}} \quad (9)$$

Where, Q_G -generator heat load on hourly basis, PF-power factor(0.85), $\eta_{inverter}$ -inverter efficiency(0.85)

The design current required from photovoltaic array(i_{spv}) is given by:

$$i_{spv} = \frac{i_{g,total} \times DF}{Peaksunshinehours} \quad (10)$$

Where $I_{g,total}$ is total current requirement in a day by generator of absorption refrigeration system in Ah, DF is de rating factor of photovoltaic module considered to be 1.25[17], peak sunshine hours to be 7 hours[18].

No. of photovoltaic modules in parallel(N_p) is given by:

$$N_p = \frac{i_{spv}}{i_{mpp}} \quad (11)$$

Where i_{mpp}-current available from a single module under peak power condition.

Net current from solar PV array is: $i_{array} = i_{pv} \times N_p$ (12)

3.Modeling of vapor absorption refrigeration system(VARS)

In the VARS, we consider a simple single effect H_2O-LiBr absorption system consisting of a SHE(solution heat exchanger). The Concentration of the strong and weak solution of the refrigerant as functions of operating temperatures is known [19].Strong solution concentration is dependent on absorber and evaporator temperature, while weak solution concentration is dependent on generator and condenser temperature. Thermodynamic properties such as specific enthalpy, entropy of the refrigerant (water) both in liquid and vapour state at various pressures and temperature i.e. at points 1,2,3, and 4 are determined from International Associations for the properties of water and steam (IAPWS) formulation 1997 [20]. Similarly the thermodynamic properties of H_2O-LiBr solutions at various temperatures and concentration i.e at points 5,6,7,8,9 and 10 are calculated using the correlations proposed by Patek and Klomfar [21].

The mass flow rate of strong($\dot{m}_{ss}$)along points 5,6,7and weak solution($\dot{m}_{ws}$)along points 8,9,10are calculated from the equations from ref.[19].

The thermal load in the generator, absorber and condenser can be expressed as:

$$Q_G = \dot{m}_{H_2O} h'_1 + \dot{m}_{ws} h'_8 - \dot{m}_{ss} h'_7 \quad (13)$$

$$Q_A = \dot{m}_{H_2O} h'_4 + \dot{m}_{ws} h'_{10} - \dot{m}_{ss} h'_5 \quad (14)$$

$$Q_C = \dot{m}_{H_2O} \left(h'_1 - h'_2 \right) \quad (15)$$

$$Q_E = \dot{m}_{H_2O} (h_4' - h_3') \quad (16)$$

Where h'-enthalpy at salient points, Q_G-generator load, Q_A-absorber load, Q_c-condenser load.Q_E-evaporator load.

4.Results and Discussion

A numerical code in C was developed for simulating combined photovoltaic and absorption refrigeration system for storing different vegetables in godown.

Table 2. Load requirements for storing different vegetables.

Commodities	Temperature(°C)	Heat release in k J/ton-24hour	TOR (for 5 tones of mass)
Carrots	15	8374[22]	0.1384
Potatoes	15	6280[22]	0.1038
Tomatoes	15	5860[22]	0.0968

In table 2 it is seen that vegetables are stored at 15^{0}C. The heat release in k J/ton-24hour is obtained from ref.[22]. The masses of each vegetables stored is 5 tones i.e. 5000kg.Cooling load is given in TOR i.e. tons of refrigeration

Table3. Number of photovoltaic modules requirement and cumulative battery charging and discharging in different months

Commodities	No. of photovoltaic modules in parallel	No. of photovoltaic modules in series	Battery charged(Ah) for the month of January	Battery discharged(Ah) for the month of January	Battery charged(Ah) for the month of May	Battery discharged(Ah) for the month of May
Carrots	17	2	323.467	43.07	529.357	44.24
Potatoes	13	2	247.833	32.35	405.105	33.18
Tomatoes	12	2	228.529	30.15	373.679	30.86

Table 3 shows the number of photovoltaic modules (in parallel and series), battery charging (Ah) and battery discharging(Ah) for the month of January and May. Here two months i.e. January and May is taken because January month has lowest solar radiation and May month have highest solar radiation. If a system works well in these two months it can work successfully throughout the year.

Based on above mentioned results it is seen that rated battery capacity of 238.846 Ah is sufficient to run the combined photovoltaic and VAR system.

5. Conclusion

Based on the analysis it is found that 17, 13, and 12 modules in parallel each having 2 modules in series of Central Electronics Limited Make PM 150 for vegetables carrots,potatoes and tomatoes respectively of 5000 kg mass each can support the cooling requirement of vegetables present in godown located in Kolkata, India.The power back up is provided using battery bank of rated capacity of 239 Ah. The photovoltaic module requirement and battery capacity required will change depending on the temperature storage of vegetables and mass of vegetables.

6. References

[1] T. Tsoutsos, E. Aloumpi, Z. Gkouskos , M. Karagiorgas, Design of a solar absorption cooling system in a Greek hospital, Energy and Buildings 42 (2010) 265–272.
[2] W. Rivera, G. Moreno-Quintanar, C.O. Rivera , R. Best, F. Martinez, Evaluation of a solar intermittent refrigeration system, Solar Energy 85 (2011) 38–45.
[3] A. Pongtornkulpanicha, S. Thepaa, M. Amornkitbamrungb, C. Butcher, Experience with fully operational solar-driven 10-ton LiBr/H_2O, Renewable Energy 33 (2008) 943–949.
[4] R. Dorantes, C. A. Estradat, I. Pilatowsky, Mathematical simulation of a solar ejector-compression refrigeration system, Applied Thermal Engineering 16 (8/9) (1996) 669-675.
[5] J. Guo, and H.G. Shen, Modeling solar-driven ejector refrigeration system offering air conditioningfor office buildings, Energy and Buildings 41 (2009) 175–181.
[6]H. Vidal, S. Colle, G. dos Santos Pereira, Modelling and hourly simulation of a solar ejector cooling system, Applied Thermal Engineering 26 (2006) 663–672.
[7]M. Helm, C. Keil, S. Hiebler, H. Mehling, C. Schweigler,Solar heating and cooling system with absorption chiller and low temperature latent heat storage: Energetic performance and operational experience,International journal of Refrigeration 3 2 (2 0 0 9) 5 9 6 – 6 0 6.
[8]R. Best and N. Ortega, Solar refrigeration and cooling, Renewable Energy 16 (1999) 685-690.
[9]S.O.Enibe, Solar refrigeration for rural applications, Renewable Energy 12(2) (1997) 157-167.
[10]N-K.C.Nair and N.Garimella, Battery energy storage systems: Assessment for small-scale renewable energy integration, Energy and Buildings 42 (2010) 2124–2130.
[11]J. M. Ortiz, E. Expósito, F. Gallud, V. G.-García, V. Montiel, A. Aldaz, Electrodialysis of brackish water powered by photovoltaic energy without batteries: direct connection behavior,Desalination 208 (2007) 89–100.
[12]A. Urbina, T.L. Paez, C. O'Gorman, P. Barney, R. G. Jungst, D. Ingersoll, Reliability of rechargeable batteries in a photovoltaic power supply system,Journal of Power Sources 80 (1999) 30–38.
[13]Solar photovoltaic modules pm 150.http:-celindia-co-in.preview1.cp247.net/cal/PM150.pdf,2011(accessed 1.11.2011).
[14]R.Chenni, M.Makhlouf, T.Kerbache, A.Bouzid,A detailed modeling method for photovoltaic cells, Energy 32 (2007) 1724–1730.
[15]G.N.Tiwari, Solar energy-Fundamentals,Design, Modeling and Applications, Narosa Publishing House, New Delhi, 2004.
[16]Wind speed in Kolkata,West Bengal 700001,India, http://www.synergyenviron.com/tools/wind_data.asp?loc=Kolkata%2CWest+Bengal%2CIndia,2014 (accessed 12.10.2014).
[17] Telecommunication Engineering Centre (TEC), New Delhi, Planning and maintenance guidelines for SPV power, http://www.tec.gov.in/guidelines.html, 2011 (accessed 23.03.2011).
[18] S.K.Patra, P.P.Datta, "Some insights into solar photovoltaics-solar home lighting system", NABARD Technical Digest 7, http://www.nabard.org/,2009 (accessed 26.06.2009).
[19]F.L. Lansing, Computer modeling of a single stage Lithium Bromide/Water Absorption refrigeration unit, JPL Deep Space Network Progress Report 42-32, DSN Engineering section, 247-257.
[20]W. Wagner, J.R. Cooper, A. Dittmann, J. Kijima, H.J. Kretzschmar, A. Kruse, R. Mares, K. Oguchi, H. Sato, I. Stocker, O. Sifner, Y. Takaishi, I. Tanishita, J. Trubenbach, and T. Willkommen, The IAPWS Industrial Formulation 1997 for the thermodynamic properties of water and steam, J of Engg. for Gas Turbine and Power 122 (2000)150-181.
[21]J. Patek, and J. Klomfar, A computationally effective formulation of thermodynamic properties of LiBr-H_2O solutions from 273 to 500K over full composition range, Int. J. of Refrigeration 29 (2006) 566-578.
[22]M.Prasad, Refrigeration and Air Conditioning, New Age International Publishers.