African University of Science and Technology Abuja
Knowledge is Freedom

Fondation 2iE

EXERGY ANALYSIS OF HYBRID SOLAR PV-DIESEL / BIOFUEL SYSTEM FOR COGENERATION (ELECTRCITY AND COLD)

MEMORY TO OBTAIN A MASTER OF SCIENCES IN THEORETICAL PHYSICS

PRESENTATION

BRUNO SENAKPON DANDOGBESSI

DIRECTOR

DR. YAO AZOUMAH

CO-DIRECTOR

DANIEL YAMEGUEU

MADIEUMBE GAYE

PERIOD FROM 15 OCT 2010 TO 15 JANUARY 2011

THANKS

I thank AUST academic staff for their support particulary the great charismatic Dr BOUBOU Cisse

My gratitude address to Dr. Yao AZOUMAH my supervisor and likewise the head of laboratory SEESL for its moral and technical support

I address my reconnaissance to Daniel YAMEGUEU and Madieumbe GAYE my co-directors in the laboratory SEESL. You guys, we had a rich reflection about my topic

I wish to express my deep gratitude to Prof Yezouma COULIBALY for his entire cooperation

I thank warmly Constante ASSOGBA. My darling ,you have encouraged me through this work. I wish to express my deep gratitude to you in this way

Thank you to everyone in the laboratory particulary Pascal BIEUPOUDE, Henri KOTTIN, Cheik Ethmane

Thank you Mathieu FAGOTAT, my colleague probationer for the atmosphere that reigned among us

I pay tribute to my parents for their financial and moral supports: Fofo, Papa, Fassinouhoue, David, Martin, Jacqueline, maman Jacqueline, Abogo

My thanks address to all my friends especially Vincent MONWANOU, Constant MONWANOU, Benoit TCHANGO, Achille AGBOHOUNGBO

I thank enormously Dr. Guy DEGLA , Dr. Jean Pierre NOUDOGBESSI for their encouragement and perseverance messages

ABSTRACT

In this study, Flexy energy analysis taking exergy analysis and heat recovery into account on performance has been performed. The effects of wasting heat on exhaust gas temperature and cooling engine, is analysed in terms of design paramèters. It was observed that thermal exergy from a wasting heat for Flexy energy might be used to produce cold. In the theoretical study, the achievement of heat recovered is to circulate water through the source of exhaust gas. It was found that the temperature of water increased. Likewise, water passed through solar collectors before reaching the chiller. Thus , as a consequence the temperature of water increased. The important role of solar collectors is to supply the minimum temperature needed by the chiller to operate. Thus, the exergy analysis has been performed with the purpose of calculating the amount of available energy of exhaust gas and cooling engine which used to produce cold via a system of heat recovery. It was concluded that, is possible for Flexy Energy system can be used to produce simultaneously electrcity and cold.

Key Words: Flexy energy , exergy, heat recovery

NOMENCLATURE

PV :Photovoltaic
SESEL: Solar Energy and Saving Energy Laboratory
2iE:International Institute of Water and Environmental Engineering
TURT IEE: Thematic Unit of Research and Teaching Industrial Electrical and Engineering
P: Power
T: Temperature
Ex_e: Electrical exergy
am: ambient
mod: module
S_{cell}: Solar cell
COP: Coefficient of Performance
rev : Reversible
th: Thermal
η_{II} : Second law efficiency
X: exergy for closed system of mass m
X_{ke}:Kinetic exergy
X_{pe}: Potential exergy
Φ: exergy for closed system of unit mass
ΔX: the exergy change for closed system
Ψ: exergy for open system of unit mass
$\Delta\Psi$: the exergy change for open system of unit mass
h_w : enthalpy of water
s_w: water entropy
T_0: ambient temperature
P_0: environmental pressure
h_0: enthalpy of environment
A: area

SUMMARY

PANELS LIST

FIGURE LIST

I INTRODUCTION

I-1 CONTEXT OF STUDY

The use of diesel generator to supply energy has been long used in rural areas. The pressure from environmental protection as the destruction of ozone layer ,the fluctuation of the cost of Diesel , the maintenance,the production of energy for rural areas is solely subjected to the operation of diesel generator. Nevertheless ,the using sun as source of energy ,clean and abundant attracts more and more attention during these past decades. The technical transformation directe or indirecte of solar energy knows the noble advances such as simple PV system and also Hybrid PV- Diesel system with its corollaries. Currently, hybrid PV – Diesel system appears to be the best suited for energy production in areas disconnected from electrical grid because of their geographical position

I-2 PRESENTATION OF LABORATORY : SEESL

The solar energy and energy saving laboratory(SEESL) is located at Kamboinse 15 km from Ouagadougou. It's one of the other laboratories of International Institute of Water and Environmental Engineering (2iE) . SEESL depends on the thematic unit of research and teaching Industrial and Electrical Engineering (TURT IEE). Since its creation, SEESL is led by Dr Yao AZOUMAH

Scientific goal

The laboratory aims to contribute to industrial innovation in the solar power sector for a rational use of electrical /thermal in Africa

The work carried out in Laboratories are focused on some theme

Research Theme 1 : Concentrating Solar Power Plants The focus is put on assessing precisely African solar resource and energy needs to address the lack of reliable data on sunlight ratio in Africa, to better size solar installations and to meet the demand in the countries that are concerned. Because of African climate and economic context, which is quite particular, it is necessary to design and assess cycles of new models of adapted and cheaper solar stations: hybrid solar/biomass stations, combination of existing technologies

Research Theme 2: Bioclimatic habitation and architecture and solar photovoltaic (PV) systems In preparation for the shortage of conventional energy resources, the purpose is to develop, on one hand, concepts for energy and environmental sustainability in Sub Saharan habitations and, on the other hand, tools for an optimal integration of solar PV power into buildings. The second part of our research focuses on large scale power production through hybrid stations PV/generator and the assessment of issues related to the connection of solar system to existing power networks.

Research Theme 3: Optimal design and thermodynamic optimization of solar systems This theme focuses on energy efficiency. It is about developing tools for a better integration of energy processes and/or an optimal design of processes through thermodynamic optimization combined with the use of techniques of multi-scale geometric optimization.

Equipment:

(a)

(d)

(b)

(c)

(a) PV array 2.85 Kwc ; (b) Inverter ; (c) Diesel Generator 11.5 KVA; (d) Local Flexy Energy

Team

2 professors
5 research engineers
4 PhD students
1 Postdoc

I-3 THE OBJECTIVE OF THE STUDY

The goal of the study are firstly to quantize the irreversibilities related at components of prototype hybrid PV-DIESEL and secondly to propose an optimization of the hybrid plant production electricity and cold based on exergy analysis. Indeed, it is to recorver the wasting energy by the generator (Diesel) . We intend recover this energy by appropriate technology which is focused on first and second law of thermodynamic

I-4 METHODOLOGY AND WORK FOCUSES

To attain our goals,four steps will be followed
1)Bibliographic study on hybrid PV-Diesel system and production of cold
2) Optimization thermodynamic study on energetic system
3) Exergy analysis of viewpoint on hybrid PV-Diesel (Flexy – Energy) of production of electrcity and cold simultaneously
4) Propose an optimization of a system focused on exergy analyse

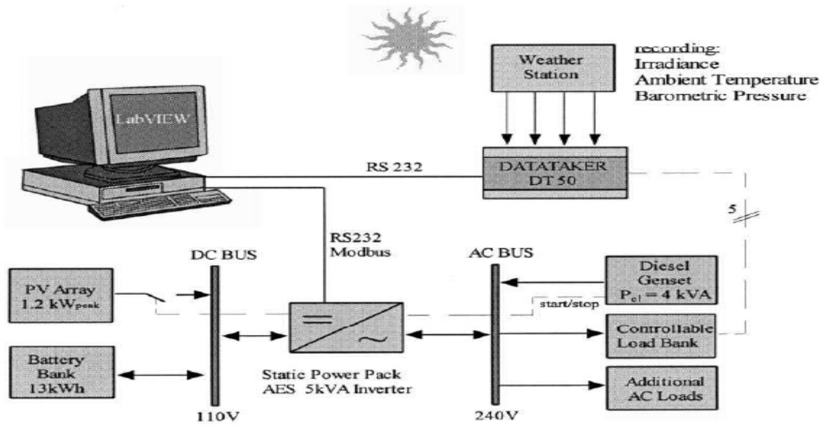
II LITERATURE REVIEW

II-1 INTRODUCTION

Exergy analysis method is employed to detect and to evaluate quantitatively the cause of the thermodynamic imperfection of the process under consideration.This imperfection should be studied in order to understand the improvement of efficiency energy systems with an objective of sustainable development.

To allow a sustainable development of energy essentially in the remote areas ,it's compulsory to stick to exergy analysis hybrid PV-Diesel system

The figure II-1 showns hybrid PV-Diesel system with storage [1]



II -2 PERFORMANCES

II-2-1 PERFORMANCE OF PHOTOVOLTAIC SYSTEM

Photovoltaic module system is constituted of cells associated in several rows.The PV conversion efficiency is theoretical 11% to 13 % [2]

The PV system power output (DC) has approximately a linear relationship to the insulation [3]

$$P_{PV,DC} = \eta_{PV} \text{ x } I_{PV}$$

$P_{PV,DC}$: available power output

η_{PV}: conversion factor

I_{pv}:the insolation impinging on the total area on the PV array

The power output after inversion (AC) is dependent of inventer efficiency

$$P_{PV,AC} = \eta_{inv} \text{ x } P_{PV,DC} \qquad (2)$$

where $P_{PV,AC}$ is available power output (AC) and Ninv is the inversion efficiency

The power output depends only on the module temperature Tmod and the in- plane irradiance G

$$P(G, T_{mod}) = P_{STC} \cdot \frac{G}{G_{STC}} \cdot \eta_{rel}\,(G', T') \qquad (3)$$

P_{STC} is the power standard test condition (STC) of G_{STC} = 1000 W/m and $T_{mod\_ STC}$ =25 C. The instataneous relativr coefficiency , n_{rel} is given by

$$\eta_{rel}\,(G', T') = 1 + k_1\, lnG' + k_2\,(lnG')^2 + T'(k_3 + k_4 lnG' + k_5 (lnG')^2 + k_6\, T'^2 \qquad (4)$$

Where G' and T ' are normalized paramèters to STC values
$G'=G/G_{STC}$; $T'=T/T_{STC}$
and k1 -k6 must be found by fitting model to experimental data measured at one or more test sites. The instataneous relative efficiency depends on the intataneous irradiance and module température T_{mod} .

Under steady state conditions , T_{mod} can be estimated from the ambient température and the irradiance in the following way:

$$T_{mod}= T_{am} + C_T G$$

The coefficient C_T describes how much the PV module is heated by the solar radiation

Electrical energy is not affected by ambient conditions and therefore is equivalent in work. If global irradiance is I, energetic efficiency of the solar cell is Z_{scell} , the instantaneous electrical exergy is then as follows [4]

$$Ex_e = I.Z_{scell}$$

where Z_{scell} is the exergetic efficiency of the solar cell

II-2-2 PERFORMANCE OF DIESEL GENERATOR

The diesel generator model used is proposed by Van Dijk [2]. The fuel consumption of the generator can be presented by a linear equation, which has an offset for the fuel consumption at the rated output power of the generator. The fuel consumption of the diesel generator is presented by fuel consumption (FC) is

$$FC = \alpha(P_{DG} - P_{DG,rated}) + FC_{rated}$$

where FC is the fuel consumption (L/h), P_{DG} the diesel generator operating power (W), $P_{DG,rated}$ the rated power of diesel generator, alpha the fuel consumption efficiency, FC_{rated} the diesel generator fuel consumption at rated power (= 1.55 L/h).

The consumption of 30 KW of generating set is given by in figure II 2

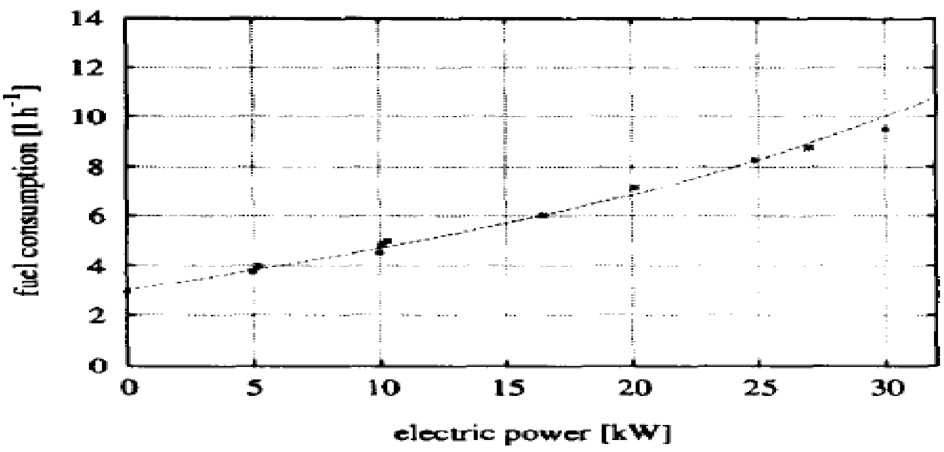


figure II-2: consumption of generating set of 30K

The Diesel generator manufacturers usually recommend that their generators should not be run below certain load, expressed as a percentage of its rated capacity

The optimisation of the hybrid system, using the Farm load profile, shows that the total net present value depends on the minimum Diesel output power allowed. For example, if the manufacturer of the Diesel generator used in the system optimised in Table 5 recommends not to run under 15% of its rated capacity, if run at this capacity, the total cost of the system throughout its life will be higher than if we had built the system preventing the generator running under 30% of its rated capacity. So the optimal minimum generator output power allowed can be higher than the one given by the manufacturer. [5]

As show in fig II 2,the cost of energy produced by the diesel generator is favourable when it operating nearly to its rated power [1]

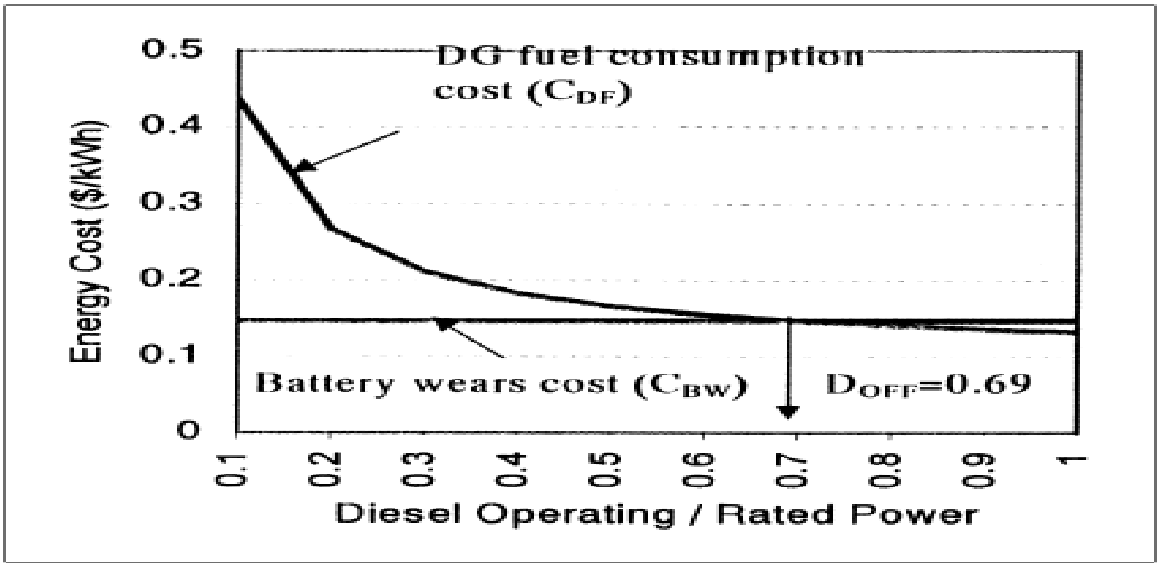


Figure II-3 :DG fuel consumption cost

II-2-3 PERFORMANCE OF INVERTER

The inverter was rated based on the PV array.IT is assumed that the efficiency of inverter is around 90%. There was no operating and maintenance cost estimated. [6]

II-2-4 PERFORMANCE OF SOLAR COLLECTOR

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment, or to a thermal energy storage tank from which can be drawn for use at night /or cloud days

There are basically two types of solar collectors: non- concentrating or stationary and concentrating

Stationary Collectors

Stationary collectors are basically distinguished by their motion.These collectors are permanently fixed in position and do not track the sun .Three type of collectors fall in this category:
1-Flat plate collectors (FPC)
2-Stationary compound parabolic collectors (CPC)
3-Evacuated Tube collectors (ETC)

Concentrating collectors

Energy delivery températures can be increased by decreasing the area from which the heat losses occur.
The collectors fall in this category are:
1-Parabolic Trough Collectors (PTCs)
2- Linear Fresnel Reflector (LFR)
3-Parabolic dish
4-Central receiver [7]

Fig II-4: Helioman3/32 collector

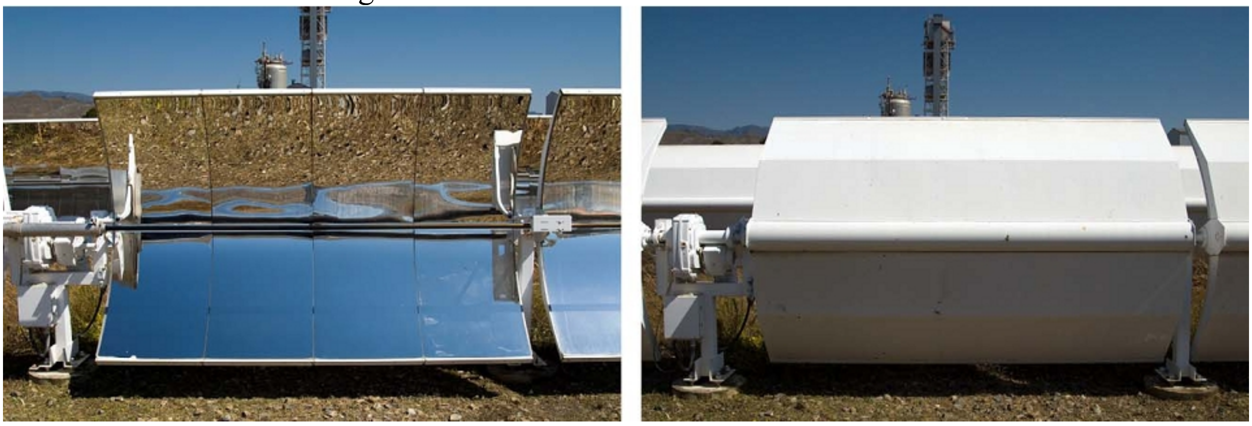


Fig II-5 : Front (Left) and rear (right) views of the acurex 3001 collector

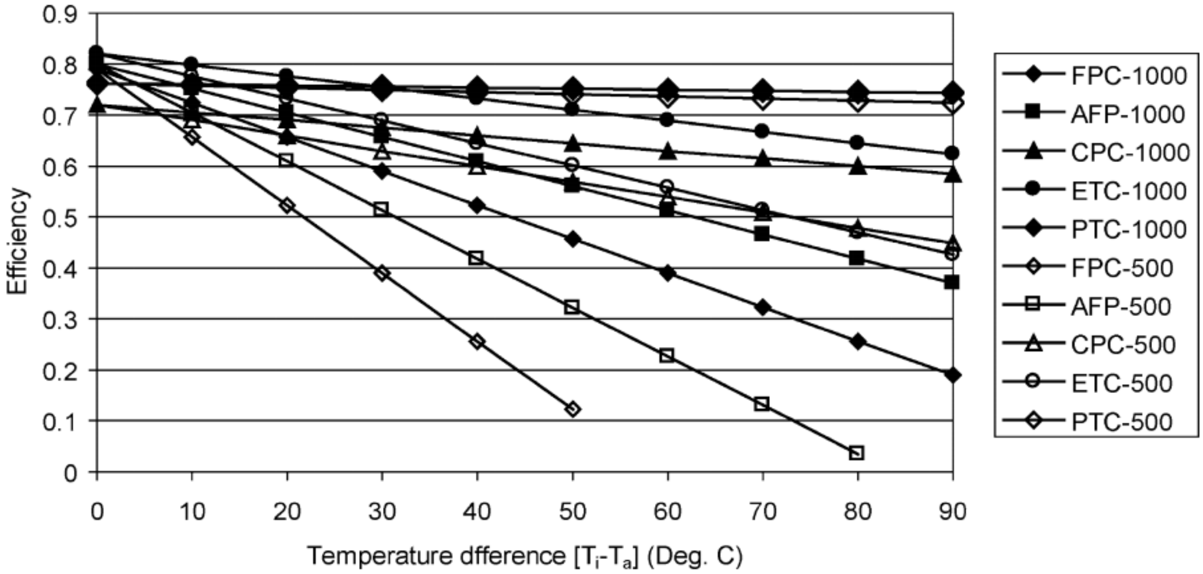


Fig. 20. Comparison of the efficiency of various collectors at two irradiation levels, 500 and 1000 W/m^2.

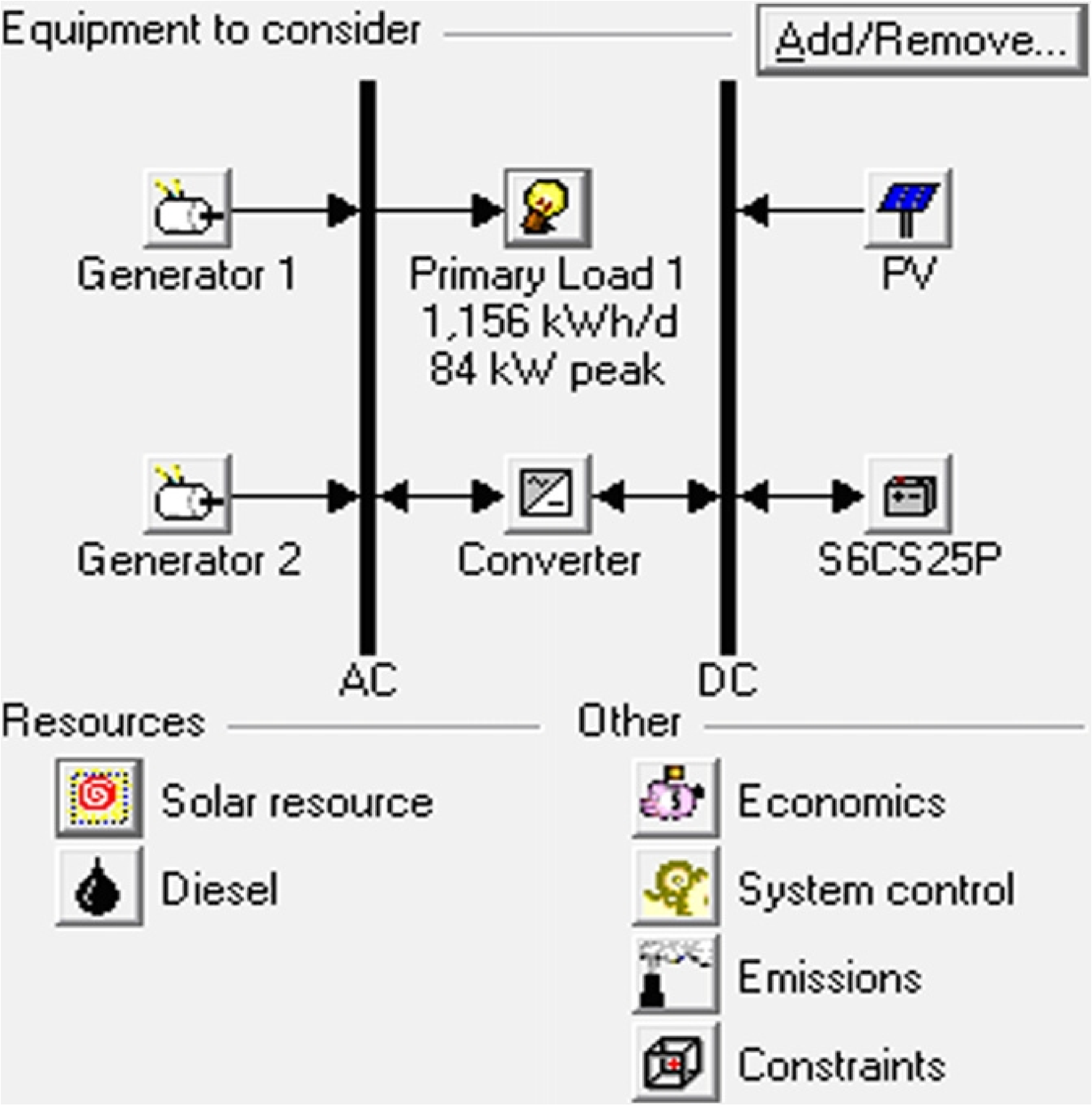
Figure II-6 : Comparaison of the efficiency of various collectors at two irradiation levels

II-2-5 PERFORMANCE OF COOLING SYSTEM

The most common methods for producing cold utilizing heat source are called thermally activated cooling or heat powered cooling in which sorption cooling is dominated . Sorption may contain both absorption and adsorption: absorption is the process in which a substance in one phase is incorporated into another substance of a different phase (e.g. gases being absorbed by a liquid); The process of adsorption concerns separation of a substance from one phase, accompanied by its accumulation or concentration on the surface of another. Besides absorption and adsorption refrigeration, desiccant cooling is a new kind of thermally activated technology; it works on
the principle of incorporating desiccant dehumidification and the cooling unit, and its unique merit is that the sensible and latent heat can be processed separately. [8]

II-2-6 PERFORMANCE OF HYBRID PV-DIESEL SYSTEM

Hybrid PV-DIESEL it's a combinaison of two sources of energy.It's one the most popular system using in remote locations
The use of hybrid PV-DIESEL sytem comes with various advantage. Among them are improved reliability reduced emissions and pollutions ,reduced cost and more efficient use of power [6]
The level of renewable energy penetration in hybrid systems (deployed around the world) is generally in the range of 11- 25% [6].



FigII-7 Configuration of PV-DIESEL Energy system [6]

II-3 CONCLUSION

It's remarkable that hybrid PV-DIESEL system is one of the key to supply energy in remote locations .The increased of energy demand in these areas has caused to reexamine their energy policies and take seriously the wasted heat.

The achievement and maintenance of high performance of any system , in general ,require an understanding and quantification of system losses across the operating period ,which in turn requires the measurement and analysis of system performance , according to the needs of the system and the user [9]

Among the existing analyse of performance,the thermodynamic optimisation has been considered as the starting point of this work. Futhermore ,exergy analysis is considered as the capital assessment of performance.

III THERMODYNAMIC OPTIMISATION

Optimization process is defined as finding a set of values for a vector of design variables so that it leads to an optimum value of an objective or cost function [10]

There are great deal of waste heats been released into environment by Diesel generators and this phenomen lead serious our environment pollutions. Solar is one the abundant and clean source of energy . Aims to Combine Solar collectors with generator is to reheat water which come from generator

In order to recover the waste heats and utilize renewable energy, the cogeneration cycle has been explored for improving overall energy conversion efficiency. Fig III -1 illustrates a cogeneration for using hybrid PV- Diesel system without storage

The system consist of four majors components: Tank of water ,Diesel generator ,sollar collectors ,PV , absorption Chiller ,Inverter

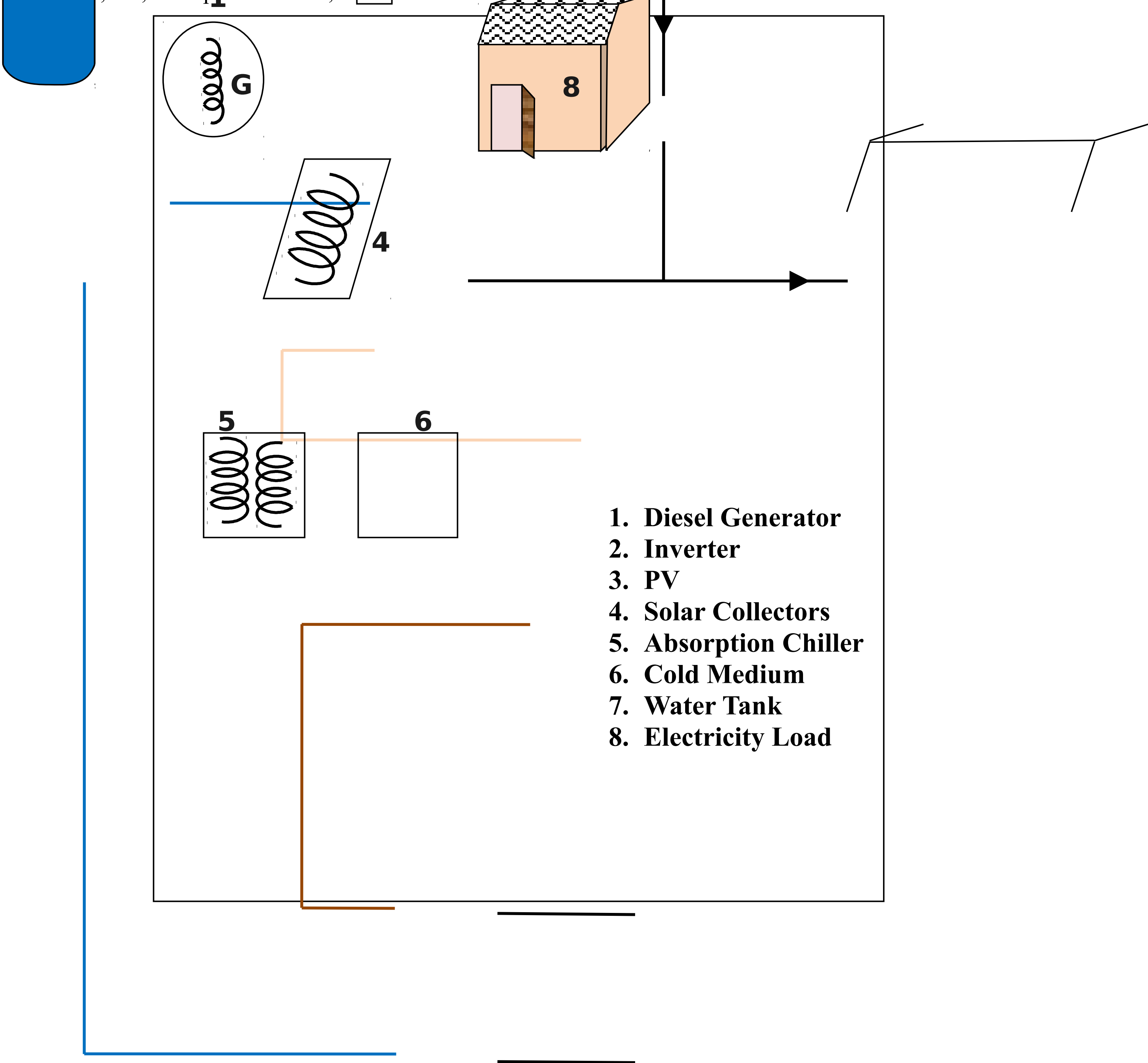


Fig III-1 Cogeneration for using hybrid PV-Diesel system without storage

III 1 DESCRIPTION OF COMPONENTS

III-1-1 SOLAR COLLECTORS

Solar collector is a device in which high temperature and pressure is generated by utilizing heat source such as solar energy and weaste heats. The vapor is expanded through absorption chiller to produce cold .In this work the choice is made on Parabolic trough collector (PTC) .
A PTC is a concentrating solar collector ,which focuses the solar radiation on an absorber pipe by a parabolic mirror.[11]
In order to deliver high temperature with good efficiency a high performance solar collector is required. PTC can effectively produce heat between 50 and 400 C [7]

III-1-2 ABSORPTION CHILLER

The pressure and temperature of stream leaving PTC drop in the absorption chiller. In the absorption chiller, one part of the working fluid leaving the condenser and enter the evaporator.The working fluid enter evaporator at low pressure and temperature. Thus a cooling effect is produced. Finally ,water leaves the chiller for the tank at temperature below to dead state temperature

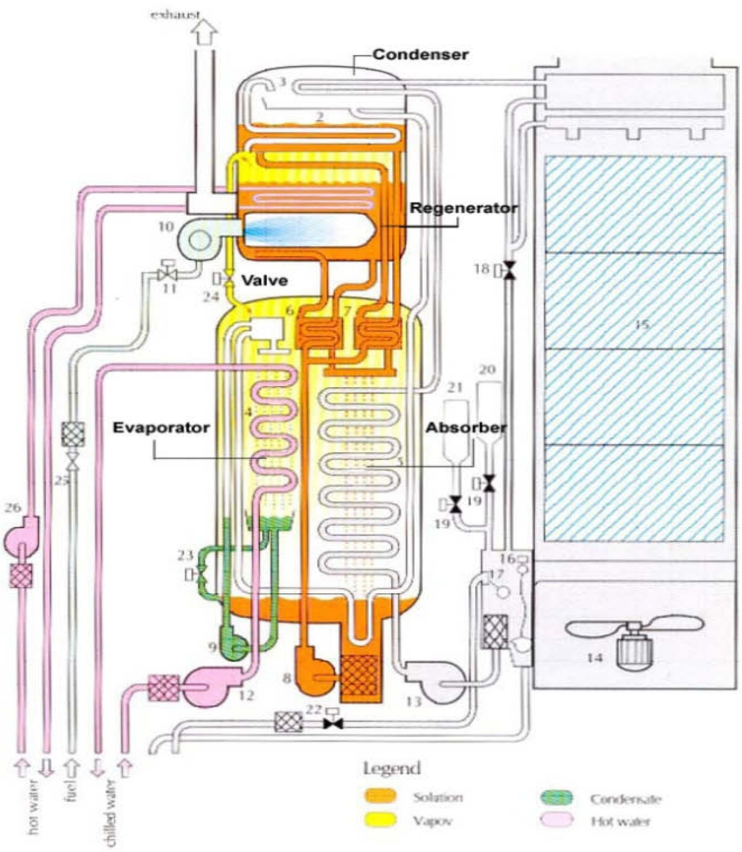


Figure III-2: Absorption chiller in cooling cycle [12]

Another potential solar- powered cooling system is the solar adsorption cooling system. The main difference compared to absorption systems is that two or more adsorbers are necessary in order to provide continuous operation . Adsorption systems allow for somewhat lower driving temperature but have a somewhat lower COP compared to absorption systems unders the same conditions. The use of adsorption cooling technology is preferable for minitype solar – powered cooling systems [13]

III-1-3 PHOTOVOLTAIC

The role of renewable energies , in particulary , solar energy is important . Photovoltaic system have turned into one of the promising ways to handle the electrification of remote villages.The PV was used as base load which produced DC power.The role of inverter is to converte DC loading into AC source. The performance of PV in hybrid PV DIESEL system is the range 11 to 25 %[6]. This configuration does not take account a storage of energy . If PV is insufficient or unvailable to supply a demand , the generator will take over to fill both electrcity and cold

III-1-4 DIESEL GENERATORS

Diesel generators has used in remote areas to supply energy for long time.The performance of diesel is around to 35%, the most of its energy is weasted as heats due to the irreversibilities.In order to increase the performance of diesel and to reduce emissions and pollutions and also reduce dependance in fossil fuel , in this work we will recover heat by circulating water from tank which pass through exhaust heat. Generator will use to supply both power and cold

III-2 EXERGY ANALYSIS

III-2-1 DEFINITION

Exergy is defined as the maximum theoretical work obtainable from the interaction of a system with its environment until the equilibrium state between both is reached and can also be seen as the departure state of one system from that of the reference environment [14]

Exergy is a measure of the maximum useful work that can be done by a system interacting with an environment which is at a constant pressure P_0 and temperature T_0 [4]

PROPERTIES

Exergy like energy ,can be transferred to or from a system in three forms: heat , work and mass flow

Exergy of a system at a specified state depends on the conditions of the environment. Therefore exergy is a thermodynamic property and the value of a property does not change unless the states changes.Exergy si an extensive property. It is important to realize that exergy does not represent the

amount of work that a work producing device will actually deliver upon installation.
Kinectic and potential energies are a form of mechanical energy and thus they can be converted to work entirelyTherefore, the work potential or exergy of kinectic or potential energies of a system is equal to the kinectic or potential energies itself regardless of the temperature and pressure of the environment.

$$X_{ke} = ke = m.(v.v)/2 \quad (KJ/Kg) \quad (5)$$

$$X_{pe} = pe = mg.z \quad (KJ/Kg) \quad (6)$$

where g is the gravitational acceleration, Z is the elevation and V is the velocity of the system relative to a reference level in the environment
In an exergy analysis ,the initial state is specified , and thus it is not a variable.The work output is maximized when the process between two specified states is excuted in a reversible manner. The exergy destruction ,is called Irreversibility. Anything generates entropy destroys exergy.
The irreversibility can be viewed as the wasted work potential or the lost opportunity to do work.

Second- law Efficiency

We define a second law efficiency η_{II} as the ratio of the actual thermal efficiency to the maximum possible (reversible) thermal efficiency under the same conditions

$$\eta_{II} = (\eta_{th} / \eta_{th,rev}) \quad \text{(heat engine)} \quad (7)$$

The second law efficiency can also be expressed as the ratio of the useful work output and the maximum possible(reversible) work output

$$\eta_{II} = (W_u / W_{rev}) \quad \text{(work – producing device)} \quad (8)$$

We can also define a second law efficiency for work consuming noncyclic (such as compressors) and cylic (such refrigerators) devices as the ratio of minimum (reversible) work input to the useful work input:

$$\eta_{II} = (W_{rev} / W_u) \quad \text{(working consuming device)} \quad (10)$$

For cyclic devices such as refrigerators and heat pumps ,it can also be expressed in terms of performance as :

$$\eta_{II} = (COP / COP_{rev}) \quad \text{(refrigerators and heat pumps)} \quad (11)$$

The definition above do not apply to devices that are not intended to produce or consume work. Therefore ,we define the second law efficiency of a system during a process as:

$$\eta_{II} = \text{(Exergy recovered / Exergy supplied)} = 1 - \text{(Exergy destroyed /Exergy supplied)} \quad (12)$$

The second law efficiency is intended to serve as a measure of approximation to reversible operation , and thus its value should range from zero in the worst case to one in the best case

EXERGY CHANGE OF A SYSTEM

The property exergy is the work potential of a system in a speficied environment and represent the maximum amount of useful work that can be obtained as the system is brought to equilibrium with the environment.
The exergy of a system that is equilibrium with its environment is zero.The state of the environment is referred to as the "dead state" from thermodynamic point of view
Exergy for a closed system of mass m in general is

$$X=(U-U_0) + P_0(V-V_0) - T_0(S-S_0) + m\ V.V/2+mgz \quad (13)$$

On a unit mass basis , the closed system exergy

$$\Phi = u-u_0 +P_0(v-v_0) - T_0(s-s_0) + V.V/2 +gz \quad (14)$$

The exergy change of a closed system during a process is the difference between the initial and final exergies of the system

$$\Delta X = X_2 - X_1 = m(\Phi_2-\Phi_1) = (U_2 - U_1) + P_0(V_2-V_1) - T_0(S_2-S_1) +m\ (V_2-V_1)/2 + mg(z_2-z_1) \quad (15)$$

Exergy for open system (flow or stream exergy) is

$$\psi =(h-h_0) - T_0(s-s_0) + (v.v)/2 + gz \quad (16)$$

Then the exergy change of a fluid stream as it undergoes a process from state 1 to 2 becomes

$$\Delta\Psi =(h_2-h_1) - T_0(s_2-s_1) + (V_2-V_1) /2 + g(z_2-z_1) \quad (17)$$

EXERGY BY HEAT TRANSFER ,Q

$$X_{heat} =(1-T_0/T)Q \quad (18)$$

when the temperature T at the location where heat transfer is taking place is not constant ,the exergy transfer is determined by integration to be

$$X_{heat} =\int (1-T_0/T)\delta Q \quad (19)$$

The exergy transfer by heat is zero for adiabatic systems

EXERGY TRANSFER BY WORK ,W

$X_{work} = w - w_{surr}$ (for boundary work) (20)

$X_{work} = w$ (for other forms of work) (21)

$w_{surr} = P_0(V_2 - V_1)$ where P_0 is atmospheric pressure and V_1 and V_2 are the initial and final volumes of system. (22)

EXERGY TRANSFER BY MASS,m

$X_{mass} = m\Psi$ (23)

Exergy flow associated with a fluid stream when the fluid properties are variable can be determined by integration form

$X_{mass} = \int_{Ac}\psi\rho V_n dA_c$ and $X_{mass} = \int\psi\delta m = \int_{\Delta t} X_{mass} dt$ (24)

The exergy transfer by mass X_{mass} is zero for systems that involve no mass flow across their boundaries

The total exergy transfer is zero for isolated systems since they involve no heat ,work or mass transfer

EXERGY BALANCE

-Closed systems

The exergy can be transferred to or from a system by heat , work , and mass transfer .Then the exergy balance for any system undergoing any process can be expressed more explicitly as:

$X_{in} - X_{out} - X_{destroyed} = \Delta X_{system}$ (KJ) (25)

in the rate form

$X_{in} - X_{out} - X_{destroyed} = dX_{system}/dt$ (KW) (26)

$X_{destroyed} = T_0 S_{gen}$ (27)

-Control volumes

$X_{heat} - X_{work} + X_{mass,in} - X_{mass,out} - X_{destroyed} = (X_2 - X_1)_{cv}$ (28)

or

$$\Sigma(1-T_0/T_k)Q_k - [w- P_0(V_2-V_1)]+\Sigma_{in}m\Psi-\Sigma_{out}m\Psi - X_{destroyed} = (X_2-X_1)_{cv} \quad (29)$$

It can be expressed in the rate form as

$$\Sigma(1-T_0/T_k)Q_k-[w-P_0(dV/dt)_{cv}]+\Sigma_{in}m\Psi-\Sigma_{out}m\Psi-X_{destroyed} = (dX_{cv}/dt) \quad (30)$$

-FOR STEADY FLOW

$$\Sigma(1-T_0/T_k)Q_k-w+\Sigma_{in}m\Psi-\Sigma_{out}m\Psi-X_{destroyed} = 0 \qquad [15] \quad (31)$$

III-2-2 APPLICATION

III-2-2-1 DIESEL GENERATORS

Think: T_2 should be greater than T_1 of water and a pipe is not adiabatic. T_1 and T_2 are temperatures inlet and outlet of water respectively

Assumption: steady state, potential and kinectic energies are negligibles ,

energy= exergy + anergy

$$E_D= (\Sigma_i m_i e_i)_{in}-(\Sigma_i m_i e_i)_{out} +\Sigma_j(1-T_0/T_j)Q_j - W \quad (32)$$

where W is mechanical exergy and $E_D = T_0 S_{gen}$ is exergy destroyed

E_i is the total exergy of each chemical species i .

$e=\Sigma_i m_i e_i$ is sum of the physical and chemical exergies

Physical exergy

$$e_i=(h-h_0)_i- T_0(s-s_0)_i \text{ ; } h-h_0=\int(C_p)_i dT \text{ with T from } T_0 \rightarrow T \text{ and} \quad (33)$$

$$s-s_0=\int[(C_p)_i / T]dT \quad (34)$$

Chemical exergy

$$e_i=-RT_0\ln[(x_iP_i)/P_0] \quad (35)$$

with x_i is molar fraction of the gas i

for water

$$\psi=C (T-T_0-T_0\ln(T/T_0)) \quad (36)$$

III-2-2-2 SOLAR COLLECTORS

The instantaneous exergy efficiency of the solar collector can be defined as the ratio of the increased water exergy to the exergy of the solar radiation . In other words, it is a ratio of the useful exergy delivered to the exergy absorbed by the solar collector

$$\eta_{II}=(m\Delta\Psi)/X_{scol} \quad (37)$$

with

$$\Delta\Psi=m[(h_{w,2} - h_{w,1}) - T_0(s_{w,2}-s_{w,1})] \quad (38)$$

and

$$X_{scol}=A\theta_{srad,max}\, I_T \quad (39)$$

I_T irradiance total
$\theta_{srad,max}$ the maximum efficiency ratio or exergy to energy ratio for radiation

$$\theta_{srad,max}= 1-(T_0/T) \quad \text{(Jeter)} \quad (40)$$

III-2-2-3 PHOTOVOLTAIC

Electrical energy is not affected by ambient conditions and therefore is equivalent in work. If global irradiance is I, energetic efficiency of the solar cell is η_{scell} , the instantaneous electrical exergy is then as follows

$$X = \eta_{scell} I =\varepsilon_{scell} I \quad (41)$$

Where ε_{scell} is the exergetic efficiency of solar cell

III-2-2-4 ABSORPTION CHILLER

Each component of the absorption system can be treated as a control volume with inlet and outlet stream ,heat transfer and work interactions.The exergy of a fluid stream can be defined as:

$$\Psi=(h-h_0) - T_0(s-s_0) \quad (42)$$

The availability loss in each component is calculated as: [16]

$$\Delta\Psi=\Sigma m_i\Psi_i – \Sigma m_0\Psi_0 – [\Sigma Q(1-T_o/T)_i – \Sigma Q(1-T_o/T)_o] +\Sigma W \quad (43)$$

where ΔΨ is the lost exergy or irreversibility that occurred in the process. The first two terms of the right hand side of Eq.(43) are the exergy of the inlet and outlet streams of the control volume. The third and fourth terms are the exergy associated with the heat transferred from the source maintained at a temperature T. The last term is the exergy of mechanical work added to the control volume. This term is negligible for absorption systems as the solution pump has very low power requirements

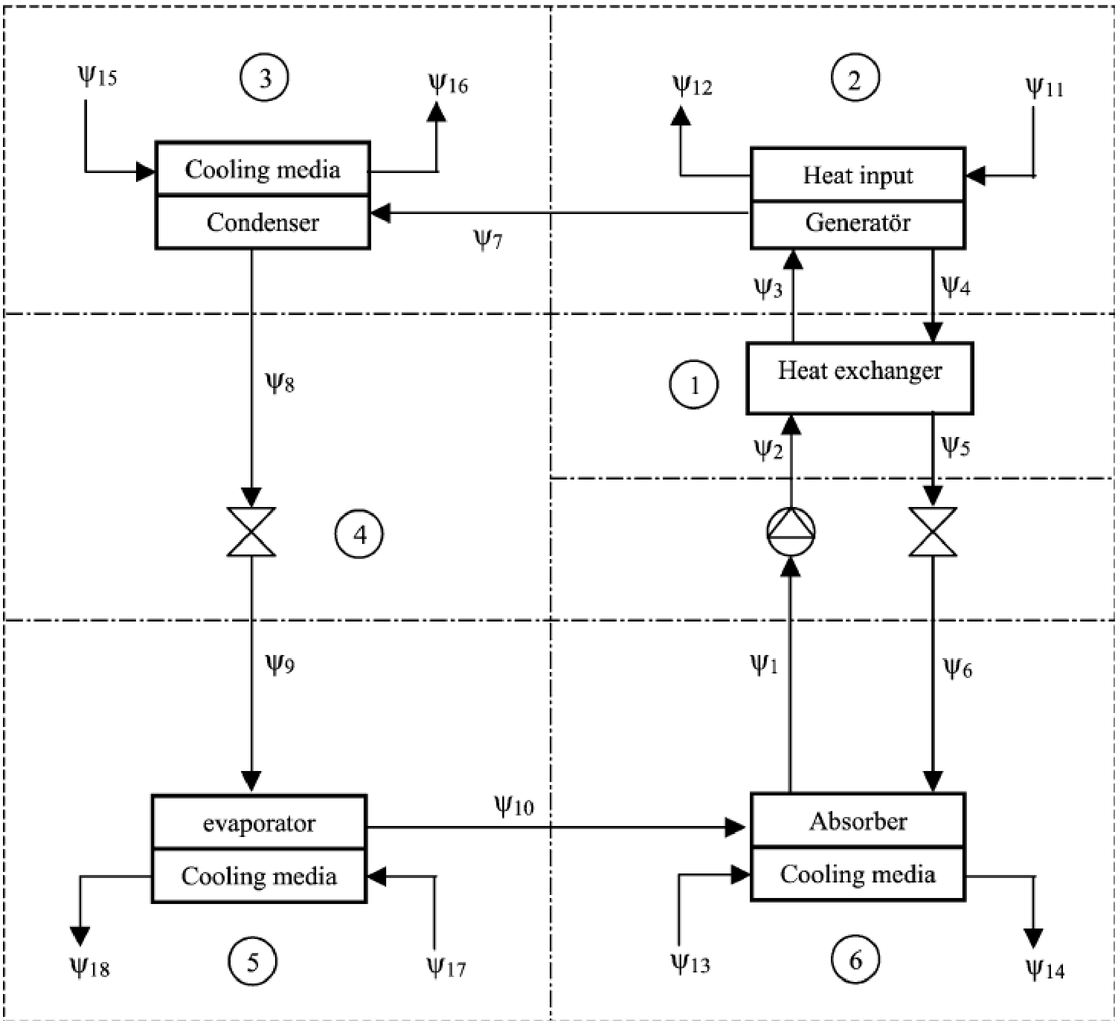


Fig III-3: Availability flow balance of the absorption system [16]

The total exergy loss of absorption system is the sum of exergy loss in each component and can be written as :

$$\Delta\Psi_T = \Delta\Psi_1 + \Delta\Psi_2 + \Delta\Psi_3 + \Delta\Psi_4 + \Delta\Psi_5 + \Delta\Psi_6 \quad (44)$$

The exergy efficiency of the absorption system for cooling is the ratio of the chilled water exergy at the evaporator to the exergy of the heat source at the generator

$$\eta_{II} = m_{17}(\Psi_{17} - \Psi_{18}) / m_{11}(\Psi_{11} - \Psi_{12}) \quad (45)$$

IV- RESULT

IV-1 PV

Exergy analysis on PV of Flexy Energy with LOAD of 7.2 KW

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P
T_{01}	26.5	28.7	31.3	31.1	33.8	34.9	35.6	35.4	35.3	35.3	36	37.1	38.4	36.4	36.6
T_{02}	29.1	31.2	32.1	32.4	34.3	36	37	39	38	37	36.3	39	37.9	35.7	35.6
X_1	4654.8	6970.75	9133.8	11081.56	12553.48	13490.67	14294.43	14479.5	14194.5	12567	11995.05	10785	8770.3	6458.4	4462.05
X_2	6718.65	8831.85	10878.45	12472.65	13743.9	14125.65	14324.55	14017.65	13366.05	12194.25	10971.15	9087.9	6758.7	4697.55	2986.35
E_1	685	1017	1343	1631	1837	1966	2077	2107	2059	1962	1758	1586	1306	951	637
E_2	984	1296	1603	1830	2000	2066	2077	2041	1933	1791	1618	1349	996	681	415
η_1 %	14.71	14.58	14.7	14.72	14.63	14.57	14.53	14.55	14.51	15.61	14.65	14.7	14.89	14.72	14.27
η_2 %	14.64	14.67	14.73	14.67	14.55	14.62	14.49	14.56	14.46	14.68	14.74	14.84	14.74	14.49	13.89

Exergy analysis on PV of Flexy Energy with LOAD of 5.4 kw

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P
T_{01}	300.25	302.85	304.55	305.45	306.65	308.85	308.75	310.35	309.75	310.65	311.65	310.75	311.95	311.75	312.75
T_{02}	302.75	304.35	304.55	306.85	309.35	309.25	311.35		309.85	311.85	311.85	312.15	311.75	313.15	313.25
X_1	4066.22	4517.83	5842.88	7302.45	12688.48	17196.65	18119.72	9392.77	7783.4	8218.24	8636.02	7262.11	6371.87	5382.74	6471.57
X_2	4450.73	6195.69	6548.06	12184.55	14980.75	15266.2	10514.69	8788.56	8236.17	10631.15	6355.22	10999.47	5466.58	6236.41	7644.55
E_1	563	610	772	884	1686	2285	2380	1257	1000	1114	1118	988	897	690	733
E_2	605	801	903	1626	1966	2117	1596	1333	1104	1462	852	1400	719	770	457
η_1 %	13.84	13.50	13.21	12.10	13.28	13.28	13.13	13.38	12.85	13.55	12.94	13.60	14.07	12.82	11.32
η_2	13.59	12.92	13.79	13.34	13.12	13.86	15.17	15.16	13.40	13.75	13.40	12.72	13.15	12.34	5.98

%															

Exergy analysis on PV of Flexy Energy with LOAD of 3.6 Kw

	A	B	C	D	E	F	G
T_{01}	297.75	305.75	310.35	311.55	315.05	314.95	314.55
T_{02}	301.85	307.55	311.55	313.45	314.65	313.75	314.15
X_1	4689.97	9551.44	13300.83	15578.64	14496.49	12401.83	8681.89
X_2	6937.51	11511.80	14371.26	15087.29	14380.18	11214.30	7173.96
E_1	33	161	296	174	14	169	187
E_2	50	244	121	229	177	146	178
η_1 %	0.703	1.68	2.22	1.12	0.1	1.36	2.15
η_2 %	0.72	2.11	0.84	1.51	1.23	1.30	2.48

All data used to this calculation are produced by “ FLEXY ENERGY “ system and are collected in March 2010 according to different load which is constant. 15 modules PV were stacked together, since the area of each module would be 1.179186 square metre, the total modules resulted in an area is 17.68779 square metre. It should be highlighted that PV array would only generate electricity at day time from 8 a.m to 4.30 p.m. The output from PV would be 0 W at night

Conclusion

The irreversibility ie exergy destroyed is high when the load is low.

IV-2 DIESEL GENERATOR

Chemical Exergy is our input exergy of diesel generator

$$E_{chim}=\Delta H_f - T_x\Delta S_f + Q \qquad (46)$$

Q is contribution of element, T_x is temperature of environment where exergy is zero usually 288.15 K. ΔH_f and ΔS_f are respectively enthalpy standard of formation and entropy standard of formation.

$$Q=410034x +118580y +1875z \text{ of } C_xH_yO_z \qquad (47)$$

Diesel is not a pure substance ,it's a mixture of hydrocarbon including from 8 to 20 carbon atoms

	A	B	C	D	E	F	G	H	I	J	K	L	M	N

Formula	H_f J/mol	G_f J/mol	P mol	Teb	V mola Tb	C	H	O	S_f	H_f - TxS_f	Celem	Exergy J/mol	Exergy J/g	Exergy J/l
C8 H18	-208412	16399	114.232	398.8	0.1869	8	18	0	-754.018	8858	5414712	54235704 7479	47479	29018568
C10 H22	-249617	33215	142.286	447.3	0.1949	10	22	0	-948.625	23729	6709100	6732829	47319	34542918
C10 H18	-182266	73417	138.254	460.4	0.1589	10	18	0	-857.565	64841	6234780	6299621	45566	39637211
C15 H32	-352694	75216	212.421	543.8	0.3688	15	32	0	-1435.216	60864	9945070	10005934	47104	27133263
C20 H42	-455687	117300	282.556	617.0	0.5138	20	42	0	-1921.808	98082	13181040	13279122	46996	25845427
C20 H40	-394945	153862	280.540	625.0	0.5100	20	40	0	-1840.708	135455	12943880	13079335	46622	25645755

Average exergy from C8 to C20 is 46848 J/g
density of gazoil is 832g/l
Chemical Exergy by unity of volum is 38977229 J/l which is input exergy
ASSUMPTION

1. 30% of chemical exergy is transformed to electrical exergy
2. 55% is converted to thermal exergy
3. 15% is wasted which is not possible to recover

In order to recover some amount of thermal exergy, we propose to circulate water with a rate m where T_1 and T_2 are temperatures of water inlet outlet respectively in themal source.

$\Delta\Psi = h_2 - h_1 - T_0(s_2 - s_1)$ is thermal exergy of water by unity of mass (48)

$$\Delta\Psi = C[T_2 - T_1 - T_0 \ln(T_2/T_1)] \quad (49)$$

$$E_X = m\Delta\Psi = mC[T_2 - T_1 - T_0 \ln(T_2/T_1)] \quad (50)$$

$T_2 = 353.15$ k
$T_1 = 323.15$K
$T_0 = 303.15$ K
$C = 4186$ J/kg.K
$m = 0.62$ kg/s
$E_X = 8.012$ kw

IV-3 SOLAR COLLECTORS

T_3 is the temperature of water after crossing the solar collectors.

$$\psi_2 = C\,[T_2 - T_0 - T_0 \ln(T_2/T_0)] \quad (51)$$

$$\psi_3 = C[T_3 - T_0 - T_0 \ln(T_3/T_0)] \text{ where } C = 4186 \text{ J/kg.k and } T_3 = 363.15\text{k} \quad (52)$$

$$E_{xscol} = IA(1 - T_0/T) \leftrightarrow A = E_{xscol}/I(1 - T_0/T) \quad (53)$$

Where $I = 660$ W/m.m
Then $A = 10.60$ m.m which is total area of solar collectors

V RECOMMENDATION

In order to avoid rust of engine parts and likewise other consequences, it should perferable to use ethyleneglycol and to consider it at the time of the exergy analysis.

VI CONCLUSION

The recovery of wasting energy to supply cooling is very interesting. In addition, exergy analysis allows to optimise the performance of system. It's also an important asset to calculate the dimensions. Nevertheless the technical and economic study on the air conditioning is going further information on the cost of achievement. The solar collectors system is used to supply a minimum temperature for the chillers. These chillers use the fluid refrigerating which do not own any impact on the environment. It was clear that hybrid solar PV-Diesel system is capable to produce both electrcity and cold by simple recovery energy in cooling the engine and exhaust gas. It is important to continue to do research on the exergy analysis, it able to identify all the points of irreversibility and specially finding a solution of recovery energy in order to increase the efficiency

References

[1] **B. Wicherta, M. Dymondb.** Development of a test facility for photovoltaic-diesel hybrid energy systems. *Renewable Energy* . 2001, Vol. 22, 311-319.

[2]**S.M. Shaahid, I. El-Amin.** Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery. *Renewable and Sustainable Energy Reviews.* 2009, Vol. 13, 625–633.

[3] **Christopher W. Ajan, S. Shahnawaz Ahmed.** O n the policy of photovoltaic and diesel generation mix for an. *Solar Energy.* 2003, Vol. 74, 453–467.

[4] A. Hepbasli / A key review on exergetic analysis and assessment of renewable energy resources for a sustainable future. Renewable and Sustainable Energy Reviews 12 (2008) 593–661]

[5] Rodolfo Dufo-Lopez, Jose L. Bernal Agustin.Design and Control Strategies of PV- DIESEL System using genetic algorithms .Solar Energy 79 (2005) 33-46

[6] K. Y. Lau, M.F.M. Yousof, S.N.M. Arshad, M. Anwari, A.H.M. Yatim. Performance analysis of hybrid photovoltaic/ diesel energy system under Malaysian conditions

[7] Soteris A. Kalogirou. Solar thermal collectors and applications. Progress in Energy and Combustion science 30 (2004) 231 – 295

[8] J. Deng a, b, R.Z. Wang a, *, G.Y. Han b A review of thermally activated cooling technologies for combined cooling, heating and power systems .Progress in Energy and Combustion science xxx (2010) 1-32

[9] Luis Arribas, Luis Cano, Ignacio Cruz, Montserra Mata, Ermen Llobet. PV-Wind hybridsystem performance: A new approach and a case study. Renewable Energy 35 (2010) 128-137

[10] M. Pouraghaie, K. Atashkari, S.M. Besarati, N. Nariman- Zadeh. Thermodynamic performance optimization of a combined power/cooling cycle. Energy Conversion and Management 51 (2010) 204-211

[11] Clemens Pollerberg, Ahmed Hamza H. Ali, Christian Dotsch. Solar driven steam jet ejector chiller . Applied Thermal Engineering 29 (2009) 1245-1252

[12] Ming Qu, Hongxi Yin, David H. Archer. A solar thermal cooling and heating system for a building: Experimental and model based performance analysis and design 84 (2010) 166-182

[13] X. Q. Zhai, R. Z. Wang. A review for absorbtion and adsorbtion solar cooling system in China. Renewable and Sustainable Energy Reviews 13 (2009) 1523-1531

[14] Herena Torio, Adriana Angelotti, Dietrich Schmidt. Exergy analysis of renewable energy- based climatisation systems for buildings: A critical view. Energy and Buildings 41 (2009) 248-271

[15] Yunus A. Cengel. Micheal A. Boles . THERMODYNAMICS An Engineering Approach Sixth Edition (SI Units)

[16] Arzu Sencan, Kemal A. Yakut, Soteris Kalogirou . Exergy analysis of lithium bromide/water absorption systems. Renewable Energy 30 (2005) 645- 657