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OPTIMIZATION OF SECOND LAW BASED EXPONENTIAL MODEL TO ASSESS THE EXECUTION OF PV ARRAY

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Abstract

The use of photovoltaic (PV) Array to produce energy has increased in the last few decades and keeps growing as their manufacturing cost decreases and as the world becomes more concerned about energy use. Awareness is required so that environmental resources can be used for safe and clean energy production. Study is focused to evaluate the sustainability of electricity generation through renewal resources and evaluation is based upon the Energy and Exergy analysis through an exponential parametric model with the help of operating and reference parameters. It is found that Energy efficiency is greater than electrical efficiency and the exergy efficiency. The exergy productivity and electrical effectiveness expand at first and afterward subsequent to achieving the sun based radiation power of about G= 300 W/m^2, they decrease linearly.

Keywords: PV, energy efficiency, radiation, exergy balance, electrical efficiency.

1. INTRODUCTION

The energy utilization on the planet especially in the industrialized nations has been developing at disturbing rate. Fossil energizes which today meet real part of the vitality interest are being drained rapidly. World has begun coming up short on oil and it is evaluated that 80% of the world's supply will be expended in our lifetimes. Coal supplies may seem, by all accounts, to be substantial however even this stock may not last more than a couple of decades. More over the contamination peril emerging out of fossil fuel smouldering is turned out to be entirely critical as of late. Atomic force has proposed various issues and atomic combination is still a theoretical innovation. In this way we are compelled to search for offbeat vitality sources, for example, geothermal sea tides, wind and sun. It is likewise trusted that these option energy sources will have the capacity to meet impressive part of the energy request. Different Sorts of unpredictable power sources are, for example, geothermal sea tides, wind and sun. All unusual energy sources have geological constraints however Solar energy has less land confinement when contrasted with other unpredictable energy sources on the grounds that sun powered energy is accessible over the whole globe and just the extent of the gatherer field should be expanded to give the same measure of warmth or power [10]. It is hopefully evaluated that half of the force to be reckoned with necessities amidst 21st century will come just from sunlight based energy. Enough walks have been made amid most recent two decades to build up the immediate energy change frameworks to expand the plant effectiveness 60% to 70% by maintaining a strategic distance from the transformation of thermal energy into mechanical energy.

2. EXERGY AND ENERGY ANALYSIS-

Exergy has the trademark that it is monitored just when all procedures happening in a framework and the earth are reversible. The exergy exchange connected with warmth exchange, notwithstanding, relies on upon the temperature at which it happens in connection to the temperature of nature [3]. Energy investigation is the customary technique for surveying the way vitality is utilized as a part of an operation including the physical or substance handling of materials and the exchange and/or transformation of energy. The idea of exergy depends on both the main law of thermodynamics and the second law of thermodynamics. Exergy investigation obviously shows the areas of energy corruption in a procedure and can in this manner lead to enhanced operation or innovation. Exergy investigation can likewise evaluate the nature of warmth in a waste stream. A principle point of exergy investigation is to recognize significant (exergy) efficiencies and the causes and genuine extents of exergy misfortunes.The energy efficiency η = Energy output in product/Energy input = 1 − [Energy loss/Energy input]
The exergy efficiency ψ = Exergy output in product/Exergy input = 1 − [Exergy loss/Exergy input]
= 1 − [(Exergy waste emission + Exergy destruction)/Exergy input]

3-PARAMETRIC MODEL AND ANALYSIS-

The conduct of photovoltaic (PV) Array can be displayed with an identical circuit appeared. In spite of the fact that this model is broadly utilized and acknowledged as a part of the re-enactment and testing of photovoltaic modules for exactness. At the point when R_{sh} is vast the model can be understood effortlessly, yet the precision is not exactly the greater model. So because of precision parameter model is constantly favoured on the little parameter model. Application of Kirchhoff's Current Law on the equivalent circuit results in the current flowing to the load $I = I_{ph} - I_D - I_{sh}$ if the diode current and the current through the shunt resistance are expanded, Equation is obtained [24].

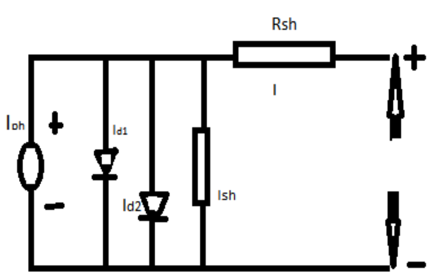

Fig. 1- Equivalent circuit model

$$I = I_{ph} - I_0\left[\exp\left(\frac{(V+IR_s)}{a}\right)-1\right]-\frac{(V+IR_s)}{R_{sh}} \quad (1)$$

Ideality factor $$a = \frac{N_s n_1 k T_{cell}}{q} \quad (2)$$

Application of Kirchhoff's Current Law on the equivalent circuit results in the current flowing to the load $I = I_L - I_{D1} - I_{D2} - I_{sh}$ (3)

If the diode current and the current through the shunt resistance (I_{D1}, I_{D2} and I_{sh}, respectively) are expanded, Equation is obtained [24].

$$I = I_{ph} - I_{s1}\left[\exp\left(\frac{N_s n_1 (V+IR_s)}{a}\right)-1\right] - I_{s2}\left[\exp\left(\frac{(V+IR_s)}{a}\right)-1\right]-\frac{(V+IR_s)}{R_{sh}} \quad (4)$$

The parameters (I_{ph}, I_{s1},I_{s2}, R_s, R_{sh} and a) vary with temperature and irradiance and depend on manufacturing spread. R_{sh} is infinite; model is reduce. In this case,

$$I = I_{ph} - I_0 \left[\exp\left(\frac{(V + IR_s)}{a} \right) - 1 \right] \quad (5)$$

An alternate equation for calculating a_{ref} is presented by Duffie and Beckman (1991) [12].

$$a_{ref} = \frac{\beta_{Voc} T_{cell,ref} - V_{OC,ref} + \varepsilon N_s}{\frac{\alpha_{ISC} T_{cell,ref}}{I_{ph,ref}} - 3}$$

For short circuit current: $I = I_{sc,ref}$, $V = 0$

$$I_{sc,ref} = I_{ph,ref} - I_{0,ref}\left[\exp\left(\frac{I_{sc,ref} R_{s,ref}}{a_{ref}}\right) - 1\right] - \frac{I_{sc,ref} R_{s,ref}}{R_{sh,ref}}, \quad (6)$$

For open circuit voltage: $I = 0$, $V = V_{oc,ref}$

$$0 = I_{ph,ref} - I_{0,ref}\left[\exp\left(\frac{V_{oc,ref}}{a_{ref}}\right) - 1\right] - \frac{V_{oc,ref}}{R_{sh,ref}},$$

At the maximum power point: $I = I_{mp,ref}$, $V = V_{mp,ref}$

$$I_{mp,ref} = I_{ph,ref} - I_{0,ref}\left[\exp\left(\frac{V_{mp,ref} + I_{mp,ref} R_{s,ref}}{a_{ref}}\right) - 1\right] - \frac{V_{mp,ref} + I_{mp,ref} R_{s,ref}}{R_{sh,ref}}, \quad (7)$$

The derivative with respect to power at the maximum power point is zero.

$$\left[\frac{dP}{dV}\right]_{mp} = \left[\frac{d(IV)}{dV}\right]_{mp} = I_{mp} - V_{mp}\left(\frac{dI}{dV}\right)_{mp} = 0$$

The derivative of current with respect to voltage is

$$\frac{dI}{dV} = -I_o \frac{d}{dV}\left(\exp^{\frac{V+IR_s}{a}} - 1\right) - \left[\frac{1}{R_{sh}} + \frac{d}{dV}\left(\frac{IR_s}{R_{sh}}\right)\right]$$

$$\frac{d}{dV}\left(\exp^{\frac{V+IR_s}{a}} - 1\right) = \frac{d}{dV}\left(\exp^{\frac{V}{a}} \exp^{\frac{IR_s}{a}} - 1\right) = \exp^{\frac{V}{a}} \exp^{\frac{IR_s}{a}} \frac{R_s}{a}\frac{dI}{dV} + \exp^{\frac{IR_s}{a}} \exp^{\frac{V}{a}} \frac{1}{a}$$

$$\frac{dI}{dV}\left[1 + \frac{I_o \exp^{\frac{V+IR_s}{a}}}{a} R_s + \frac{R_s}{R_{sh}}\right] = \frac{I_o \exp^{\frac{V+IR_s}{a}}}{a} - \frac{1}{R_{sh}}$$

Where $(dI/dV)_{mp}$ is given by

$$\left[\frac{dI}{dV}\right]_{mp} = \frac{-\left(\frac{I_o}{a}\right)\exp^{\frac{V_{mp}+I_{mp}R_s}{a}} - \frac{1}{R_{sh}}}{1 + \left(\frac{I_o R_s}{a}\right)\exp^{\frac{V_{mp}+I_{mp}R_s}{a}} + \frac{R_s}{R_{sh}}} \quad (9)$$

At short circuit current-

$$\frac{dI_{sc}}{dV} - -\frac{1}{R_{sh,ref}}$$

The cell temperature used for this purpose is not critical since values of T_{cell} ranging from 1 to 10 K above or below $T_{cell,ref}$ provides essentially the same result. To calculate the model parameters at new climatic and operating conditions (G_{new} , $T_{cell,new}$) a set of equations is used such as follows [21]. The reference conditions are ($T_{cell,ref}$ =25^{0}C, G_{ref} = 1000W/m^2). In order to calculate the model parameters at new climatic and operating conditions $T_{cell.}$ With this expression. So solar array temperature.

$$T_{cell} = \frac{T_{amb} + \left(\frac{G}{G_{ref}}\right)\left(\frac{U_{L,NOCT}}{U_L}\right)\left(T_{cell,NOCT} - T_{amb,NOCT}\right)\left[1 - \frac{\eta_{el,ref}\left(1+\lambda_{ref}T_{cell,ref}\right)}{(\tau\alpha)}\right]}{1 - \frac{\lambda_{ref}\eta_{el,ref}}{(\tau\alpha)}\left(\frac{G}{G_{ref}}\right)\left(\frac{U_{L,NOCT}}{U_L}\right)\left(T_{cell,NOCT} - T_{amb,NOCT}\right)} \quad (10)$$

The ideality factor parameter (a) depends only on cell temperature, but not on irradiance level. Ideality factor is the linear function of the solar cell temperature.

$$\frac{a}{a_{ref}} = \frac{T_{cell}}{T_{cell,ref}}$$

E_g exhibits a small temperature dependence for silicon, $E_{g,T_{cell,ref}}$ 1.121 eV for silicon cells.

$$\frac{E_g}{E_{g,T_{cell,ref}}} = 1 - .0002677(T_{cell} - T_{cell,ref}) \quad (11)$$

Messenger and Ventre [20] present an equation from diode theory for the diode reverse saturation current I_o. The ratio of their equation at the new operating temperature to that at the reference temperature yields:

$$\frac{I_o}{I_{o,ref}} = \left(\frac{T_{cell}}{T_{cell,ref}}\right)^3 \exp\left[\frac{1}{k}\left\{\left(\frac{E_g}{T}\right)_{T_{cell,ref}} - \left(\frac{E_g}{T}\right)_{T_{cell}}\right\}\right]$$

The photo-generated current $I_{ph,}$ $I_{ph} = \left(\frac{G}{G_{ref}}\right)\left[I_{ph,ref} + \alpha\left(T_{cell} - T_{cell,ref}\right)\right]$ (12)

voltage difference & current difference is given by [21]

$$\Delta I = \left(\frac{G}{G_{ref}} - 1\right)I_{sc,ref} + \alpha\left(\frac{G}{G_{ref}}\right)\left(T_{cell} - T_{cell,ref}\right)$$

$\Delta V = \beta\Delta T - R_s\Delta I$ The maximum energy efficiency of a PV system is given by [8].

$$\eta_{en} = \frac{E_{el,the}}{I_t A_c} = \frac{V_{oc}I_{sc}}{I_t A_c}$$

The energy efficiency of a PV system at maximum power is given by [8].

$\eta_{el} = \frac{E_{el,act}}{A_c I_t} = \frac{V_{mp} I_{mp}}{A_c I_t}$ The electrical efficiency of a PV array can also be defined in terms of fill factor (FF) as follows by [8],

$$\eta_{el} = \frac{FF \times V_{oc} I_{sc}}{I_t A_c}$$

The general form of exergy balance equation for a control volume is written as

$$\sum EX_{in} - \sum EX_{out} = \sum EX_{dest}$$

The outlet exergy for a PV array $\sum EX_{out} = \sum EX_{th} + \sum EX_{el}$ (13)

Where $Ex_{th.}$ and $Ex_{el.}$ are thermal exergy and electrical exergy, resp.
The inlet exergy, According to the Petela theorem, it is given by [9], [6].

$$\sum EX_{in} = EX_{Q,SUIN} = A_C I_t \left(1 + \frac{1}{3} \left(\frac{T_{amb}}{T_{SUN}} \right)^4 - \frac{4T_{amb}}{3T_{SUN}} \right)$$

The thermal exergy (Ex_{th}) is given by $EX_{th} = EX_{physical} + EX_{chemical}$

The physical exergy output for a PV cell system can be expressed as [8]

$$EX_{physical} = \frac{m_{cell} C_P}{\Delta t} \left(T_{cell} - T_{amb} \right) + T_{amb} \left(C_P \ln \frac{T_{cell}}{T_{amb}} - \frac{Q_{loss}}{T_{cell}} \right)$$

Q_{loss} represents heat losses from the PV cell. The first term on the right side of this equation is the enthalpy and second term is the entropy contributions, respectively.

$$Q_{loss} = C_P \left(T_{cell} - T_{amb.} \right)$$

$$EX_{chemical} = \frac{T_{cell}}{T_{SUN}} \left[V_{oc} I_{sc} - V_{mp} I_{mp} \right]$$

The efficiencies cannot be evaluated easily for some components at open-circuit voltage and short-circuit current, which are the conditions at which maximum power can be generated in a PV array system [8].

3.1. Exergy efficiency-
Exergy efficiency is defined as the ratio of total output exergy (recovered) to total input exergy (supplied) [16]

$$\eta_{ex} = \frac{\sum EX_{out}}{\sum EX_{in}} = 1 - \frac{\sum EX_{dest}}{\sum EX_{in}} = \frac{\sum EX_{th} + \sum EX_{el}}{\sum EX_{in}} = \frac{\sum EX_{physical} + \sum EX_{chemical} + \sum EX_{el}}{\sum EX_{in}}$$

(15)

Substituting Eqs., so the exergy efficiency of a PV array is obtained. This is an equation for the exergy efficiency of a PV array in terms of operating, electrical, thermal design parameters and climatic conditions. It includes all of the exergy components of a PV array.

$$\eta_{ex}=\frac{\frac{m_{cell}C_p}{\Delta t}\left(T_{cell}-T_{amb}-T_{amb}\ln\left(\frac{T_{cell}}{T_{ambs}}\right)\right)-\left(I_{sc}V_{oc}-I_{mp}V_{mp}\right)\left(\frac{T_{cell}}{T_{sun}}\right)+\eta_{el}A_cI_t}{A_CI_t\left(1-\frac{4}{3}\frac{T_{amb}}{T_{sun}}+\frac{1}{3}\left(\frac{T_{amb}}{T_{sun}}\right)^4\right)} \quad (16)$$

4. RESULTS

The efficiency of the photovoltaic (PV) systems has been increased, while their production cost reduced which contribute to the expansion of PV systems globally. The results under the reference condition and the NOCT conditions are showing by using the mathematical modelling for the energy and exergy evaluation of a solar array, the output results carried out.

From the output the values of different parameters are obtained that the energy efficiency is restricted to theoretical cases. Electrical efficiency is about 11.5279% and the exergy efficiency is 12.0993%. The hourly variation of energy and exergy efficiency for different parameters of PV array is shown in Figures. Solar radiation data and ambient temp. Data from the data logger are conducted in Himachal Pradesh. The output parameters depend upon the climatic condition of that place. It the hourly variations of solar radiation intensity. The solar radiation intensity is maximum on 1:00 PM and lowest at the 5:00 PM during the time interval of 10:00 AM to 5:00 PM of the day test conditions. The higher surrounding temperature is recorded instead of sun oriented cell temperature at the season of sunrise. Negative exergy suggests that work is to be supplied to work the framework and is useless for the present framework. . In the present contemplations the radiation touching base at the leaf surface is thought to be

Table1-
The results of simulation program.

Description of function	Symbol	Output value
Temp. of the cell	T_{cell}	318.8038 K
Temp. difference	ΔT	20.6538 K
Ideality factor	a	1.5162
Maximum power point current	I_{mp}	4.2273 A
Maximum power point voltage	V_{mp}	16.2407 V
Short-circuit current	I_{sc}	4.8473 A
Open-circuit voltage	V_{oc}	20.5407 V
Photo-generated current	I_{ph}	2.4309 A
Energy Efficiency	$\eta_{el,theortical}$	16.7185%
Electrical Efficiency	$\eta_{el,actual}$	11.5279%
Exergy Efficiency	η_{exergy}	12.0993%
Specific Heat	C_p	0.7291

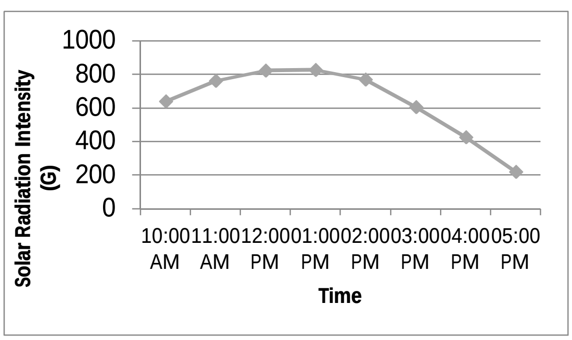

Fig.2-The hourly variations of ambient temperature in April

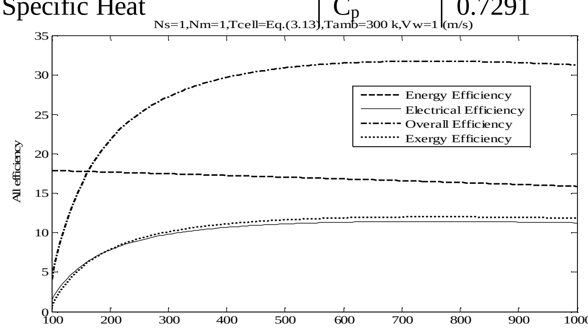

Fig.3- The variations of all efficiencies with respect to radiation

discretionary radiation landing from the sun. The radiation is perceived as non-energized and consistently spreading inside the strong point under which the sun is seen from the earth. The varieties of vitality productivity, exergy effectiveness and electrical proficiency as for sun oriented radiation force (G) are plotted. Sunlight based radiation power expanding from 100 to 1000 (w/m2) decides the sensible increment of these efficiencies, however in higher sun powered radiation force sun based cell efficiencies somewhat diminish. The exergy effectiveness and electrical productivity build at first and after that subsequent to accomplishing the sun oriented radiation power of about G= 300 W/m2, they diminish directly.

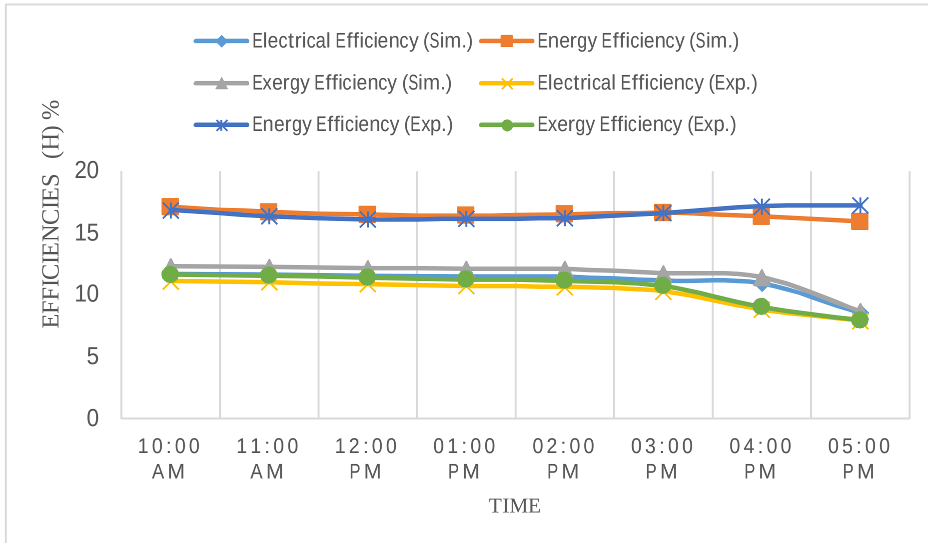

Fig.4: The simulated and experimental values of different efficiencies

The energy productivity, exergy effectiveness and electrical proficiency have a slight variety (16.7%, 1 2% and 11.5%, separately) as for the progressions of PV exhibit region (0.42537). For electrical effectiveness marginally consistent on 11.5%, the PV cluster range will be higher, exergy proficiency somewhat steady on around 12.6% and the energy productivity steady around the 17.1%.For littler PV exhibit region is lower than the higher zone. The different efficiencies as for surrounding temperature appeared here furthermore demonstrate some comparability of efficiencies concerning sunlight based cell temperature. Since the surrounding temperature changes amid the day, PV cluster outline ought to be founded on the everyday normal of this parameter. The varieties of energy effectiveness, exergy proficiency and electrical productivity as for surrounding temperature are plotted. Encompassing temperature expanding from 300 to 320 K decides the sensible decline of these efficiencies. At the 300oC the energy, exergy and electrical effectiveness is 16.5, 12.1 and 11.5 separately however efficiencies diminish because of augmentation of the encompassing temperature. At the 320oC the energy, exergy and electrical productivity is 15.3, 11.0 and 10.2 separately. The re-enacted values have been approve by their comparable to test values [14]. The exergy demonstrates the nature of energy. The nature of warm energy in a PV exhibit is low subsequently the exergy productivity estimation of a PV cluster is close to its electrical proficiency esteem ($\eta_{ex} \approx \eta_{el} \approx 11.6\%$).

5. Conclusion

Study manages the execution assessment of a photovoltaic exhibit framework. The exergy proficiency of sun based PV cluster is constantly more prominent than electrical effectiveness. Energy efficiency is more prominent than electrical effectiveness and the exergy productivity, however vitality effectiveness considered in hypothetical case and gave not the better precision yield of the framework. The outline Parameters, for example, Area of photovoltaic exhibit smalls affects the exergy effectiveness, electrical productivity and vitality proficiency. PV cluster temperature greatly affects the exergy productivity. To enhance the productivity heat expulsion happen on the PV cluster surface. Exergy proficiency regarding the variety of working and climatic parameters is particularly like the electrical effectiveness. It unmistakably demonstrates the need of the arranged studies towards expanding exergy efficiencies in the part examined and particularly the basic part of policymakers in setting up compelling Energy-productivity conveyance systems. It might be presumed that the present philosophy is helpful for dissecting the sectorial vitality and exergy use, giving vitality sparing open doors.

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