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Design and Analysis of Hybrid Solar Cell for e-Vehicle Charging

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Abstract

This work aims to develop and analyze Hybrid Solar cell which is the combination of Dye -sensitized solar cell (DSSC) and photovoltaic (PV) cell. PV cells are more efficient during day time and generating good amount of electricity but less effective during low light conditions due to the weakness of being a minority carrier device. To overcome this DSSC are used which are capable of being effective during both high and low light conditions because electrons are easily ejected from dye compared to that of P-N junction. DSSC provides a technically and economically viable alternative energy to present P-N junction PV cells. In this work Natural Dyes are used because they are easily available and economically viable. Hybrid solar cell is developed using PTC CREO software virtually for visual representation. Performance analysis of Hybrid solar cells is obtained using MATLAB software at various conditions. Results of Hybrid solar cell are compared for the combination of different dyes. By this Hybrid solar cell generates power throughout the day, which many be used for charging e-vehicles.

Keywords: *DSSC, PV cell, Hybrid Solar cell, Natural Dyes, TiO_2 plate*

1. Introduction

Automobile vehicles that are in the market today cause pollution and fuel cost is also increasing day by day. In order to compensate the fluctuating fuel cost and reducing the pollution a good remedy to the transportation system is needed. Due to ignition of the hydrocarbon fuels in the vehicle, sometime difficulties such as wear and tear may be high and more attention is needed for proper their maintenance [1, 2]. Current vehicles are easy to handle and no fuel cost to the other existing vehicles. Hence a need for a change in the existing alternative system which can produce higher efficiency at minimum cost. So this is very much useful, since it is provided with good quality of energy source with simple operating mechanism. Hence "each and every drop of fuel saves our economy and meet the needs" is the saturation point that is to be attained as soon as possible. This alternate energy must be much more convenient in availability and usage. The most effective and promising energy source against the natural resource is solar energy which produces green energy and suitable for future automobile vehicles. The solar energy is one of the solutions for this problem. Overall solar energy to current conversion up to efficiencies over 15 to 20% has been reached. But the PV cells are not capable of producing energy during low light conditions. Dye-sensitized solar cells (DSCs) have attracted much attention in recent years, because of their good photovoltaic performance, specifically under low-light conditions, as well as their flexibility in terms of colors and appearance, their relatively simple fabrication procedures and their potential low cost. In contrast to the conventional systems where the semiconductor assumes both the task of light absorption and charge carrier transport, but these two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band semiconductor. Charge separation takes place at the interface via photo-induced electron injection from the dye in to the conduction band of the solid. Charge carriers are transported in the conduction band of the semiconductor to the charge collector. The use of sensitizers having a broad absorption band is conjunction with oxide films of Nano crystalline morphology permits to harvest a large fraction of sunlight nearly quantitative conversion of incident photon into electric current is achieved over a large spectral rangeextending from the Ultraviolet (UV) to the near Infrared (IR) region [3, 4]. The first embodiment of modem day DSSC dates back to late 1980s. However, the fundamental work of Graetzel and O'Regan in 1991 proved that DSSC can be a feasible alternative energy source. From 2009 to 2013, the efficiency of Solid State DSSCs has dramatically increased from 4% to 15%. Michael Graetzel fabricated Solid State DSSCs with 15.0% efficiency. As on 2019, the world record for solar cell efficiency is 46.0% using multi-junction concentrator solar cells developed in Germany which is above the standard rating of 37.0% for polycrystalline PV or thin-film solar cells. DSSCs offer transparency, low cost and high power conversion efficiencies under cloudy and light conditions. Hence, this paper gives an insight on design and analysis of hybrid solar cell which is the combination of PV cell and DSSC to harness the hybrid energy which is more effective and efficient to energize e-vehicles in future [5].

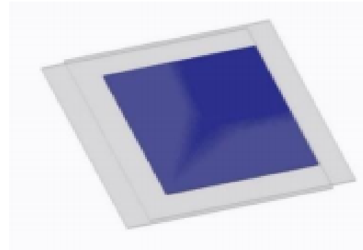

Figure 1: Conceptual Image of DSSC [7]

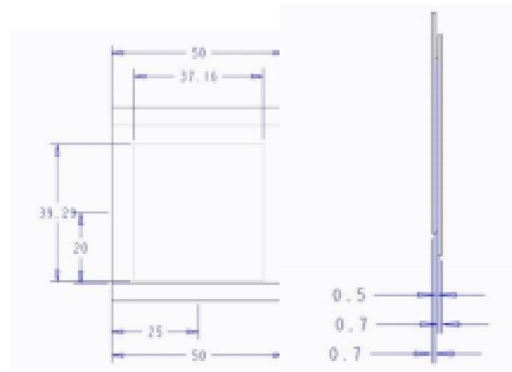

Figure 2: Schematic Diagram of DSSC [7]

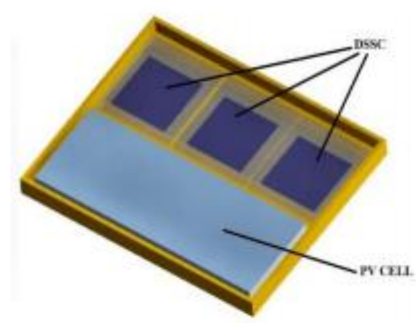

Figure 3: Conceptual Image of Hybrid Solar Cell

2. Design of Hybrid Solar Cells

2.1. Conceptual Design

Conceptual design and schematic diagram of DSSCs cell is as shown in Figure 1 and Figure 2. Also the conceptual design of hybrid solar cell model is shown in the Figure 3. Using MATLAB tool [6], DSSC, hybrid solar cell with various combinations of Natural dyes were modeled and analyzed as per the design standardsl.

2.2. Materials and Methodology

Following materials are used for developing the DSSC and hybrid solar cell. Methodology is used for the analysis of designed cells is as represented in the flowchart (Figure 4).

A. **ITO Glass Plates**

i. Dimension: 50x50x0.7mm.
ii. Resistivity: ≤10 ohms/sq.
iii. Transmittance: ≥86%

B. **Nano Titania (TiO2)**

Crystal Size: 25±5 with Purity 99.9%

C. 5% Nitric Acid and 15% Acetic Acid

D. Iodine Solution (0.5M KI + 0.05MI2)

E. Ethanol,

F. TiO2 Nano Powder

G. De-ionized Water.

H. Liquid Electrolyte Solution,

I. Binder Clips

J. PV Cell

K. Lithium Ion Battery

L. E-Vehicle chasis.

N. Natural Dyes

i. Coffee
ii. Turmeric
iii. Mixture of coffee and turmeric
iv. Phyllanthus reticulatus poir (Karihuli)
v. Piper crocatum (Red betel leaf),
vi. Melaleuca leucadendra (Weeping paperback/ Cajeput).

2.3 Simulation on the Performance of Dye Senstized Solar Cell Incorporated with TiO_2 layer

In this work, characteristics of the DSSC has been simulated using MATLAB based on TiO_2 by modifying the internal parameters (**Φ** , **τ** , **α** ,**m**,) and external parameters [6]. The simulation has been performed to determine the performance of natural dyes of coffee, turmeric, mixture of coffee and turmeric, phyllanthus reticulates pair (Karihu-li), piper crocatum (Red betel leaf) and mela-leuca leucadendra (weeping paperback/ Cajuput) in terms of the change due to the intensity of solar radiation and temperature by displaying the I-V and P-V curve characteristics[8,9,10,11].This simulation was performed to obtain the performance of DSSC using various natural dyes to determine the effect of work temperature and solar light intensity between 08.00 to 17.00 Hours. The results of the analysis are plotted using graphs representing the relationship between current density and voltage (I-V) and the maximum Power Vs. voltage (P-V) produced by DSSC were obtained through simulation. The simulation process was carried out on the characteristics of natural dye by initially collecting parameters to material's model flowchart as shown in Figure 4 and the input parameters are listed in Table 1. The simulation has produced highest DSSC performance by using natural dye from melaleuca leucadendra with a maximum voltage, current density and power of 0.7882 V, 0.0032 A/cm2 and 0.0015W respectively using a cell area of 1.5 x 1.5 cm[2]. The DSSC produced maximum power of 0.0013W at 12.00 o'clock in the afternoon. Therefore some of these natural dyes have indicated the highest potential of becoming low-cost photosensitizer which is abundantly available and eco-friendly [4].

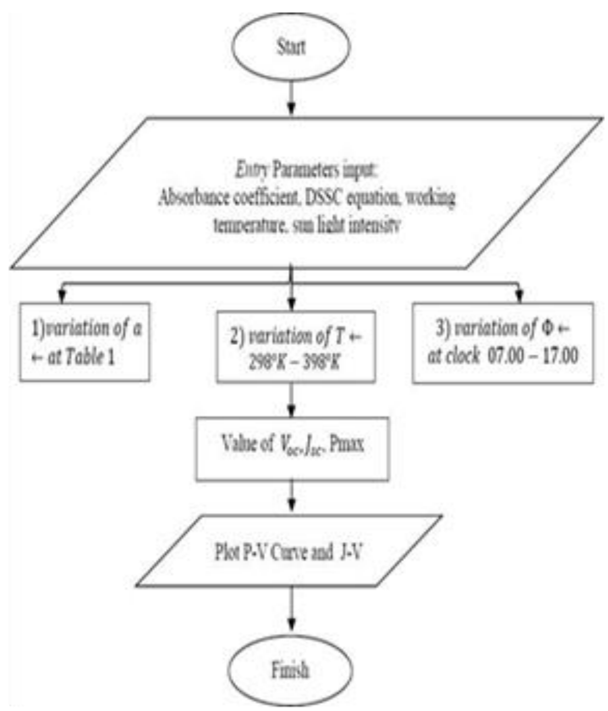

Figure 4: Flowchart of the Simulation Process [9].

Table 1: Input Parameters

Parameters	Value	Information
k	$1.381 x 10^{-23}$ J/K	Boltzmann constant
q	$1.602 x 10^{-19}$ C	Electron charge
L	$2.2361 x 10^{-3}$ cm	Length of electron diffusion
d	$5 x 10^{-4}$ cm	Length of TiO_2
α	Coffee (2.41), Turmeric(2.26), Phylantus Reticulatus Poir(3.46), Piper Crocatum (3.82), Melaleuca Leucandendra (4.47), cocktail dye (2.41)	Absorption coefficient
m	4.5	Ideal factor
D	$2.3x10^{-5}$ cm^2/s	Diffusion coefficient
no	1016 electron/cm^2	Electron concentration
t	0.01 s	Lifetime
ϕ	$1x10^{17}$ $cm^{-2}s^{-1}$	Sunlight intensity
T	300 K	Temperature

2.4 Simulation procedure

The equations (1), (2) and (3) related to the system model are as follows, where Jsc is short-circuited current density, Voc is open circuit voltage, J is current density and V is voltage produced by DSSC [10].

$$J_{SC} = \frac{q\Phi L\alpha}{1-L^2\alpha^2}\left[-L\alpha + \tanh\left(\frac{d}{L}\right) + \frac{L\alpha\exp(-d\alpha)}{\cosh\left(\frac{d}{L}\right)}\right] \quad \text{-- (1)}$$

$$V_{OC} = \frac{kTm}{q} In\left[\frac{LJ_{SC}}{qDn_o\tanh\left(\frac{d}{L}\right)} + 1\right] \quad \text{-- (2)}$$

$$J = J_{SC} - \frac{qDn_o}{L}\tanh\left(\frac{d}{L}\right)\left[\exp\left(\frac{qV}{kTm}\right) - 1\right] \quad \text{-- (3)}$$

2.5 Simulation of the PV Cells

The mathematical model of solar PV module which is based on the fundamental building blocks of the current source, diode, series and parallel resistors was developed in step by step procedure under MATLAB/SIMULINK system using the above-described modelling. Figure 5 depicts the steps involved in PV cell modelling. For simulation JAP6-72-320/4BB PV solar module has been selected as a reference model and provides input parameters for modeling (Datasheet JAP6-72-320/4BB, JA Solar). The final model of PV cell transforms the solar energy into electricity and provides the characteristics curves for given radiation and temperature as input parameters given in Table 2.

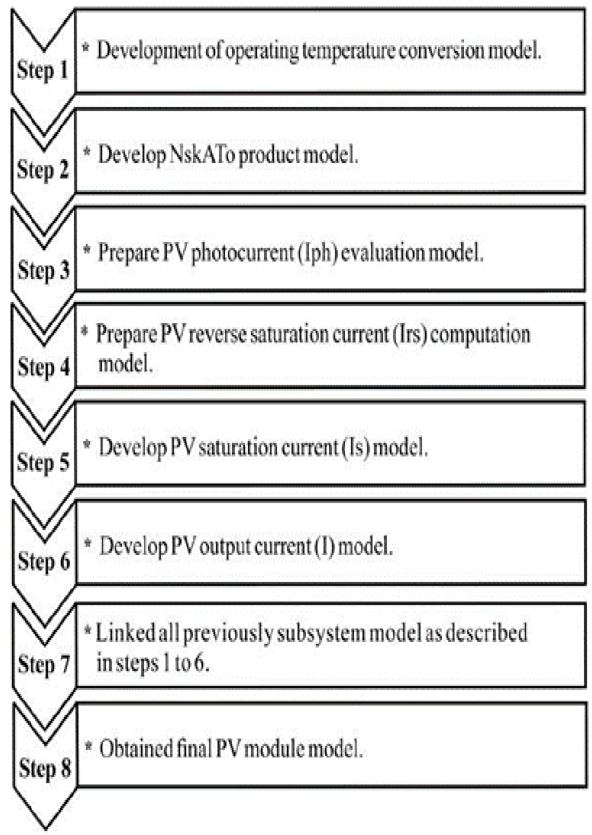

Figure 5: Photovoltaic modelling steps involved in Simulink [10]

Table 2: Electrical Parameters of JAP6-72-320/4BB Solar PV Module

S. No.	Parameters	Variables	Values
1.	Maximum power at STC (Pm)	Pm	320 W
2.	Maximum power voltage (Vmp)	Vm	37.38 V
3.	Maximum power current (Imp)	Im	8.56 A
4.	Open circuit voltage (Voc)	Voc	46.22 V
5.	Short-circuit current (Isc)	Isc	9.06 A
6.	Total series cells	Ns	72
7.	Total parallel cells	Np	1
8.	Ideality factor of diode	A	1.3
9.	Cell short circuit current temperature coefficient of Isc	Ki	0.058%/°C
10.	Reference temperature	Tref	25 °C
11.	Solar Irradiance	Gref	1000 at STC

Source: Data sheet JAP6-72-320/4BB, JA solar.

3. Calculations

A. DSSC under Ideal conditions:

- The value of sunlight intensity is kept constant in equation 1 and 2, i.e., ϕ = 1x10^{17} cm^{-2} s^{-1}
- The Voltage generated in DSSC from the simulation software for dimension 1.5x1.5cm is 0.7882 V
- Voltage generated in DSSC for dimension 5 x 15cm is Vdssc = 8.7578 V

B. DSSC under Practical/real conditions:

- The value of maximum sunlight intensity is substituted from Table 4 in equation 1 and 2 i.e. = 867.8 w/m^2 at 12.00 PM

C. Voltage:

- The Voltage generated in DSSC by simulation for dimension 1.5x1.5cm is 0.4287V,
- Then by calculation, the voltage generated in DSSC for dimension 5x15cm (3 cells), VDSSC= 14.29 V

D. Current:

- The Current generated in DSSC for dimension 1.5x1.5cm is **0.14mA.**
- The Current generated in DSSC for 5x5cm (1 cell) is **1.55 mA,**
- Then the current generated for three cells, IDSSC=1.55x3=4.65mA, Power: PDSSC = VI = **14.29x4.65x10-3** W

E. Power:

PDSSC = VI = 14.29x4.65x10^{-3}= 0.06644 W.

F. Calculation for PV cell:

- Voltage generated from the PV cell according to the simulation software for 195x95cm is 37 V
- Current generated from the PV cell according to the simulation software for 195x95cm is 9.06 A
- By calculation the voltage and current generated by PV cell of dimension 5 x15cm are,

VPV = 21.3336 V and IPV = 1.058 A and Power, PPV = VI = 21.3336x1.058 = 1.2375 W

G. Calculation for Hybrid Solar cell:

- Total current I = 4.56mA + 58mA =**62.56 mA**
- Total voltage V = 14.29+21.336 = **35.62 V**
- Total power P = 1.2375+0.0644= **1.304 W**

4. Results and Discussion

4.1 Results obtained for the Dye Sensitized Solar Cell Incorporated with TiO2 Layer

The gap between the conduction band and the valence band is called band gap energy. This band gap energy is used to analyze the performance of DSSC related to solar energy or wavelength of sunlight absorbed by the natural dye in DSSC. Using [8] the value of the wavelength of sunlight absorbed by the natural dye is calculated using Equation 4. From the calculation results, the relationship between wavelength and photon energy absorbed by the natural dye is presented in Table 3.

Table 3: Wave length and natural dye's photon energy

Variation of Dye	Wavelength (nm)	Photon Enegy (eV)
Phyllanthus Reticulatus Poir	350	3.55
Piper Croca-tum	410	3.03
Coffee	450	2.76
Tumeric	480	2.58
Melaleuca Leucadendra	520	2.39
Cocktail (Cof-fee+ turmeric)	450	2.76

From Table 3, it indicated that the larger the wavelength of the sunlight absorbed by the natural dye the smaller the absorbed energy [8] or else a natural dye that absorbs the large wavelengths has small bandgap energy. This is suitable with the equation (4) which states that the wavelength is inversely proportional to the photon's energy. The lowest bandgap energy of Melaleuca Leucadendra which was equal to 2.39 eV is suitable with the bandgap energy of TiO_2 semiconductors used as a photo electrode DSSC in this work. . The larger bandgap between the dye energy gap and the large bandgap TiO_2 energy helps electrons to move rapidly from the valence band to the conduction band and only requires less energy for electron recombination and increases DSSC efficiency [2].

The first simulation of this work is examining the performance of DSSC using various natural dyes prepared in the laboratory. The natural dye candidates are made from local ingredients such as coffee, turmeric, cocktail (coffee and turmeric), phyllanthus reticulatus poir, piper crocatum, and melaleuca leucadendra. All parameters of input are listed in Table 1. From the simulation results with the use of equations (1), (2) and (3) the performance of DSSC using some natural dye candidates that obtained the maximum voltage, current density and power are presented in Table 4. It is observed that melaleuca leucadendra (f) has highest Voc, Jsc and power than the other natural dyes due to the higher absorbance coefficient of melaleuca leucadendra (f) compared to other natural dyes. The absorbance coefficient of natural dye is the ability to absorb the sunlight. The J-V and P-V curves are shown in Figure 6 and 7 respectively.

Table 4: DSSC performance based on various local natural dye

Combination of Dyes	Absorbance Coefficient	Voc, V	Jsc mA/cm^2	P_{max}
Coffee (b)	2.41 [4]	0.7220	0.0018	7.6×10^{-4}
Tumeric (a)	2.26 [4]	0.7150	0.0017	7.1×10^{-4}
Cocktail (Coffee+ Tumeric) (c)	2.41 [4]	0.7220	0.0018	7.6×10^{-4}
Phyllanthus Reticulatus Poir (d)	3.46 [13]	0.7613	0.0025	0.0012
Piper Crocatum (e)	3.82 [13]	0.7710	0.0027	0.0013
Melaleuca Leucadendra (f)	4.47 [13]	0.7882	0.0032	0.0015

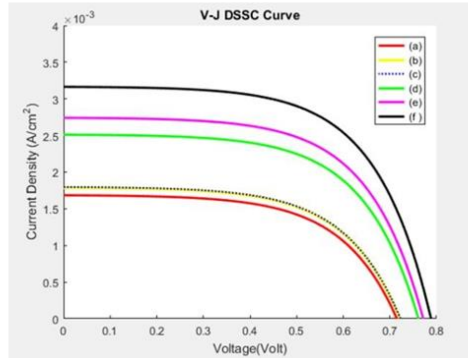

Figure 6: J-V Curve on Various Local Natural Dyes, (a) Tumeric,(b) Coffee, (c) Cocktail Dye (Coffee + Tumeric), (d) Phyllanthus Reticulatus Poir, (e) Piper Crocatum, (f) Melaleuca Leucadendra[9]

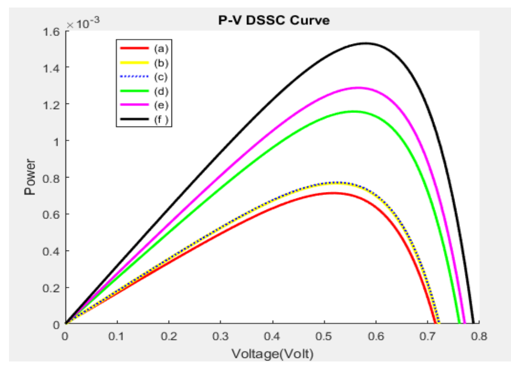

Figure 7: P-V Curve on Various Local Natural Dyes, a) Tumeric, (b) Coffee, (c) Cocktail Dye (Coffee + Tumeric), (d) Phyllanthus Reticulatus Poir, (e) Piper Crocatum, (f) Melaleuca Leucadendra[9].

4.2 Results obtained for the Simulation of the PV Cell

Solar PV module model is developed using MATLAB/SIMULINK based on the mathematical equations of solar cells. The JAP6-72/320/4BB module parameters from manufacturer datasheet are incorporated during simulation block model and consider as reference module. The final Solar PV model simulated results are depicted in Figure 8. The output results of current, voltage and power is due to the variation in radiation and temperature as input parameters. The final PV solar model is evaluated in standard test conditions (STC), which is kept same as in the world and performed in irradiance of 1000 W/m^2 under a temperature of 25°C in air mass of 1.5. Simulation of the solar PV model executes the I–V and P–V characteristics curves. Generally a good agreement was observed between various performance parameters results of reference model and simulated PV model at STC as illustrated in Table 5. The relative error for all the parameters of solar PV model is comprised between 0 to 1.65%.

Table 5: Comparison of reference model values and simulation model values at SYC

Parameters	Parameters of JAP6-72/320/4BB datasheet -reference model	Parameters from simulation of the model	Relative error (%)
Pmax (W)	320	319.9996	0.000125
Voc (V)	46.22	46.2063	0.030
Isc (A)	9.06	9.06	0
Vmp (V)	37.38	38	1.63
Imp (A)	8.56	8.421	1.65
Efficiency (η %)	16.51	16.51	0

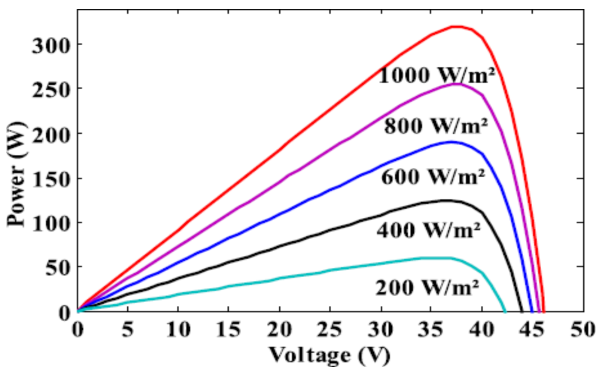

Figure 8: I–V characteristics for varying irradiance at Constant temperature

The effect on solar PV model I–V and P–V characteristics curves is depicted in Figures 8 and 9 by varying the intensity of irradiance from 200 to 1000 W/m^2 at constant temperature of 25° C. It is observed that current remains constant with rising voltage up to 30V after which it decreases. Moreover, the current increases while rising the irradiance intensity. This demonstrates that irradiance has a substantial effect on short circuit current, at the same time open circuit voltage is quite low as shown in Figure 9. The maximum power evidence exists on power performance curves. The generation of power by solar PV model is increased by increasing the intensity of solar irradiance as shown in Figure 9.

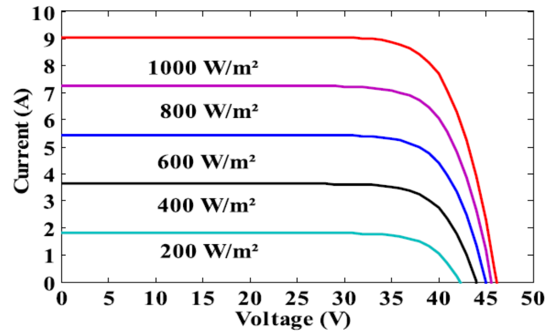

Figure 9: P–V characteristics, varying solar radiation at Constant temperature

The temperature demonstrates a significant effect on the output performance of PV solar module when irradiance intensity is kept constant at 1000 W/m^2. In current characteristics, minor variation is observed when the temperature varies from 10° C to 70° C. The voltage value shows increasing trend in I–V performance curve when the atmospheric temperature reduces as shown in Figure 10.

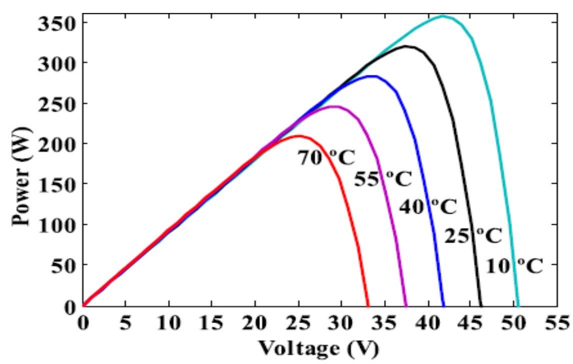

Figure 10: I–V characteristics, varying temperature at constant solar radiation.

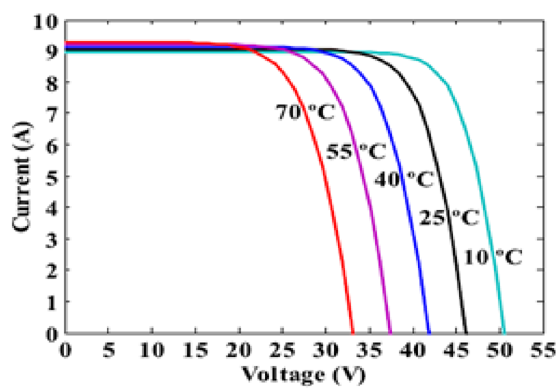

Figure 11: P–V characteristics, varying temperature at Constant solar radiation

Also PV solar cell generates more power when the atmospheric temperature reduces as shown in Figure 11. So, solar cell shows inverse relationship with temperature.

5. Conclusions

Based on the simulated results of the present work, the following interpretations are derived.

- Hybrid Solar Cell is more effective and efficient compared to the individual PV cells and DSSCs.
- The power generated from the Hybrid solar cell is independent of the time in a day.
- Efficiency of the Hybrid Solar cell can be increased by changing the individual dye as well with combination.
- Air and Noise pollutions can be reduced by the use of Hybrid e-Vehicle.
- The e-Vehicle can be charged throughout the day.

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