

System Modelling of Dye-Sensitized Solar Cells (DSSC) with Three Natural Dye Extracts Using Simulation MATLAB

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ABSTRACT

This article designs the modeling of the electrical parameters of dye-sensitized solar cells (DSSCs) using MATLAB simulation. An equivalent single diode circuit model is developed to simulate the physical parameters that affect the electron work in DSSCs. In this study, we investigate the suitability of natural dye extracts of Vernonia amygdalina (VAA), Goepertia macrosepala (GMA) leaves and Cnestis ferruginea (CFA) fruit as photosensitizers in DSSCs. The influence of solvents on the performance of these three natural dye extracts is also examined. These coefficients are determined from existing UV-Vis analysis data. The model simulates the I-V and P-V characteristics of DSSCs sensitized with natural dyes at temperatures ranging from 17 to 37°C (290-310 K) and solar radiation intensity between 2-4 kWh/m². The results show that increasing the temperature slightly increases the voltage output, while higher solar radiation intensity significantly increases the current in all dyes. The validity of the model is confirmed through experimental data, with slight differences caused by the operating temperature in the experimental setup. Comparative analysis shows that dyes with higher absorption coefficients, such as GMA and VAA, produce higher current and power output than CFA. This study resulted in an effective MATLAB modeling to predict the performance of DSSCs with natural dyes and improve understanding and optimization.

INTRODUCTION

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The need for energy as electrical energy is becoming increasingly significant, one of the basic needs of the community is electrical energy and along with the increase in population and economy, it triggers the need for energy. This pattern is also reinforced by the inaccessibility of environmentally friendly resources (solar, wind, geothermal, atomic, and so on) with cheap manufacturing costs [1]. Of the several existing resources, the sun is a very possible competitor as an alternative energy, especially in Indonesia which is located on the equator, which receives very high radiation. To be able to utilize solar energy to become a source of electrical energy, a solar panel is needed.

The increasing global energy demand and environmental concerns caused by the use of fossil fuels have intensified the use of sustainable renewable energy sources. Solar energy is abundant and clean, making it the best option, and further improvements in the technologies used to harness it are still ongoing [2][3]. One such technology is the use of Dye-Sensitized Solar Cells (DSSCs) in photovoltaic technology currently being researched. This new technology stands out because it is cost-effective, easy to manufacture, and can operate with relatively higher efficiency even under reduced solar radiation intensity compared to silicon solar cells. The working principle of DSSCs is also very different. Unlike the direct excitation of electrons in silicon cells, DSSCs behave more like photoelectrochemical systems (PECs), systems that convert solar energy into electrical energy by triggering chemical reactions that cause the movement of electrons and other materials.

DSSC components are inexpensive, flexible substrates and use a variety of transparent and lightweight materials. This gives manufacturers flexibility in their designs, making them suitable for a wide range of applications, from building-integrated photovoltaics (BIPV) to powering small portable electronic devices [6]. Unlike traditional silicon solar cells, which are widely used and known for their high power conversion efficiency (PCE) of between 18-22% [7], which involve energy-intensive processes, expensive components, and time-consuming processes, due to the dense semiconductors required by silicon cells, their application in small, flexible electronic devices is limited [8]. Furthermore, most silicon solar cells have a lifespan of about 10 years and are often discarded in landfills after their useful life due to few or no recycling options. This raises concerns about their long-term sustainability, as toxic metals such as lead and cadmium used in cell manufacturing leak and accumulate in the environment, potentially having a significant negative impact on the environment in the long term.

DSSCs typically consist of natural or synthetic dyes coated on the surface of a semiconductor layer on conductive glass, allowing the dye molecules to absorb sunlight and inject electrons directly into the semiconductor's conduction band[10]. This unique working of DSSCs opens up opportunities for researchers to develop models that will accurately represent the electrical behavior of DSSCs and also help in analyzing the influence of various factors and materials to improve cell efficiency for better performance.

These qualities make them ideal devices for charging small electronic devices. Imagine a day when Internet of Things (IoT) devices, wireless sensors,

calculators, smart tags, and even self-charging wearables operate without the need for traditional batteries [15]. This ability to harness energy from ambient light represents a truly battery-free solution for low-power devices, effectively eliminating the need for repeated battery replacements, a fact noted by .

Because they are transparent, visually appealing, and potentially manufactured in a variety of colors and shapes, they are well-suited for simple integration into architectural elements such as windows and skylights . This means that buildings could potentially generate electricity with DSSCs, without sacrificing design freedom and allowing natural light to enter . Furthermore, their low production cost and simple fabrication process, which is typically compatible with efficient roll-to-roll printing techniques, make DSSCs a viable option for fabricating large-scale, flexible, and customized energy solutions . Continued research into new materials and investigation of their performance for improved stability will be crucial to expanding their utilization.

Ongoing research on DSSCs aims to optimize materials and structures, with a recent emphasis on simulation modeling for efficient and cost-effective understanding of electrochemical reactions and performance prediction. Software such as MATLAB plays a crucial role in simulating the P-V and I-V characteristics, energy band levels, and electrical response of DSSCs under various environmental and material conditions . For example, a MATLAB-based simulation using an electron diffusion model compared the photovoltaic efficiencies of two dyes.

LITERATURE REVIEW

Dye Sensitized Solar Cells (DSSC) Structure

A typical example of Dye sensitized solar cell (DSSC) consist of different layers of components, in cluding substrate, transparent conducting layer, TiO₂ nanoparticles, dyes, electrolyte, photo electrode and counter electrode coveredwith sealing gasket. The block diagram of DSSC is shown in Figure 1.

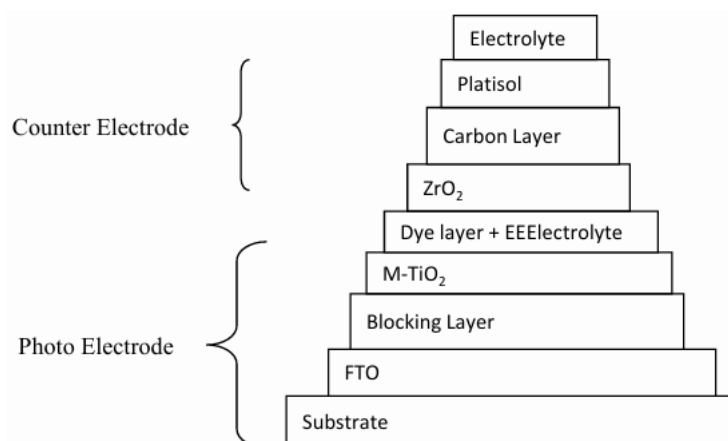


Figure 1. Block diagram of monolithic DSSC layers.

Dye-sensitized solar cells (DSSCs) have arisen as a technically and economically credible alternative to the p-n junction photovoltaic devices. In the

late 1960s, it was discovered that electricity can be generated through illuminated organic dyes in electrochemical cells. At the University of California at Berkeley, chlorophyll was extracted from spinach (photosynthesis). First chlorophyll-sensitized zinc oxide (ZnO) electrode was synthesized in 1972. For the first time, through electron injection of excited dye molecules into a wide band gap of semiconductor, photons were converted into electricity [1]. A lot of research has been done on ZnO-single crystals [2], but the efficiency of these dye-sensitized solar cells was very poor, as the monolayer of dye molecules was able to absorb incident light only up to 1%. Thus, the efficiency was improved by optimizing the porosity of the electrode made up of fine oxide powder, so that the absorption of dye over electrode could be enhanced and as a result light harvesting efficiency (LHE) could also be enhanced. As a result, nanoporous titanium dioxide (TiO₂) electrodes with a roughness factor of ca.1000 were discovered, and in 1991, DSSCs with 7% efficiency were invented .

The working electrode, sensitizer (dye), redox-mediator (electrolyte), and counter electrode are four key parameters for a DSSC. DSSC is an assembly of working electrode soaked with a sensitizer or a dye and sealed to the counter electrode soaked with a thin layer of electrolyte with the help of a hot melt tape to prevent the leakage of the electrolyte (as shown in Fig. 2). The components as well as the construction and working of DSSCs are shown below:

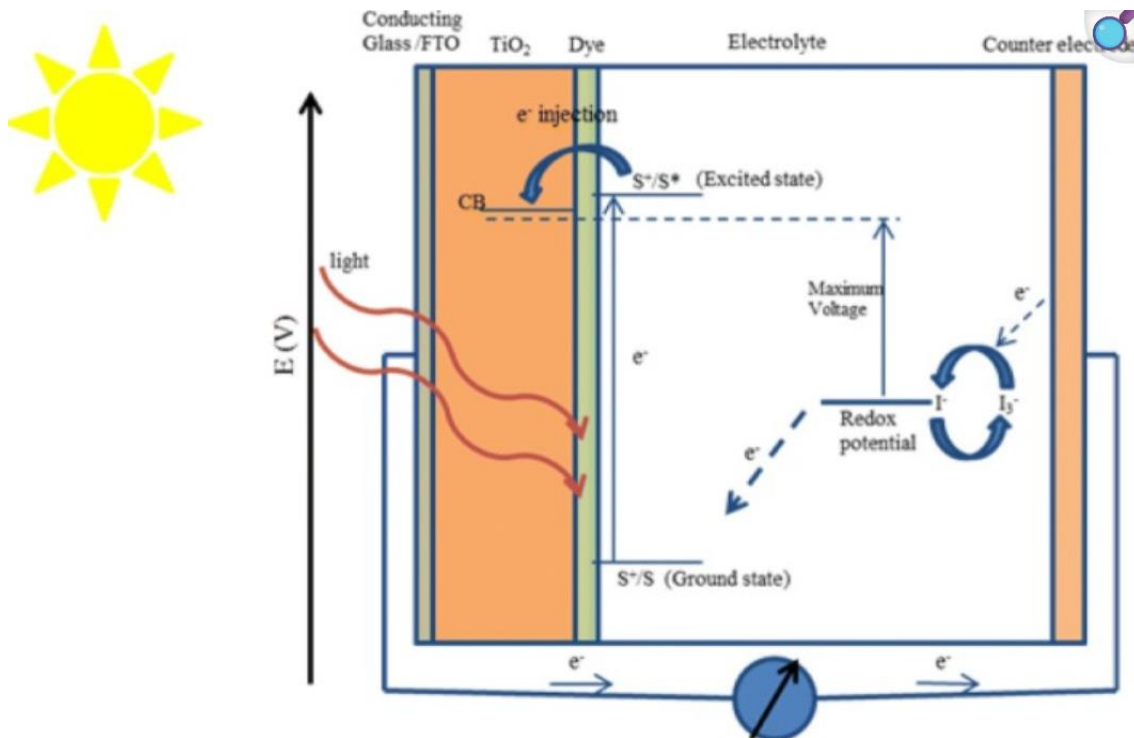


Figure 2. How DSSC works

DSSC is composed of five elements which include; two transparent conductive substrates, nanostructure titanium dioxide layer, platinum layer, dye molecules and electrolyte. Transparent conductive substrates are coated with a thin layer of TiO₂ and platinum nanostructures respectively. The mechanism of this type of solar cell is a replica of the processes involved in photosynthesis cycle of a plant .

By absorption of light, the dye molecule is excited from ground state to excited state as described in Figure 2. This leads to electrons being transferred into the conduction band of the semiconductor layer. The oxidized dye is reduced back by its ground state by donor electron that is present in the iodide electrolyte which allows the dye in an oxidized state to absorb photon [34]. The electrons are accepted by the electrolyte, catalyzed by the platinum on the counter electrode, and recombine with tri-iodide into di-iodide again. This process leads to the conversion of sunlight to electrical energy. The equivalent equations for the DSSC model are crucial for modelling the electrical characteristics of a DSSC. These expressions capture the interplay of charge generation, transport, and recombination within the DSSC structure. The DSSC equations for ISC and VOC are notably more complex and physically detailed than typical simplified models for conventional solar cells.

They explicitly incorporate parameters related to the unique charge transport and recombination mechanisms within the porous TiO₂ and dye layers, such as electron diffusion length (L), TiO₂ thickness (d), absorption coefficient (α), electron concentration (n₀), and diffusion coefficient (D).

a) Short-Circuit Current (ISC): The equation for short-circuit current density represents the maximum current produced when the voltage across the cell is zero (Supriyanto et al., 2019):

$$I_{SC} = \frac{q\phi L\alpha}{1-L^2\alpha^2} \left[-L\alpha + \tanh \tanh \left(\frac{d}{L} \right) + \frac{L\alpha e^{-d\alpha}}{\cosh \cosh \left(\frac{d}{L} \right)} \right] \dots\dots\dots(1)$$

b) Open-Circuit Voltage (VOC): The equation for the open-circuit voltage represents the maximum voltage across the cell when the current of the cell is zero, and it is given as (Arumugam et al., 2022):

$$V_{OC} = \frac{kTm}{q} \ln \left[\frac{LI_{SC}}{qDn_0 \tanh \tanh \left(\frac{d}{L} \right)} + 1 \right] \dots\dots\dots(2)$$

c) General Current (I) equation (Salau et al., 2021):

$$I = I_{SC} - \frac{qDn_0}{L} \tanh \tanh \left(\frac{d}{L} \right) \left[\exp \left(\frac{qV}{kTm} - 1 \right) \right] \dots\dots\dots(3)$$

d) General Voltage (V) is the terminal voltage across the cell. This equation describes the entire current-voltage characteristic curve of the DSSC. It is used to determine the value of I for corresponding values of V (Salau et al., 2021):

$$V = \frac{kTm}{q} \ln \ln \left[\frac{L(I_{SC}-I)}{qDn_0 \tanh \tanh \left(\frac{d}{L} \right)} + 1 \right] \dots\dots\dots(4)$$

The ISC equation model contains exponential and hyperbolic terms, which emphasize the subtle interactions of photon absorption, electron injection, porous TiO₂ network diffusion, and recombination processes.

This level of detail distinguishes it from more primitive ISC models for conventional solar cells, which resort to direct proportionality to light intensity and quantum efficiency.

The VOC equation is dependent on the light-generated current (ISC) and various material-specific and recombination-related parameters. The term I_0 , effectively represents the saturation current (Io) or recombination current component, which is a primary determinant of VOC. The Ideal factor, m , is usually significantly higher compared to the typical diode ideality factors ($n = 1-2$) observed in conventional silicon solar cells. The high value allows the model to account for dominant, highly non-ideal recombination pathways or complex charge transport phenomena within the DSSC. In semiconductor physics, a high ideality factor indicates that the current-voltage relationship deviates significantly from ideal diode characteristics, typically due to recombination processes that are more complex than simple diffusion. For DSSCs, where recombination at the TiO₂ layer and within the electrolyte are significant issues, this high m value is the model's way of capturing the complex, non-ideal loss mechanisms. The DSSC equation parameters and values are presented in Table 1.

Table 1. DSSC equation parameters and values

Symbol	Description	Value	Unit
K	Boltzmann constant	1.381×10^{-23}	J/K
q	Electron charge	1.602×10^{-19}	C
L	Length of electron diffusion	2.2361×10^{-3}	cm
d	Length/thickness of TiO ₂	10×10^{-4}	cm
a	Absorption coefficient	5000	cm ⁻¹
m	Ideality factor	45	No Unit
D	Diffusion coefficient	5.0×10^{-4}	cm ² s ⁻¹
n_0	Electron concentration	10×10^{16}	cm ⁻³
Φ	Sunlight intensity	1×10^{17}	cm ⁻² s ⁻¹
T	Temperature	273-375	K

Matrix Laboratory (MATLAB)

The name MATLAB stands for MATrix LABoratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects. MATLAB [1] is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research.

MATLAB has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving technical problems. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a standard tool at most universities and industries worldwide. It has powerful built-in routines that enable a very wide variety of computations. It also has easy to use graphics commands that make the visualization of results immediately available. Specific applications are collected in packages referred to as toolbox. There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization, and several other fields of applied science and engineering.

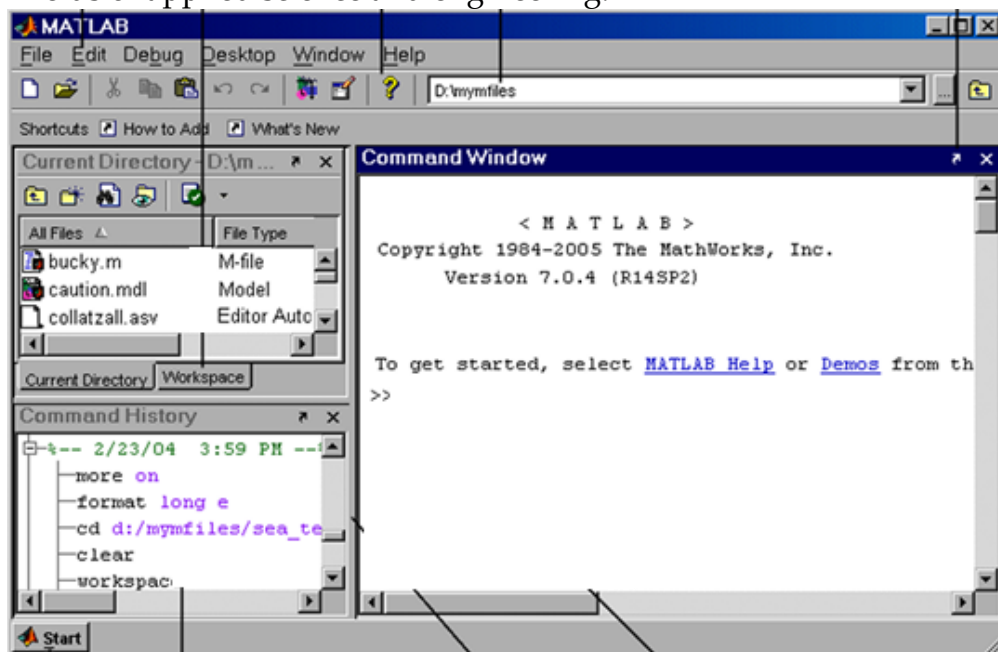


Figure 3. The graphical interface to the MATLAB workspace

Modeling is a way to create a virtual representation of a real-world system. Simulate this virtual representation under a wide range of conditions to see how it behaves. Modeling and simulation are valuable for testing conditions that are difficult to reproduce with hardware prototypes alone. This is especially true in the early phase of the design process when hardware is not yet available. Iterating between modeling and simulation can improve the quality of the system design early, by reducing the number of errors found later in the design process. Automatically generate code from a model and, when software and hardware implementation requirements are included, create test benches for system verification. Code generation saves time and prevents the introduction of manually coded errors. In Model-Based Design, a system model is at the center of the workflow. Model-Based Design enables fast and cost-effective development of dynamic systems, including control systems, signal processing systems, and communications systems.

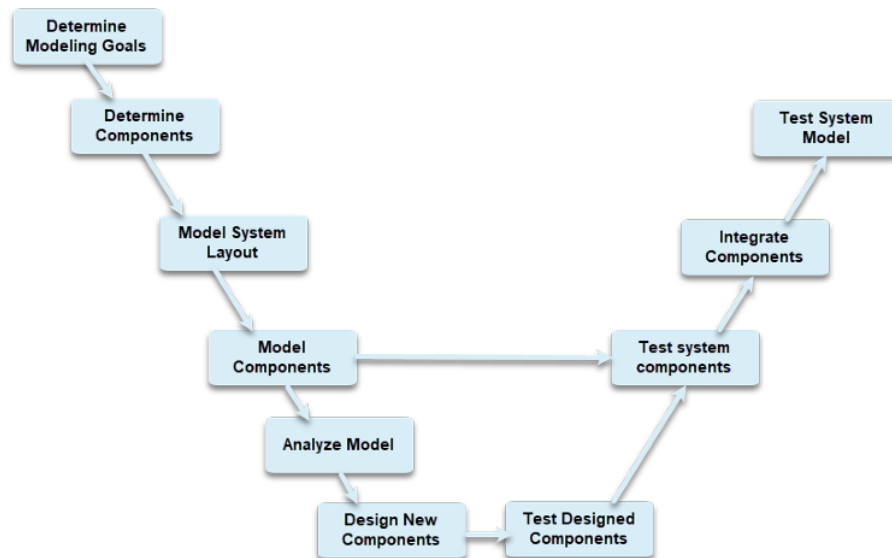


Figure 4. Model-Based Design Workflow in Simulink

Before designing a model, consider goals and requirements. The goals dictate both the structure and the level of detail for the model. If the goal is simply to figure out how fast the robot can go, modeling just for linear motion is sufficient. If the goal is to design a set of inputs for the device to follow a given path, then the rotational component is involved. If obstacle avoidance is a goal, then the system needs a sensor. Then builds a system modeling with the goal of designing DSSC.

Simulink is a graphical modeling and simulation environment for dynamic systems. Create block diagrams, where blocks represent parts of a system. A block can represent a physical component, a small system, or a function. An input/output relationship fully characterizes a block. Consider these examples faucet fills a bucket water goes into the bucket at a certain flow rate, and the bucket gets heavier. A block can represent the bucket, with flow rate as the input and its weight as the output. Use a megaphone to make your voice heard. The sound produced at one end of the megaphone is amplified at the other end. The megaphone is the block, the input is the sound wave at its source, and the output is the sound wave as hear it. Push a cart and it moves. The cart is the block, the force you apply is the input, and the cart's position is the output.

The definition of a block is only complete with its inputs and outputs defined; this task relates to the goal of the model. For example, the cart velocity may be a natural choice as an output if the modeling goal does not involve its location. Simulink provides block libraries that are collections of blocks grouped by functionality. For example, to model a megaphone that multiplies its input by a constant, you use a Gain block from the Math Operations library

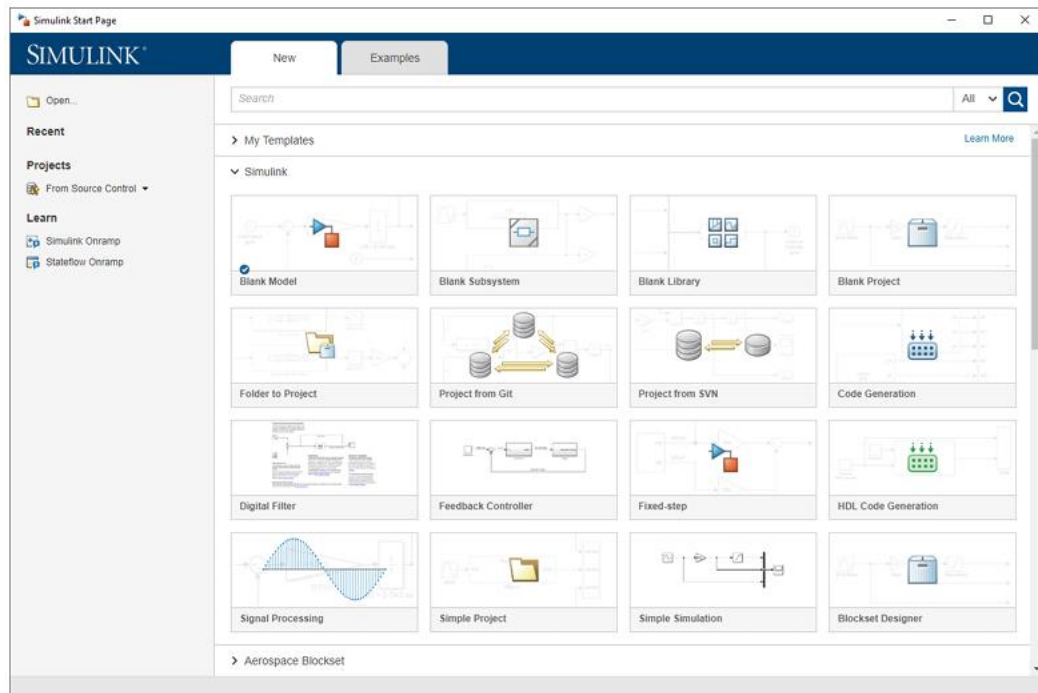


Figure 5. Simulink start page

METHODOLOGY

There are three methods in this research to solving the problem in designing a system modelling using Matlab.

1. Literature Study Method

In writing this thesis, the author studied references from various sources such as books, journals, articles related to the research that the author is researching. The various references used by the author to create this final assignment and other references related to the research.

2. Discussion or Interview Method

Collecting data by conducting direct discussions with expert

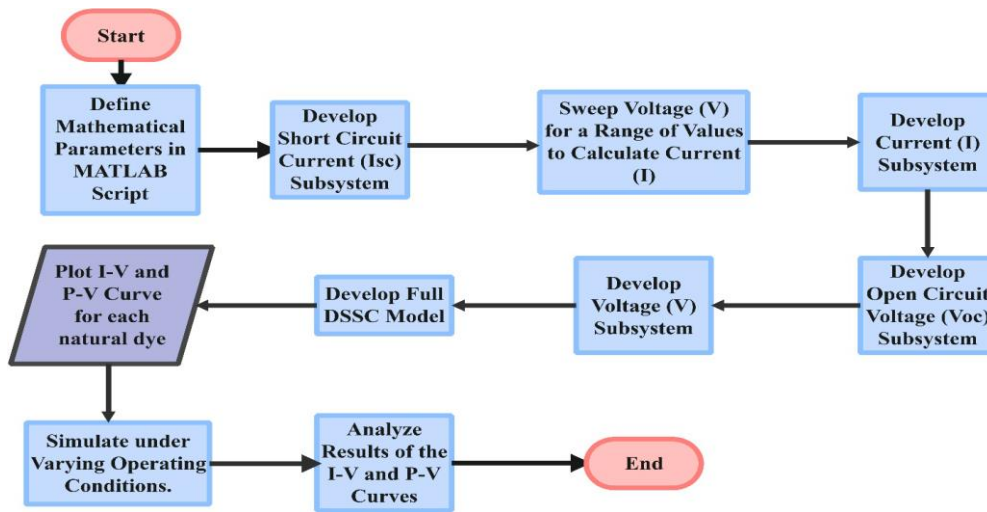
3. Observation Method

The author obtains data by coming directly to the field to observe and record the data needed to complete the thesis.

The bulk of modeling the DSSC lies in expressing the derived equations for the DSSC in Simulink functional block diagrams. It required selective choosing and establishing of various mathematical and logical blocks available in the Simulink library. Partitioning the Simulink model into well-defined subsystems (the ISC, VOC, and the implicit I-V equations) has the highest value with respect to controlling complexity in the DSSC equations. It significantly enhanced model readability and simplified debugging. It improved the re-usability of components, which is especially beneficial when scaling the model to simulate DSSC arrays. All numerical values for the DSSC constants (k , q , L , d , α , m , D , n_0 , Φ , T) are accurately entered into their respective constant blocks within the Simulink model. For enhanced flexibility and ease of modification, these parameters are defined as variables in the MATLAB workspace before running the simulation. This allowed for quick changes to environmental conditions (like

sunlight intensity or temperature) or material properties without needing to open and edit individual blocks in the Simulink model. The flow chart for the modelling and simulating DSSC in MATLAB/Simulink is illustrated in Figure 6.

Figure 6. Flowchart of the Modelling



A summary of the important Simulink blocks for the DSSC model implementation is presented in Table 2. Modular design with subsystems was adopted to manage the complexity in the DSSC equations. It was also used to formulate the model in a modular fashion with separate subsystems for each important component:

- a. Short-Circuit Current Subsystem: It contains all the blocks for computing the Short-Circuit Current (ISC). It accepts the respective constants as input and gives the computed ISC values.
- b. Open-Circuit Voltage Subsystem: Open-Circuit Voltage (VOC) Subsystem takes the value of ISC calculated, along with the rest of the constants, as input, and gives the VOC as an output.
- c. I-V Characteristic Subsystem (Implicit): This is a key component due to the implicitness of the I-V equation, i.e., voltage and current are functions of one another.

The design of system modelling by using Matlab (Simulink) for DSSCs through this communication technology need key simulink block (Table 2).

Table 2. Key Simulink Blocks for the DSSC Model

Block Name	Purpose of the DSSC Model	Simulink Library
Math Function	Implementing exponential, logarithm, and power operations	Math Operations
Trigonometric Function	Implementing hyperbolic tangent and hyperbolic cosine functions	Math Operations
Gain	Scaling parameters and coefficients	Math Operations

Sum	Performing addition and subtraction operations	Math Operations
Product	Performing multiplication operations	Math Operations
Divide	Performing division operations	Math Operations
Constant	Inputting fixed numerical parameters and constants	Sources
Scope	Visualizing simulation results (e.g., I-V curves, I_{sc} , V_{oc})	Sinks
Algebraic Constraint	Solving implicit equations and resolving algebraic loops	Math Operations

RESEARCH RESULT

Designing hardware and software system

A set of voltage values was used to calculate the corresponding values of the current. This was achieved by using a Repeating Sequence block in generating a sweep of input currents to plot the entire I-V curve (Figure 7).

The output terminals of the blocks were connected correctly with the input of the subsequent blocks with the direction of the signal flow watched so that all blocks were properly configured according to the mathematical equations and values of each parameter until found the full DSSC model.

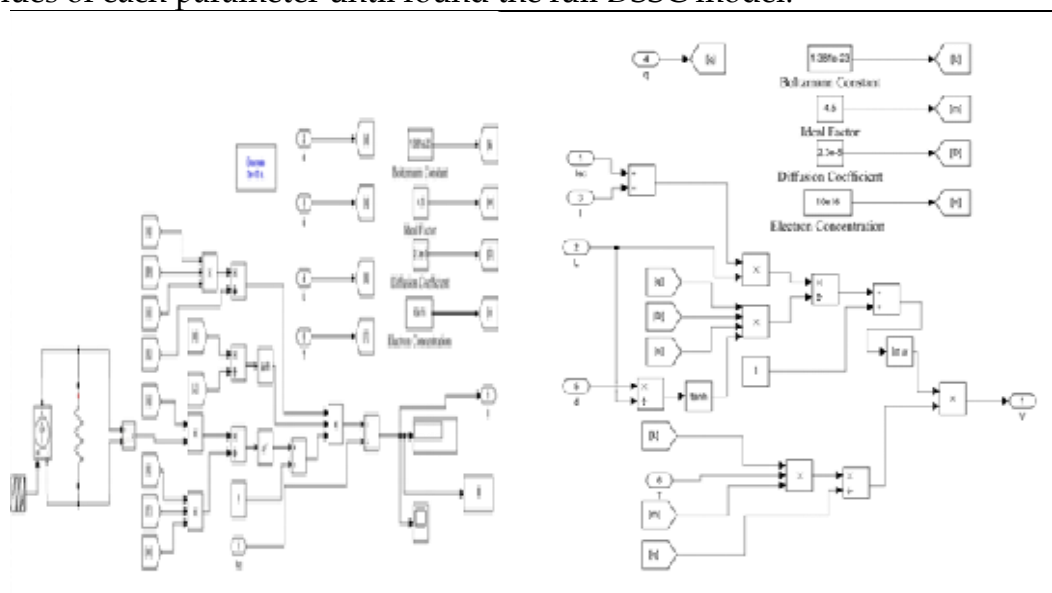


Figure 7. Repeating Sequence block in generating a sweep currents

The simulation results derived from the MATLAB (Simulink model) for DSSCs with three natural dye extracts of bitter leaf (*Vernonia amygdalina*), calathea (*Goepertia macrosepala*) leaves, and wild alder (*Cnestis ferruginea*)

fruit as photosensitizers are presented. Their P-V and I-V characteristics are displayed at different temperatures and irradiance.

Absorption coefficient is the intensity at which the dye absorbs light at a certain wavelength. In natural dyes, the absorption coefficient is wavelength, extraction solvent, concentration of the dye, and pH of the dye dependent. This is typically determined by the absorbance at the peaks of different wavelengths within the UV to visible range of light spectrum. In the 500 – 600 nm visible light range, *V. amygdalina* (VAA) dye has a peak absorbance at 504, 536, 560 and 600 nm as reported in our previous work [4]. An average peak absorbance of 0.17 is considered, which falls near 550 nm in the centre of the visible light spectrum and represents the point where the DSSC would generate most of its current during peak sunlight.

Figure 8 shows the current-voltage (I-V) characteristics of VAA-sensitized DSSC at a constant solar irradiance of 1000 W/m² across three temperatures 17 C, 27C, dan 37 C (290 K, 300 K, and 310 K). The curves indicate that as the temperature increases, the voltage also increases. At the same time, the current remains at a stable level of approximately 0.048 A. The curve for 310 K shows the highest voltage on the axis. In comparison, the 290 K curve shows the lowest value, indicating a direct positive correlation between the operating temperature and the overall voltage output of the VAA-sensitized DSSC under these conditions. The output terminals of the blocks were connected correctly with the input of the subsequent blocks with the direction of the signal flow watched so that all blocks were properly configured according to the mathematical equations and values of each parameter.

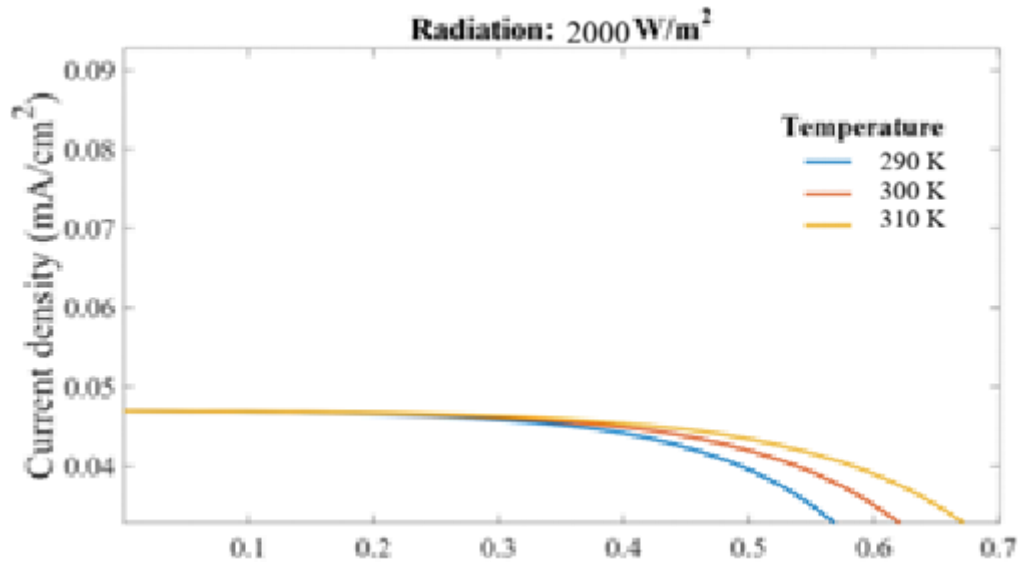


Figure 8. Comparison Temperature to Current and Voltage

DISCUSSION

Comparison the current-voltage (I-V) characteristics of the VAA dye-sensitized solar cell at a constant temperature of 300 K across three different irradiance levels: 2000 W/m², 3000 W/m², and 4000 W/m². The curves demonstrate that as irradiance increases, the current increases significantly, and the voltage also increases. The curve for 4000 W/m² shows the highest current.

It extends to the highest voltage on the x-axis. At the same time, the 2000 W/m² curve shows the lowest current and voltage output, indicating a direct positive correlation between operating irradiance and the overall current and voltage output of the VAA-sensitized DSSC under these conditions.

Similar to VAA dye, *G. macrosepala* (GMA) dye has absorbance peaks in the visible light region at 504, 536, 560 and 600 nm as previously reported by Soge et al. [4]. An average peak absorbance of 0.19 a.u. is considered, which falls near 550 nm in the centre of the visible light spectrum. The absorption coefficient of the solar cell is estimated as 4375 cm⁻¹. The I-V curves for the GMA-sensitized DSSC under varying temperatures and irradiance (Figure 9) show a similar trend to the VAA-sensitized DSSC, though the GMA absorption coefficient is slightly higher than that of VAA.

Natural dye extract of wild alder (*C. ferruginea*) fruits (CFA) dye has absorbance peaks in the visible light region at 504, 536, 560 and 600 nm like VAA and GMA dyes [4]. An average absorbance peak of 0.09 a.u. is considered, which lies near 550 nm in the centre of the visible light spectrum. The absorption coefficient of the solar cell is determined as 1400 cm⁻¹.

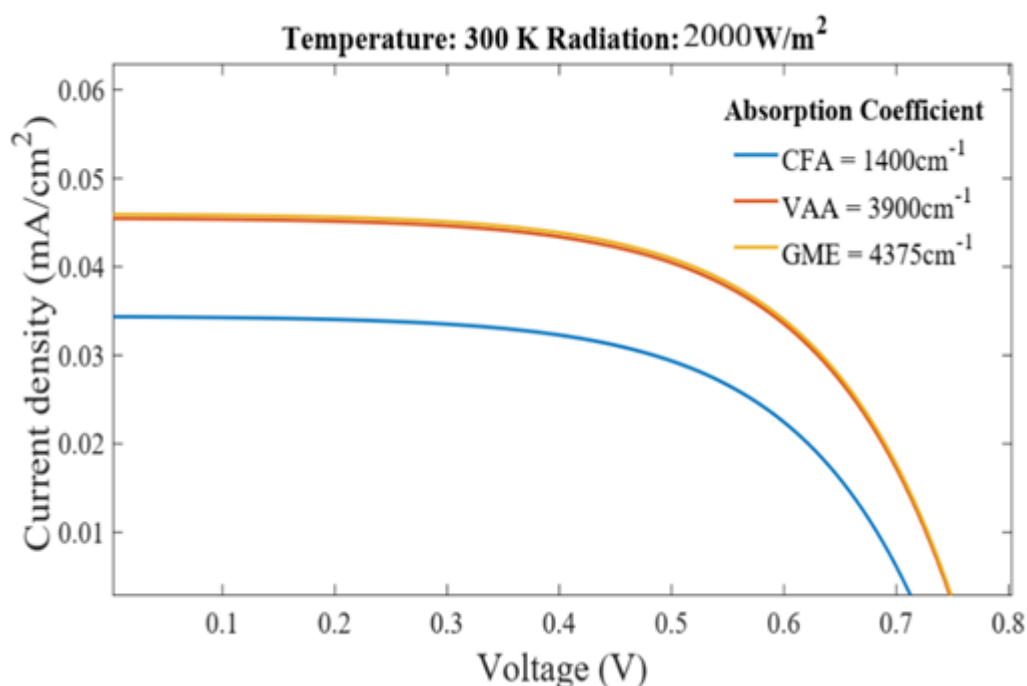


Figure 9. I-V Curve of the three dyes at temperature and solar irradiance

The simulated results were compared to those of the DSSCs fabricated using natural dyes as photosensitizers, with an active cell area of 0.36 cm² and characterised using simulated sunlight of a solar simulator at 2000 W/m² (FY700 Solar Simulator; FY Tronix Electronic) as presented in Table 3. The fabrication process and electrical characterisation of the solar cells have been reported by Soge et al. [4]. The open-circuit voltage (VOC) of the simulated result is similar to that of the experimental result, and only a difference of approximately 0.2 V was observed.

This observation in the experimental results could be attributed to a lower temperature and a higher thickness value of the TiO₂ layer, which leads to an increase in the resistance of the DSSC, resulting in a drop in the voltage output. The fill factor of the simulated results is consistent with that of the experimental results, except for that of VAA, which is 0.6 in the simulated result and 0.7 in the experimental result. The efficiency of the cells is of the same order for both simulated and experimental results.

These results validate the accuracy of the MATLAB/Simulink model and its application for the prediction of the electrical performance of DSSCs sensitized with natural dyes.

Table 3. Comparison of Experimental Results and Simulation Results

Dyes	Experimental Results				Simulation Results			
	I _{sc} (mA/cm ²)	V _{oc} (V)	η (%)	FF	I _{sc} (mA/cm ²)	V _{oc} (V)	η (%)	FF
VAA	0.119	0.522	12 × 10 ⁻²	0.7	0.0470	0.754	2 × 10 ⁻²	0.6
GMA	0.075	0.512	7 × 10 ⁻²	0.6	0.0475	0.760	2 × 10 ⁻²	0.6
CFA	0.044	0.522	4 × 10 ⁻²	0.6	0.0345	0.710	1.5 × 10 ⁻²	0.6

CONCLUSION

Based on the research and discussion on the system modelling by using Matlab with three natural dye, the following conclusions can be drawn that an equivalent MATLAB/Simulink model was developed to simulate the electrical properties of DSSCs using three natural dye extracts. A detailed single-diode equivalent circuit model was constructed in MATLAB/Simulink, accurately reflecting the complex electrochemical dynamics of DSSCs. This model was used to simulate the I-V and P-V characteristics of DSSCs sensitized with specific natural dyes across various temperatures and solar irradiance levels. Simulation results indicated that temperature positively influenced the open-circuit voltage (VOC) while the short-circuit current (ISC) exhibited minimal variation. Conversely, increased solar irradiance significantly enhanced ISC and also elevated VOC. Among the three natural dyes, *G. macrosepala* and *V. amygdalina*, with higher absorption coefficients, demonstrated superior current and power generation compared to *C. ferruginea*. The simulation outcomes were validated against experimental data, showing consistency. This work provides a versatile simulation framework for natural dye-sensitized solar cells, offering valuable insights into their performance under varying environmental conditions and aiding the preliminary design of functional DSSC solar panels.

ADVANCED RESEARCH

After designing system modelling with three natural dye by using simulation with Matlab (Simulink), the author has the following suggestions utilizing variety colours again to DSSCs. This way, in the event of a power outage, the current and voltage can be used as an alternative source.

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