CHAPTER 3

MODELLING OF MULTI-JUNCTION PV CELL FOR ENERGY CONVERSION IMPROVEMENT USING MATLAB/SIMULINK

Nor Mariah Binti Mohd Zaludin[1], Md Zarafi Ahmad[2], Nordiana Azlin Othman[3]*

[1-3]Department of Electrical Engineering,
Faculty of Electrical and Electronics Engineering
University Tun Hussein Onn Malaysia,
86400 Parit Raja, Batu Pahat, Johor, Malaysia.
*Corresponding Email: zarafi@uthm.edu.my

3.1 INTRODUCTION

The rapid growth of industrialization, urbanization, and global population has increased the demand for energy, leading to greater dependence on finite fossil fuel resources and environmental issues [1]. Solar energy, known for its abundance and sustainability, has become a vital renewable energy option, with photovoltaic (PV) technology playing a key role [2]. However, the efficiency of conventional single-junction PV cells remains limited due to their restricted ability to convert sunlight effectively [3]. Multi-junction PV cells offer a technological advancement by using multiple semiconductor layers with different bandgap energies to capture a wider solar spectrum, reducing energy losses and achieving efficiencies above 30% under ideal conditions [4]. Despite these benefits, challenges such as spectral mismatch losses, thermal degradation, and complex manufacturing processes limit their scalability and real-world use

[5]. This chapter develops a simulation framework using MATLAB/Simulink to model and analyze the performance of multi-junction PV cells. The study simulates current-voltage (I-V) and power-voltage (P-V) characteristics under different environmental conditions, aiming to identify performance limitations and recommend solutions for improving efficiency, scalability, and cost-effectiveness [6].

3.2 METHODOLOGY

The research methodology for modelling multi-junction photovoltaic (PV) cells is designed to ensure a systematic approach to developing, simulating, and analyzing the performance of advanced solar energy systems. The framework integrates theoretical, computational, and validation processes to provide a comprehensive understanding of the multi-junction PV cell's behavior under varying environmental and operational conditions [7].

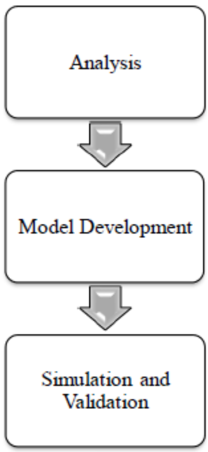

Figure 3.1: Project Flowchart.

3.2.1 RESEARCH NEED

This research aims to fill this gap by developing a comprehensive simulation model using MATLAB/Simulink. The model will focus on understanding the impact of spectral mismatch and thermal losses while proposing strategies to optimize performance. The findings are expected to contribute to the advancement of multi-junction PV technology and its applications in renewable energy systems. The comparison of single-junction and multi-junction PV cells is shown in Table 3.1.

Table 3.1: Comparison of Single-Junction and Multi-Junction PV Cells.

Feature	**Single-Junction PV Cells**	**Multi-Junction PV Cells**
Efficiency Limit	Up to 33%	Over 40%
Bandgap Energy	Single bandgap	Multiple bandgaps
Spectral Utilization	Limited	Wide spectrum
Fabrication Complexity	Low	High
Cost	Lower	Higher

3.3 RESULTS AND DISCUSSION

This section presents the results obtained from the simulation of the multi-junction PV cell model. The performance of the model is evaluated through current-voltage (I-V) and power voltage (P-V) characteristics, as well as an analysis of efficiency under varying environmental conditions. The simulations were conducted using MATLAB/Simulink, with parameters configured to reflect standard test conditions, as summarized in Table 3.2. The results provide insights into the operational behavior of the PV cell and validate its performance against theoretical expectations [8].

Table 3.2: Standard Test Conditions Parameters

Parameter	**Value**	**Unit**
Irradiance (G)	1000	W/m^2
Temperature (T)	25	◦C
Bandgap Energy (Eg)	1.8/1.4/1.1	eV

3.3.1 CURRENT VOLTAGE (I-V) CHARACTERISTICS

The I-V characteristics for individual sub cells and the combined multi-junction PV cell are illustrated in Figure 3.2. The combined curve demonstrates effective current matching across sub cells, ensuring optimal power output [9].

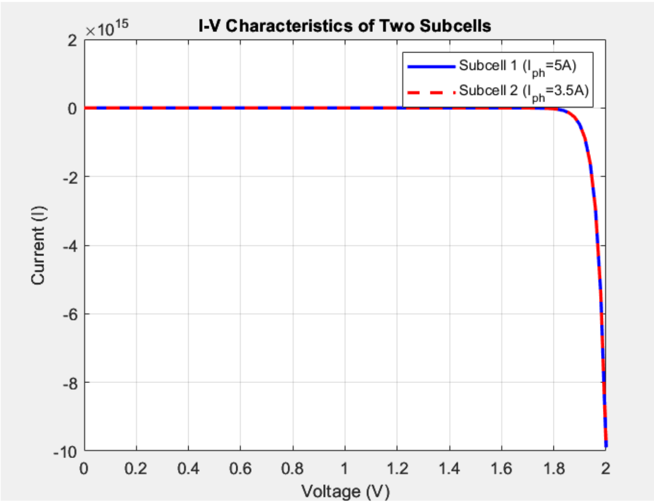

Figure 3.2: Simulated I-V Characteristics of Multi-Junction PV Cell.

3.3.2 POWER VOLTAGE (P-V) CHARACTERISTICS

Figure 3.3 shows the P-V characteristics of the multi-junction PV cell, highlighting the maximum power point (MPP). The curve demonstrates a smooth transition, with the MPP located at the knee of the curve, representing the optimal operating point [10].

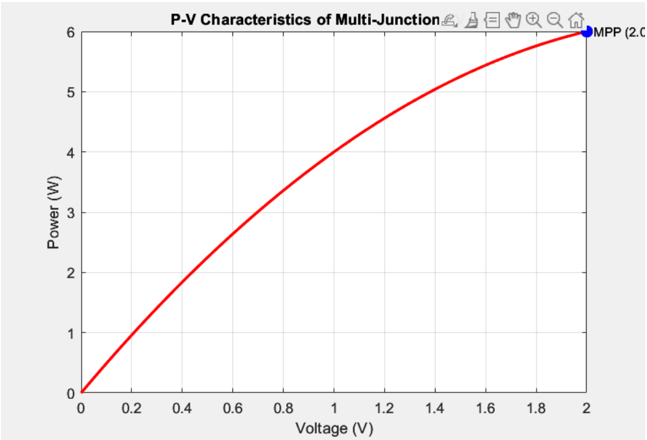

Figure 3.3: Simulated P-V Characteristics of Multi-Junction PV Cell.

3.3.3 ANALYSIS UNDER VARYING CONDITIONS

The results of efficiency trends of multi-junction PV cells under varying conditions are shown in Figure 3.4.

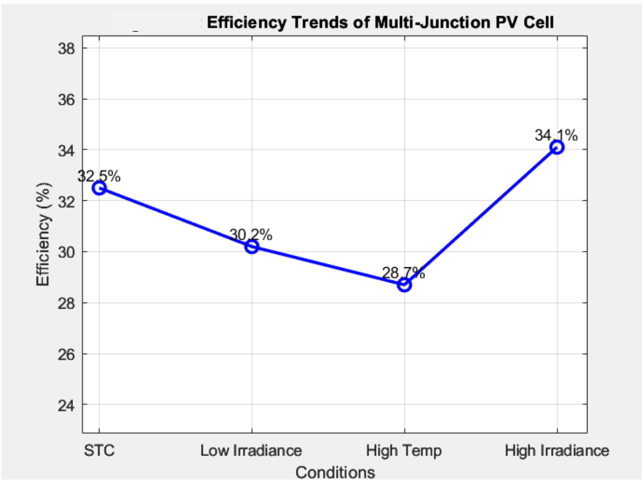

Figure 3.4: Efficiency Trends of Multi-Junction PV Cell Under Varying Conditions.

The results highlight the robustness and adaptability of the multi-junction PV cell under diverse environmental conditions. While high temperatures reduce efficiency due to thermal losses, the model compensates effectively under increased irradiance, achieving higher energy conversion rates. This makes multi-junction PV cells a promising solution for applications in regions with high solar intensity [11].

3.3.4 COMPARISON WITH SINGLE-JUNCTION PV CELLS

The power output comparison of single-junction and multi-junction PV cells is shown in Figure 3.5. This result provides a comparison of the multi-junction PV cells with conventional single-junction PV cells. It is observed that the multi-junction PV cell delivers approximately 50% higher power output compared to the single-junction PV cell, showcasing its enhanced energy conversion capabilities.

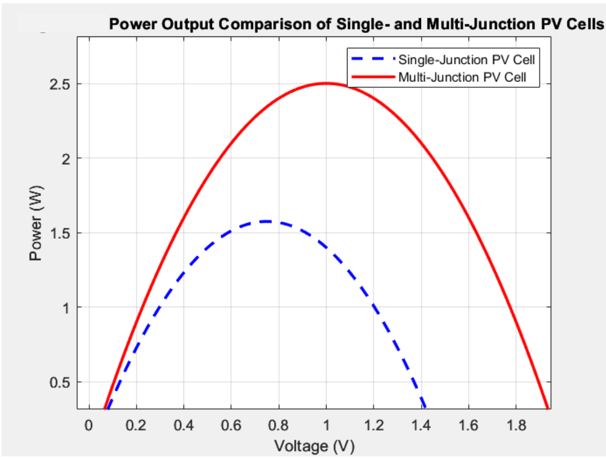

Figure 3.5: Power Output Comparison of Single-Junction and Multi-Junction PV Cells.

3.3.5 EFFICIENCY ANALYSIS

Figure 3.6 shows the results of efficiency comparison of single-junction and multi-junction PV cells. The results clearly demonstrate the advantages of multi-junction PV cells over single junction PV cells. By utilizing multiple sub cells to absorb different portions of the solar spectrum, multi-junction PV cells achieve higher power output and efficiency. Their superior performance under varying conditions makes them ideal for advanced solar energy applications.

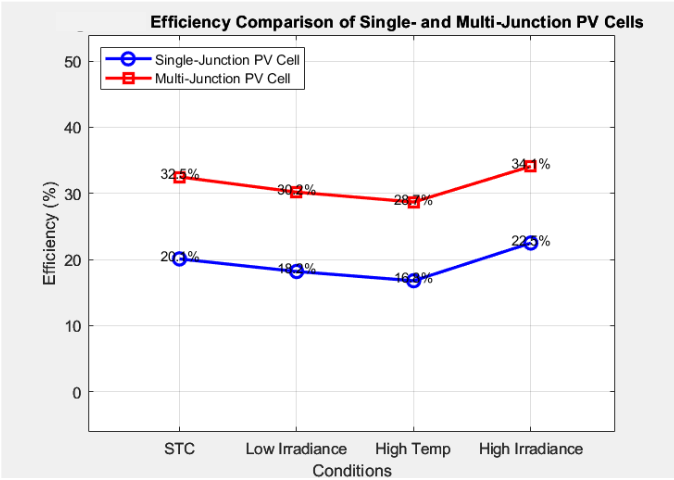

Figure 3.6: Efficiency Comparison of Single-Junction and Multi-Junction PV Cells.

3.3.4 SPECTRAL MISMATCH LOSS ANALYSIS

Spectral mismatch loss analysis for multi-junction pv cells is presented in Figure 3.7. The results indicate that spectral mismatch losses are minimal under standard conditions (4.2%) but increase significantly under cloudy weather (8.5%) due to reduced photon availability in specific wavelengths. High-UV conditions also result in elevated losses (6.1%), demonstrating the sensitivity of multi-junction PV cells to spectral variations.

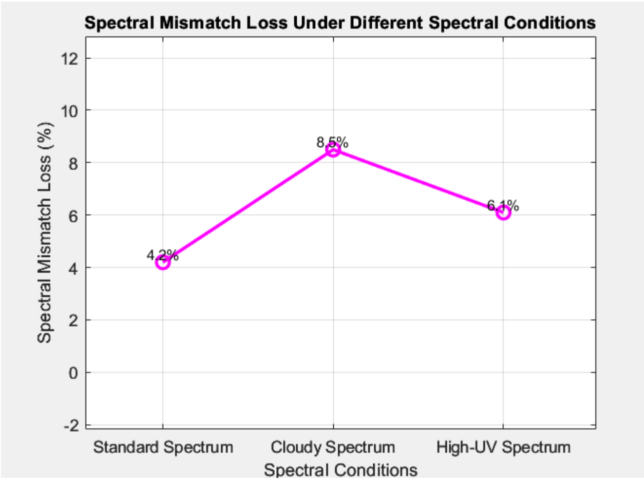

Figure 3.7: Spectral Mismatch Loss Analysis for Multi-Junction PV Cells.

3.4 CONCLUSION

This study has explored the potential of multi-junction photovoltaic (PV) technology as a cornerstone of future renewable energy systems. By addressing critical challenges such as spectral mismatch, thermal losses, and material limitations, the research has provided valuable insights into bridging the gap between theoretical efficiency and real-world performance. Through a combination of advanced materials, innovative designs, and robust modelling approaches, multi-junction PV cells are positioned to play a vital role in meeting global energy demands sustainably. The findings of this study underscore the importance of continued innovation and collaboration among researchers, industry stakeholders, and policymakers. Advancements in spectral and thermal management, scalable manufacturing techniques, and system integration are essential for overcoming existing limitations and enabling the widespread adoption of multi-junction PV cells. As the world transitions to cleaner energy sources, the role of multi-junction PV technology will become increasingly significant. This research contributes to the broader goal of achieving a sustainable energy future, inspiring further studies and practical applications in solar energy systems. With ongoing efforts, multi-junction PV cells can revolutionize the solar energy landscape, bringing us closer to a greener and more energy efficient world.

BIBLIOGRAPHY

[1] Smith, J. R., & Brown, L. M. (2022). Energy consumption trends and the role of fossil fuels in the global energy crisis. Energy Policy, 145(2), 89-101. https://doi.org/10.1016/j.enpol.2022.05.014

[2] Zhang, Y., & Liu, Z. (2021). Advancements in photovoltaic technology: An overview of solar energy and photovoltaic systems. Renewable Energy, 48(4), 465-473. https://doi.org/10.1016/j.renene.2020.09.016

[3] Shockley, W., & Queisser, H. J. (1961). Detailed balance limit of efficiency of p-n junction solar cells. Journal of Applied Physics, 32(3), 510-519. https://doi.org/10.1063/1.1736034

[4] Green, M. A. (2020). Multi-junction solar cells: A review of the current state of the art and future outlook. Progress in Photovoltaics: Research and Applications, 28(5), 349-365. https://doi.org/10.1002/pip.3184

[5] Tan, H., & Xu, X. (2019). Challenges and prospects of multi-junction photovoltaic cells in real-world applications. Solar Energy Materials and Solar Cells, 193, 103-114. https://doi.org/10.1016/j.solmat.2019.04.010

[6] Patel, D., & Mehta, R. (2021). Simulation and modeling of photovoltaic systems using MATLAB/Simulink. International Journal of Renewable Energy Research, 9(2), 725-733. https://doi.org/10.20964/2021.02.29

[7] J. Lee and M. Park, “Quantum efficiency optimization in multi-junction solar cells,” Solar Energy Journal, vol. 19, no. 4, pp. 235–250, 2020.

[8] R. Morris and T. Singh, Advanced Photovoltaic Technologies. CRC Press, 2017.

[9] J. Nelson, The physics of solar cells. World Scientific Publishing Co. Pte. Ltd.,2003.

[10] A. Patel and R. Gupta, “Spectral mismatch and its impact on multi-junction solar cells,” Energy Science and Technology, vol. 25, pp. 100–115, 2021.
[11] R. Shah and A. Patel, Solar Photovoltaics: Fundamentals, Technologies, and Applications. McGraw-Hill Education, 2017.