

A SIMULATION STUDY OF PHOTOVOLTAIC
MODELLING FOR DC-DC CONVERTER
SYSTEM

A'AZIMAH BINTI SA'ADON ZUBIR

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : A'azimah Binti Sa'adon Zubir
Date of Birth : 13 Mac 1992
Title : A Simulation of Photovoltaic Modelling for DC-DC Converter
System
Academic Session : Semester 1 2016/2017

I declare that this thesis is classified as:

- CONFIDENTIAL (Contains confidential information under the Official Secret Act 1997)*
- RESTRICTED (Contains restricted information as specified by the organization where research was done)*
- OPEN ACCESS I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserve the right as follows:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:



(Student's Signature)

920313085562

Date:26/12/2016



(Supervisor's Signature)

Mohd Shafie Bin Bakar

Date:26/12/2016

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter page 2 from the organization with the period and reasons for confidentiality or restriction.



SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of

shafie

(Supervisor's Signature)

Full Name : MOHD SHAFIE BIN BAKAR

Position : LECTURER

Date : 26 DECEMBER 2016



STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

A handwritten signature in black ink, appearing to read 'A'Azimah'.

(Student's Signature)

Full Name : A'AZIMAH BINTI SA'ADON ZUBIR

ID Number : EC11074

Date : 26 DECEMBER 2016

A SIMULATION STUDY OF PHOTOVOLTAIC MODELLING FOR DC-DC
CONVERTER SYSTEM

A'AZIMAH BINTI SA'ADON ZUBIR

Thesis submitted in fulfillment of the requirements
for the award of the degree of the
Bachelor of Electrical Engineering (Hons.) (Power Systems)

Faculty of Electrical & Electronics Engineering

UNIVERSITI MALAYSIA PAHANG

DECEMBER 2016

ACKNOWLEDGEMENT

First and foremost I would like to extend my sincere gratitude to my project supervisor Mr. Mohd Shafie bin Bakar for his patient, advice and guidance for me to complete the project.

My appreciation goes to my beloved friends for the support and help when I have any difficulty in life especially when I am completing this project.

Finally, a lot of thanks to my loving parents who always encourage me to complete the project and pray for my happiness.

ABSTRAK

Sel fotovoltaik menukarkan cahaya matahari terus kepada tenaga elektrik. Sistem kuasa fotovoltaik, digunakan secara meluas sebagai sumber tenaga kerana sifatnya yang mesra alam. Terdapat dua parameter yang memberi kesan kepada keluaran sel-sel fotovoltaik iaitu suhu fotovoltaik dan sinaran matahari. Penukar arus terus,(AT) menukarkan voltan AT ke tahap voltan AT yang berbeza dan mengawal voltan. Dalam projek ini, sebuah modul fotovoltaik direka dalam persekitaran Matlab Simulink untuk menguji kesan suhu sel fotovoltaik dan sinaran matahari kepada voltan keluaran dan arus keluaran modul fotovoltaik. Modul fotovoltaik yang dimodelkan secara pengiraan matematik ditambah dengan sambungan elektrik untuk menjadikan sebuah model fizikal modul fotovoltaik. Masukan untuk modul fotovoltaik adalah suhu antara 5 hingga 100 °C dan sinaran matahari antara 100 hingga 1000 W/m². Penukar turun AT disambungkan dengan keluaran modul fotovoltaik untuk menurunkan dan mengawal keluaran PV dengan kitar tugas 0.4 kepada nilai yang sesuai untuk bateri atau peralatan AT. Keluaran sel-sel fotovoltaik berbeza mengikut suhu sel fotovoltaik dan sinaran matahari. Kuasa maksimum modul fotovoltaik dihasilkan apabila suhu sel adalah 25 °C dan sinaran 1000 W/m². Penukar AT turun menurunkan keluaran voltan daripada modul fotovoltaik dan kecekapannya adalah sekitar 34%.

ABSTRACT

Photovoltaic (PV) cells convert sunlight directly to electricity. There are two critical parameters that affect the output of PV cells that are temperature of PV cells and irradiance. The DC-DC converter converts dc voltages to different dc voltage level and provide regulated output. In this project an equivalent PV module are modelled in Matlab Simulink environment to test the effect of PV cells temperature and irradiance to the PV module output. The PV module mathematically modelled to calculate the current of PV module and feed into controlled current source to add electric port to create physical model of PV module. The inputs of PV module are temperature from 5-100 °C and irradiance from 100 to 1000 W/m². The DC-DC buck converter then feed with the PV module output to step down and regulate the output of PV with 0.4 of duty cycle to the compatible value for batteries or dc appliances. The output of PV cells varies with the temperature of PV cells and irradiance. The maximum power of PV module gained when the cell temperature is 25 °C and the irradiance is 1000 W/m². The DC-DC buck converter step down the voltage output from PV module and the efficiency is around 34%.

TABLE OF CONTENT

DECLARATION	
TITLE PAGE	i
ACKNOWLEDGEMENT	ii
ABSTRAK	iii
ABSTRACT	iv
TABLE OF CONTENT	v
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF SYMBOLS	ix
LIST OF ABBREVIATION	xi
CHAPTER 1 INTRODUCTION	1
1.1 Background	1
1.2 Scope of Project	1
1.3 Problem Statement	2
1.4 Objectives	2
1.5 Thesis Outline	1
CHAPTER 2 LITERATURE REVIEW	2
2.1 Introduction	2
2.2 Solar Energy	2
2.2.1 Solar Radiation	2
2.3 Photovoltaic Power System	2

2.3.1	Types of PV Power System	2
2.3.2	PV Technology	3
2.3.3	Factors Affecting Output	4
2.3.4	PV Mathematical Modelling	6
2.4	DC-DC BUCK CONVERTER	8
2.4.1	Output Voltage Ripple	11
2.4.2	Continuous Conduction Mode and Discontinuous Conduction Mode	12
CHAPTER 3 METHODOLOGY		13
3.1	Introduction	13
3.2	PV Module Modelling	13
3.3	PV Module and Buck Converter	15
CHAPTER 4 RESULT & DISCUSSION		17
4.1	Introduction	17
4.2	PV Module Output	17
4.3	Buck Converter Analysis	20
CHAPTER 5 CONCLUSION AND RECOMMENDATION		24
5.1	Conclusions	24
5.2	Future Recommendation	25
REFERENCES		26
APPENDIX A1 DATASHEET OF kyocera-kc200gt pv module		28
APPENDIX b1 pv module and converter system		30
APPENDIX b2 pv module inside subsystem		31

LIST OF TABLES

Table 2.1:	PV nomenclature.	3
Table 3.1:	Kyocera-KC200GT PV module parameter	13
Table 3.2:	Parameter of Buck Converter	15

LIST OF FIGURES

Figure 2.1:	Nomenclature of cell, module, string and array.	4
Figure 2.2:	Datasheet I-V characteristic curve with dependence of temperature	5
Figure 2.3:	Datasheet I-V characteristic curve with dependence of irradiance	5
Figure 2.4:	PV module equivalent circuit diagram	6
Figure 2.5:	Equivalent circuit of dc buck converter	8
Figure 3.1:	Mathematical model of PV module	14
Figure 3.2:	Signal builder for different irradiance	14
Figure 3.3:	Signal builder with different PV cell temperature	15
Figure 3.4:	Buck converter system with PV module	16
Figure 4.1:	I-V Characteristic curve with different irradiance	18
Figure 4.2:	P-V characteristic curve with different irradiance	18
Figure 4.3:	I-V characteristic curve with different PV cell temperature	19
Figure 4.4:	P-V characteristic curve with different PV cell temperature	20
Figure 4.5:	Voltage ripple against PV cell temperature graph	21
Figure 4.6:	Efficiency against PV cell temperature graph	21
Figure 4.7:	Output voltage ripple against irradiance graph	22
Figure 4.8:	Buck converter efficiency against irradiance graph	23

LIST OF SYMBOLS

G	Irradiance
H	Irradiation
I_{PV}	Light generated current
I_D	Diode current
R_{sh}	Shunt resistor
R_s	Series resistor
I_0	Reverse saturation current
q	Electron charge
k	Boltzmann's constant
α	Ideality constant
V_t	Thermal voltage of PV module
N_s	Number of series of PV cells
I_{SC}	Short circuit current
I_{pvn}	Light generated current at standard condition
G_n	Nominal irradiance
Δ_T	Different of actual PV cell temperature and nominal temperature
V_{mp}	PV module maximum voltage
I_{mp}	PV module maximum current
P_{mp}	PV module maximum current
V_{OC}	Open circuit voltage

Kv Voltage temperature coefficient

Ki Current temperature voltage

LIST OF ABBREVIATION

PV	Photovoltaic
AT	Arus Terus
DC	Direct current
PSH	Peak sun hour
CCM	Continuous Conduction Mode
DCM	Discontinuous Conduction Mode

CHAPTER 1

INTRODUCTION

1.1 Background

The project is about to analyse PV power system components which are PV module and DC-DC converter.

The PV module output can varies by the surrounding condition such as irradiance and the PV cell temperature. DC-DC converter is an electronic technology that converts DC voltage to another level of DC voltage and provide regulated voltage. The DC buck converter converts higher level DC voltages to lower DC voltages to provide compatible DC voltage for PV power system components such as battery charge controller, battery, inverter and DC appliances.

1.2 Scope of Project

The works of the project are done under the following scopes:

- i. Design and develop software simulation of PV module.
- ii. Design and develop software simulation of DC-DC buck converter with developed PV module as the electric source for the DC-DC buck converter.

1.3 Problem Statement

- i. PV panel output voltage and current are affected by surrounding condition.
- ii. The PV output voltage not compatible with battery and DC appliances.

1.4 Objectives

The objectives of this project are:

- i. To study the PV module output based on effect of irradiance and temperature of PV cell.
- ii. To analyse the buck converter output with PV module as the electric source.

1.5 Thesis Outline

Chapter 1 (Introduction)

- a. Basic information and overview of the project.
- b. Consist of problem statements that lead to the development of the project.
- c. The objectives and the scope of the project.

Chapter 2 (Literature Review)

- a. This chapter review on the knowledge and past experiment regarding this project.

Chapter 3 (Methodology)

- a. The methods that used to develop this project will be review in this chapter.
- b. Provide block diagrams and software descriptions.

Chapter 4 (Result and Analysis)

Chapter 5 (Conclusion and recommendation)

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter is to provide reviews on the past references of the related to the PV power system, PV modelling, and DC-DC converter. Beside the listed reviews, reviews on the other relevant research effort also provided. The review is organized chronologically.

2.2 Solar Energy

2.2.1 Solar Radiation

Solar radiation can be discussed in terms of irradiance (G), irradiation (H) and Peak Sun Hour (PSH). Irradiance can be defined as the intensity of solar power at a point of observation with conventional unit (W/m^2). Irradiation is the intensity of solar energy at a point of observation and while PSH is solar insolation which a particular location would receive if the sun were shining at its maximum value for a certain number of hours.[1][2]

2.3 Photovoltaic Power System

2.3.1 Types of PV Power System

PV is a technology that converts solar radiation directly into electricity using solar cells. The components that build up PV system are PV modules, battery bank, charge controller, inverter and loads. There are two types of PV system which are grid direct system and battery based system. The grid directs refer to battery less system. These types of PV system use least component as it does not involving a battery bank.

The inverter is able to automatically control the flow of electricity from PV array to the grid. Battery based system or stand-alone system uses battery as one of the PV system component. Stand-alone battery based system support all loads in a home. [1- 3]

2.3.2 PV Technology

2.3.2.1 Types of PV cell Technology

Majority of PV cells made from silicon (Si).The common types of Si technology assemble are monocrystalline and polycrystalline cells. Another type of PV cell technology is amorphous silicon that is in thin film cells.[1- 2]

2.3.2.2 PV Nomenclature

There are some common terms that used to describe PV technology and PV system design. Table 2.1 the basic terms in PV system.[1]

Table 2.1: PV nomenclature.

PV	Description
Cell	The basic unit of PV
Module	A series connection of PV cells for higher power output
String	A series connection of PV modules for higher voltage output
Array	A combination of string of PV modules for desired production

Source: Solar Photovoltaic Power : Fundamentals. 2012.

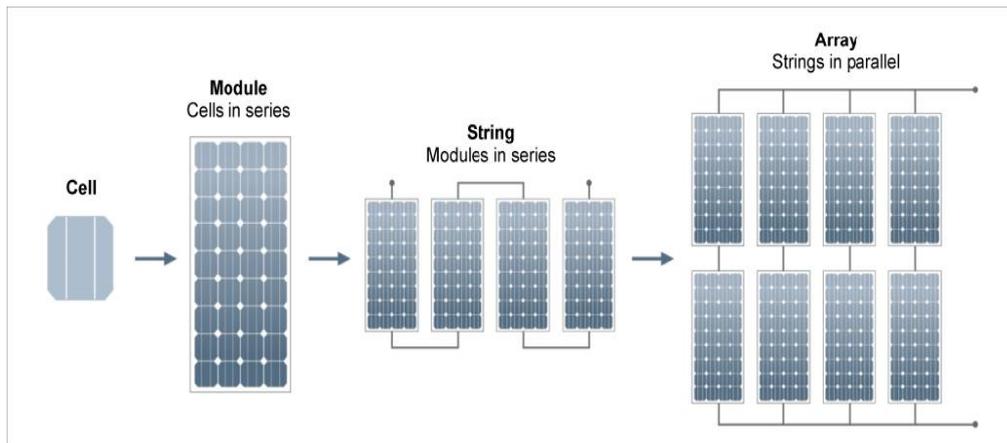


Figure 2.1: Nomenclature of cell, module, string and array.

Source: Photovoltaic systems.” [Online][4]

2.3.3 Factors Affecting Output

There are two most critical ambient parameters that affect the output of PV cells that are temperature of PV cells and irradiance. [1-2]

When the PV module exposed to sun, the module temperature gets elevated. The temperature of cell in operation must be given serious attention in PV system design.[1]

Figure 2.2 shows the IV characteristic curve of a PV module with different cell temperature. The IV curve shows marginal effect on current and drastic decrease on voltage as the cell temperature gets higher.[1]

However the current output of a PV module is highly depend on irradiance. As long as there is sunlight, the PV module does not change dramatically.[1]

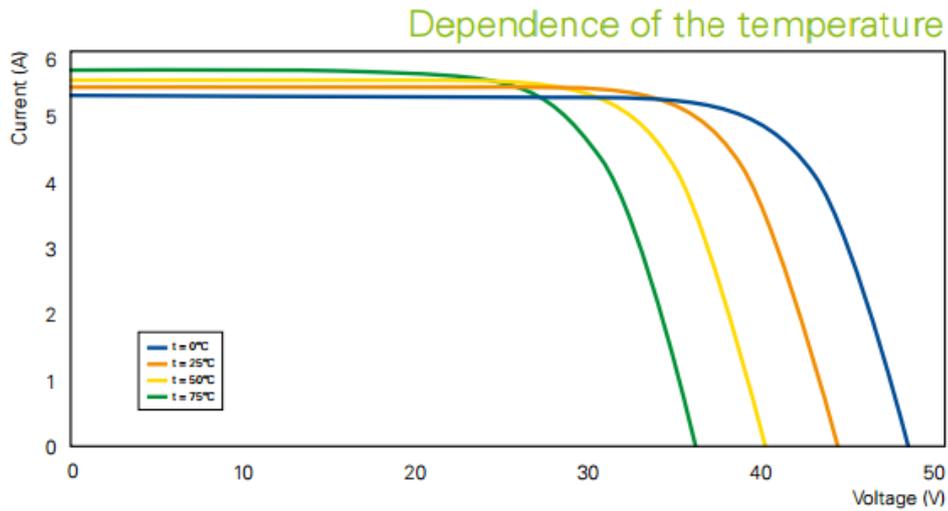


Figure 2.2: Datasheet I-V characteristic curve with dependence of temperature
Source: BP 4175B [5]

Figure 2.3 shows the IV characteristic curve of a PV module with different irradiance. The IV curve shows that there are linear increase of PV output current and for the voltage has marginal increase as the amount of irradiance increase.[1]

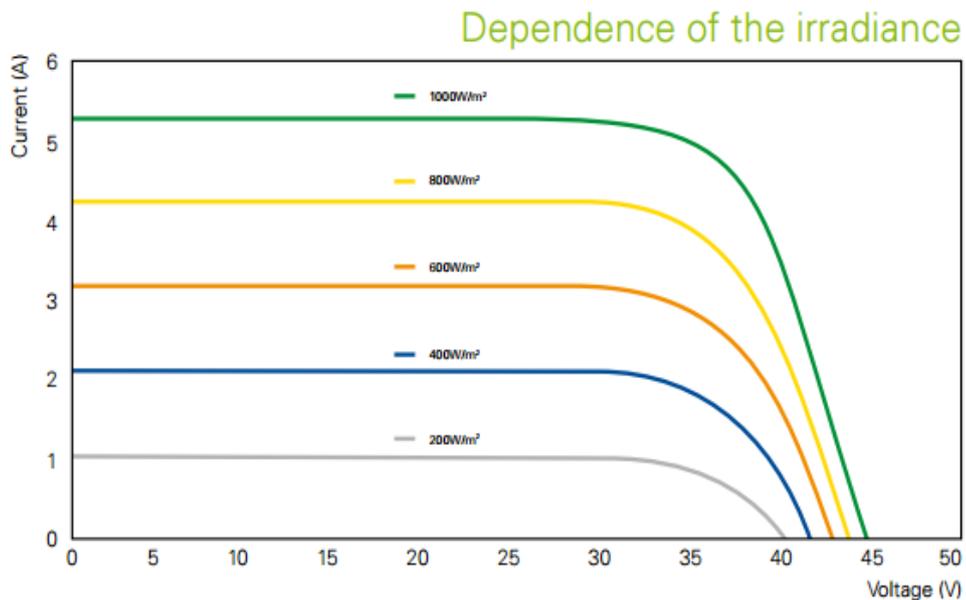


Figure 2.3: Datasheet I-V characteristic curve with dependence of irradiance
Source: BP 4175B [5]

2.3.4 PV Mathematical Modelling

The PV module equivalent circuit diagram of a p-n junction represented as in Figure 2.4. The I_{PV} is the light generated current, the I_D is the diode current, R_{sh} is the shunt resistor, R_s is the series resistor and I and V are current and voltage across the PV cell respectively.

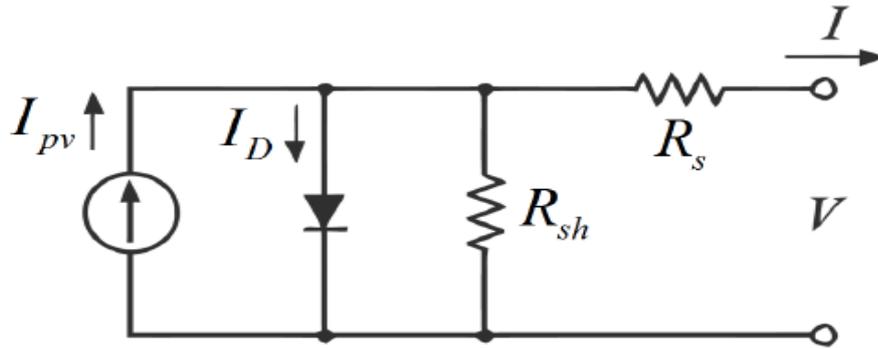


Figure 2.4: PV module equivalent circuit diagram

Source: pvpmc.sandia.gov[6]

The basic equation of the ideal PV cell that describe the the I-V characteristic is as equation 2.1 where the I_{PV} is the current that generated by the incident light where the incident light is directly proportional to the sun radiation. I_D is the Shockley diode equation, I_0 is the reverse saturation current of the diode [A], q is the electron charge [$1.60217646 \cdot 10^{-19}$ C], k is the Boltzmann constant [$1.3806503 \cdot 10^{-23}$ J/K], T [K] is the temperature of the p-n junction, and α is the diode ideality constant.[7-10]

$$I = I_{PV} - I_0 \left[\exp\left(\frac{qV}{\alpha kT}\right) - 1 \right] \quad 2.1$$

However, for the practical PV module, the basic equation of ideal PV cell does not represent the practical PV module I-V characteristic because the practical PV module composed of more than one connected PV cells which presented as R_s and R_{sh} in Figure 2.4. Thus equation below derives from equation that includes R_s and R_{sh} . [7, 10]

$$I = I_{PV} - I_0 \left[\exp\left(\frac{V+R_s I}{V_t \alpha}\right) - 1 \right] - \frac{V+R_s I}{R_{sh}} \quad 2.2$$

V_t is the thermal voltage of the PV module. V_t derives from equation 2.3 and N_S is the number of PV cells that connected in series. [7,10]

$$V_t = N_S kT/q \quad 2.3$$

From the manufacturer's datasheet there is no required parameter provided for adjusting PV module such as I_{PV} , R_S and R_{Sh} . Based on the I-V curves for irradiation and PV cell temperature, the adjustment and validation made became easier. The assumption of $I_{SC} = I_{PV}$ is used in PV models because in practical R_S is low and R_{Sh} is high in resistance. [7,10]

I_{pvn} [A] in equation 2.4 is light generated current at standard condition 25°C and 1000 W/m². Δ_T is the difference of actual temperature and nominal temperature. G and G_n are actual irradiance and nominal irradiance. [7,10]

$$I_{PV} = (I_{pvn} + K_I \Delta_T) \frac{G}{G_n} \quad 2.4$$

The PV model improved by the following equation,

$$I_0 = \frac{I_{scn} + K_I \Delta_T}{\exp\left(\frac{V_{ocn} + K_V \Delta_T}{\alpha V_t}\right) - 1} \quad 2.5$$

The value of R_S and R_{Sh} are unknown. The value of R_S and R_{Sh} then determine by the iteration of equation below with initial guess of $R_S = 0$ to find the best value of R_S and R_{Sh} that meets the IV curves from datasheet, [7,10]

$$R_{Sh} = V_{mp} (V_{mp} + I_{mp} R_S) \left\{ V_{mp} I_{pv} - V_{mp} I_0 \exp\left[\frac{(V_{mp} + I_{mp} R_S) q}{N_S \alpha kT}\right] + V_{mp} I_0 - P_{mp} \right\} \quad 2.6$$

2.4 DC-DC BUCK CONVERTER

The dc-dc converter is a power electronic circuit that convert and regulated voltages to another level of dc voltage. The buck converter is one of dc-dc converter that convert dc voltage to lower level of dc voltage means that the buck converter is a step down converter.[11]

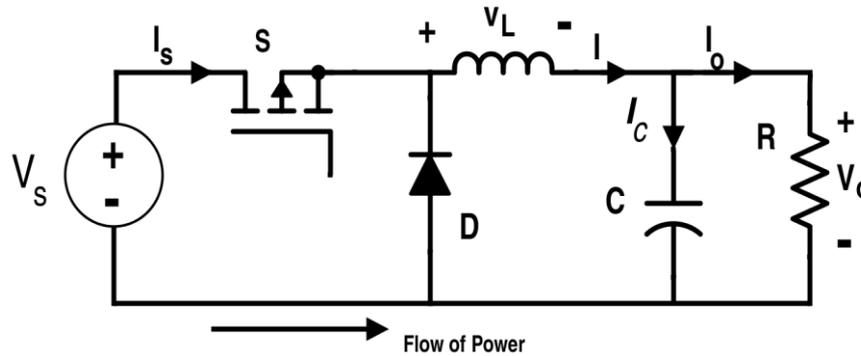


Figure 2.5: Equivalent circuit of dc buck converter

Source: www.allaboutcircuits.com [12]

When the switch is closed, the diode is reverse biased. Thus the voltage across inductor is

$$V_L = V_S - V_O = L \frac{di_L}{dt} \quad 2.7$$

rearranging,

$$\frac{di_L}{dt} = \frac{V_S - V_O}{L} \quad 2.8$$

The current increase linearly as the derivative of current is positive constant. To compute the change in current while switch is closed the equation modified as

$$\begin{aligned} \frac{di_L}{dt} &= \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_S - V_O}{L} \quad 2.9 \\ (\Delta i_L)_{closed} &= \left(\frac{V_S - V_O}{L} \right) DT \end{aligned}$$

When the switch is open, diode is forward biased to carry inductor current. The voltage across the inductor is

$$V_L = -V_O = L \frac{di_L}{dt} \quad 2.10$$

rearranging,

$$\frac{di_L}{dt} = \frac{-V_O}{L} \quad 2.11$$

The current linearly decrease as the derivative of current in the inductor a negative constant. The current inductor changes is

$$\begin{aligned} \frac{\Delta i_L}{\Delta t} &= \frac{\Delta i_L}{(1-D)} = \frac{-V_O}{L} \quad 2.12 \\ (\Delta i_L)_{open} &= \left(\frac{-V_O}{L}\right)(1-D)T \end{aligned}$$

The steady state operation needs that inductor current at the end of the switching cycle be the same as the beginning that the net change in inductor current over one period is zero which

$$(\Delta i_L)_{closed} + (\Delta i_L)_{open} = 0 \quad 2.13$$

equations are substitute into

$$\left(\frac{V_S - V_O}{L}\right)DT + \left(\frac{-V_O}{L}\right)(1-D)T = 0 \quad 2.14$$

then V_O is

$$V_O = V_S V_D \quad 2.15$$

so the buck converter will produce lower output that is or equal to the input.

Since average capacitor current must equal to zero during steady state operation, the average inductor current must equal as the average current in the load resistor,

$$I_L = I_R = \frac{V_O}{R} \quad 2.16$$

The maximum and minimum values of the inductor current are computed as

$$\begin{aligned} I_{max} &= I_L + \frac{\Delta i_L}{2} \quad 2.17 \\ &= \frac{V_O}{R} + \frac{1}{2} \left[\frac{V_O}{L} (1 - D) T \right] = V_O \left[\frac{1}{R} + \frac{(1 + D)}{2Lf} \right] \end{aligned}$$

$$\begin{aligned} I_{min} &= I_L - \frac{\Delta i_L}{2} \quad 2.18 \\ &= \frac{V_O}{R} - \frac{1}{2} \left[\frac{V_O}{L} (1 - D) T \right] = V_O \left[\frac{1}{R} - \frac{(1 - D)}{2Lf} \right] \end{aligned}$$

as $f = \frac{1}{T}$ is the switching frequency in hertz.

The continuous current in inductor need to be verified to validated the analysis. To check for continuous current, the minimum inductor must be positive.

$I_{min} = 0$ is the boundary between continuous and discontinuous current,

$$\begin{aligned} I_{min} = 0 &= V_O \left[\frac{1}{R} - \frac{(1-D)}{2Lf} \right] \quad 2.19 \\ (Lf)_{min} &= \frac{(1 - D)R}{2} \end{aligned}$$

is the desired switching frequency has determined

$$L_{min} = \frac{(1-D)R}{2f} \quad 2.20$$

where L_{min} is the minimum inductance required for continuous current.[11][13]

2.4.1 Output Voltage Ripple

For analysis, the capacitor was assumed large to keep the output voltage being constant. However, the output voltage cannot be kept perfectly constant with a finite capacitance in practice. The output voltage ripple is computed from the voltage - current relationship of the capacitor where[11]

$$I_c = I_L + I_R \quad 2.21$$

while capacitor current is positive the capacitor charging , so

$$\begin{aligned} Q &= CV_o \\ \Delta Q &= C\Delta V_o \\ \Delta V_o &= \frac{\Delta Q}{C} \end{aligned} \quad 2.22$$

the change in charge ΔQ

$$\Delta Q = \frac{1}{2} \left(\frac{T}{2} \right) \left(\frac{\Delta i_L}{2} \right) = \frac{T\Delta i_L}{8} \quad 2.23$$

resulting in

$$\Delta V_o = \frac{T\Delta i_L}{8} \quad 2.24$$

using equation

$$\Delta V_O = \frac{T}{8C} \frac{V_O}{L} (1 - D)T = \frac{V_O(1-D)}{8LCf^2} \quad 2.25$$

thus the fraction of output voltage is

$$\frac{\Delta V_O}{V_O} = \frac{1-D}{8LCf^2} \quad 2.26$$

2.4.2 Continuous Conduction Mode and Discontinuous Conduction Mode

Continuous conduction mode (CCM) is when the current in the energy transfer inductor do not goes to zero between the switching cycles. While in discontinuous conduction mode (DCM) the current goes to zero during the switching cycles.[14]

CHAPTER 3

METHODOLOGY

3.1 Introduction

The project was developed in the MATLAB Simulink environment. The information for the project was gained during the literature review. Then the mathematical modelling of a PV module and the DC-DC buck converter was developed in MATLAB Simulink environment.

3.2 PV Module Modelling

A set of PV module parameter was taken from a manufacturer datasheet which is datasheet of Kyocera-KC200GT. The PV module is a polycrystalline type. The mathematical modelling of the PV module was designed in Matlab Simulink environment using parameter in Table 3.1.

Table 3.1: Kyocera-KC200GT PV module parameter

Parameter	Value
I_{mp}	7.61 A
V_{mp}	26.3 V
P_{mp}	200.143 W
I_{sc}	8.21 A
V_{oc}	32.9 V
K_V	-0.123 V/K
K_I	0.0032 A/K
N_S	54

The PV module was simulated to generate the I-V and P-V characteristic curves of PV module. The IV characteristic of PV module affected by different irradiance with constant PV cell temperature is generated by setting the signal builder of irradiance and temperature.

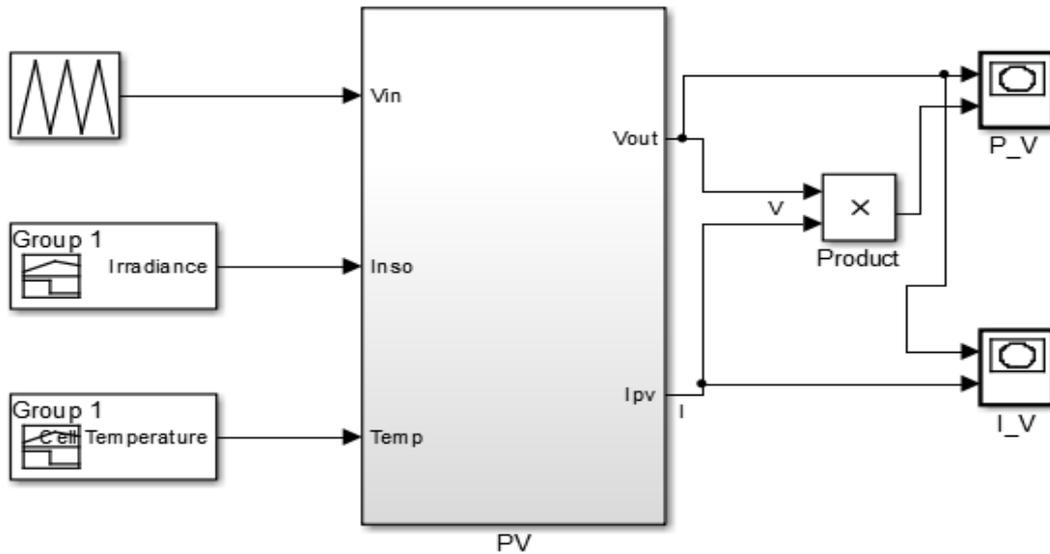


Figure 3.1: Mathematical model of PV module

Before simulated, the signal builders were modified to generate signal for 200, 400, 600, 800 and 1000 W/m^2 of irradiances and the PV cell temperature was set to constant at 25 °C.

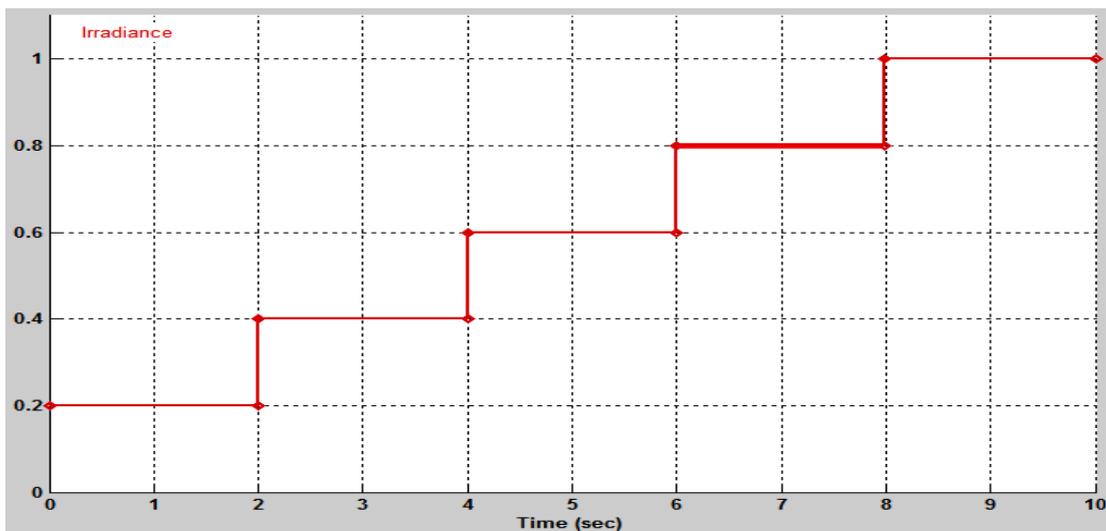


Figure 3.2: Signal builder for different irradiance

Then the signal builders are set with different cell temperatures 15, 25, 50, 75 and 100 C and constant 1000 W/m² of irradiance to see the effect of PV cell temperature.

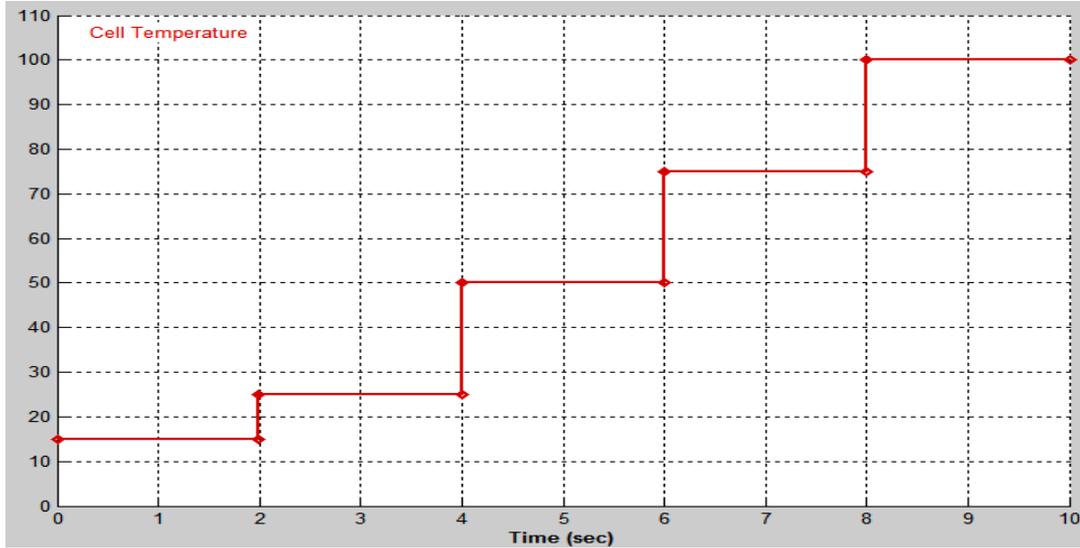


Figure 3.3: Signal builder with different PV cell temperature

3.3 PV Module and Buck Converter

The PV module was designed based on and based on PV module equivalent diagram in Figure 2.4 and Table 3.1 The value for R_{sh} and R_s was calculated and taken from previous research.[7] The buck converter was designed to step down the output voltage of PV module based on Table 3.2. Electric ports were added to the design to create physical model of PV module so the PV module can be connected to buck converter physically as electric source. The system of the buck converter was ensured in CCM operation by observing the I_L pattern is in CCM.

Table 3.2: Parameter of Buck Converter

Parameter	Value
Duty Cycle	0.4%
Frequency	50 kHz
Inductor	4 mH
Capacitor	100 μ F
Resistor	20 Ω

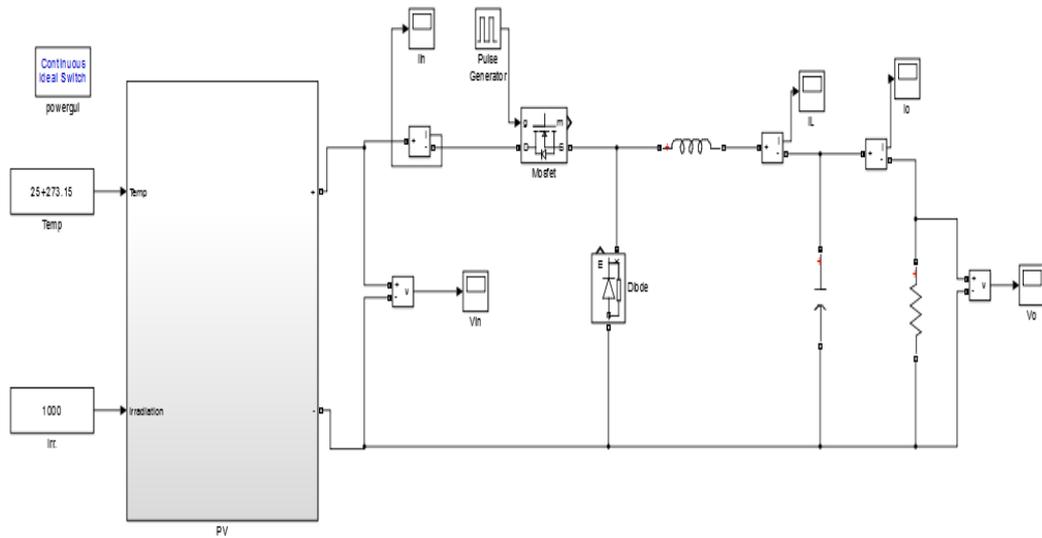


Figure 3.4: Buck converter system with PV module

The first set of data was taken by manipulating the input cell temperature of the PV module from range 0-100 °C and the irradiance is constant at 1000 W/m². The second set of data was taken for input from PV module with irradiance range from 100 to 1000 W/m² and the cell temperature set to constant value at 25 °C. The parameters that need to be observed are input voltage, input current, output voltage and output current of buck converter when the simulation was run. The parameters then used to calculate output voltage ripple and buck converter efficiency.

CHAPTER 4

RESULT & DISCUSSION

4.1 Introduction

From this project, the result was obtained by the simulation of the software. The results from the simulation will be compared with the theory situation.

4.2 PV Module Output

The simulation of the PV module resulted to generation of the graph for I-V characteristic curve graph and P-V characteristic curve graph based on PV cell temperature and irradiance.

From Figure 4.1, the y axis represents current and the x-axis represent voltage. The bottom line is when the irradiance is 200 W/m^2 and in ascending manner the upper line is when the irradiance is 1000 W/m^2 . The curve shows that the current outputs of PV module are more affected towards the different value of irradiance. The current are higher when the irradiance value increased. The value of outputs voltage also effected but not as great as the current.

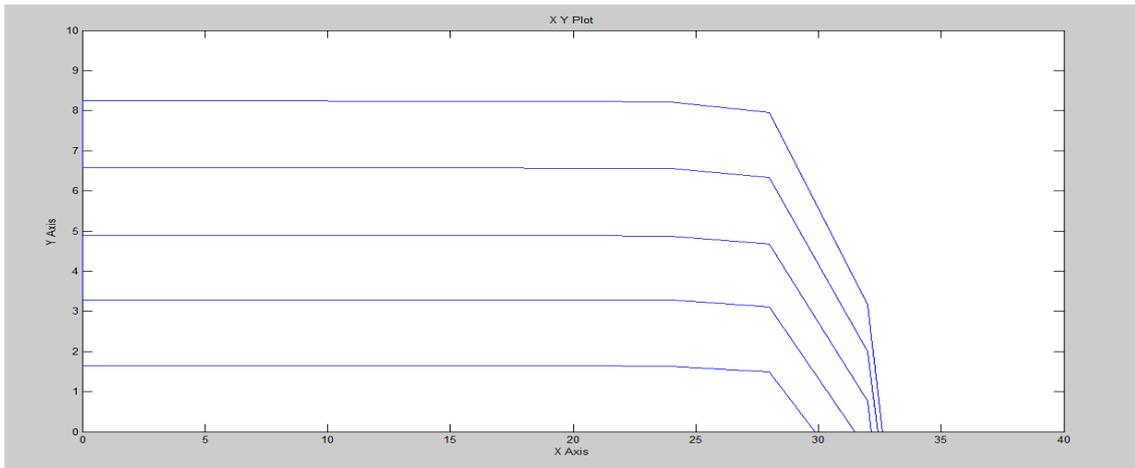


Figure 4.1: I-V Characteristic curve with different irradiance

In Figure 4.2 the y-axis represent power and the x-axis represent voltage. The same result goes to the power of the PV module. As irradiance increase the power generated from the PV module increase. Thus when irradiance at the highest value which is at the peak sun, power generated by PV module is at the maximum value.

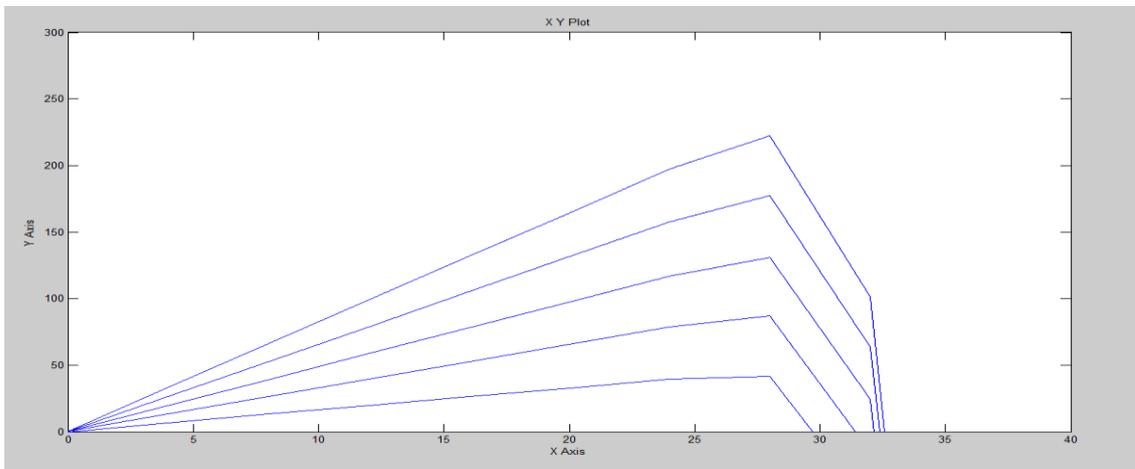


Figure 4.2: P-V characteristic curve with different irradiance

The other conditions that gives effects to the PV modue output is the temperature of the PV cells. The bottom line represent the curve when simulated at 100 °C and with descending manner the upper line is simulated at 15 °C. When the PV module was simulated with the variation of PV cell temperature and constant peak sun, 1000 W/m² irradiance, Result as Figure 4.3 is obtained. The output current were only slightly effected however the output voltage of the PV module were more effected. As the temperature goes higher the voltage value goes lower.

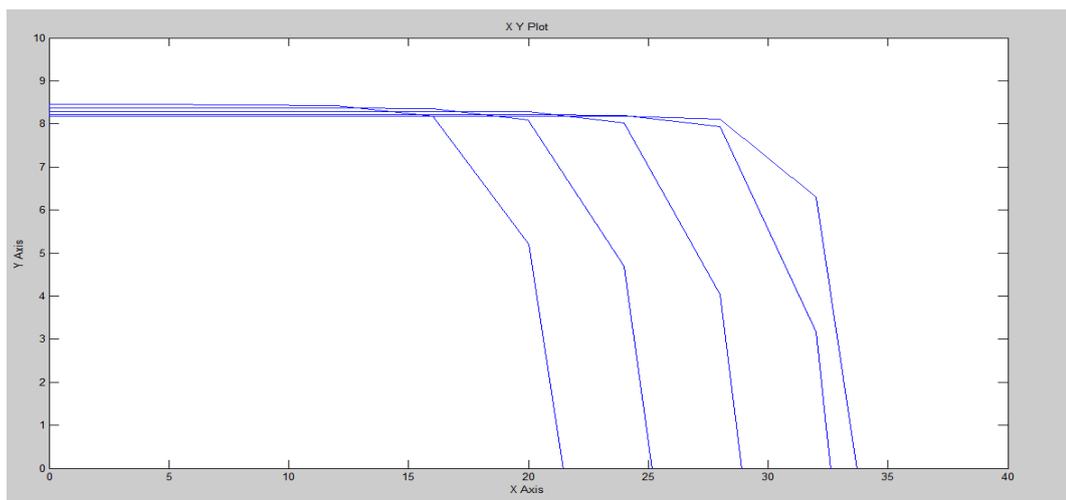


Figure 4.3: I-V characteristic curve with different PV cell temperature

Thus the power generated by the PV module goes lower as the temperature raised up. The PV module power generation drop when the temperature of the PV cell increases as shown in Figure 4.4

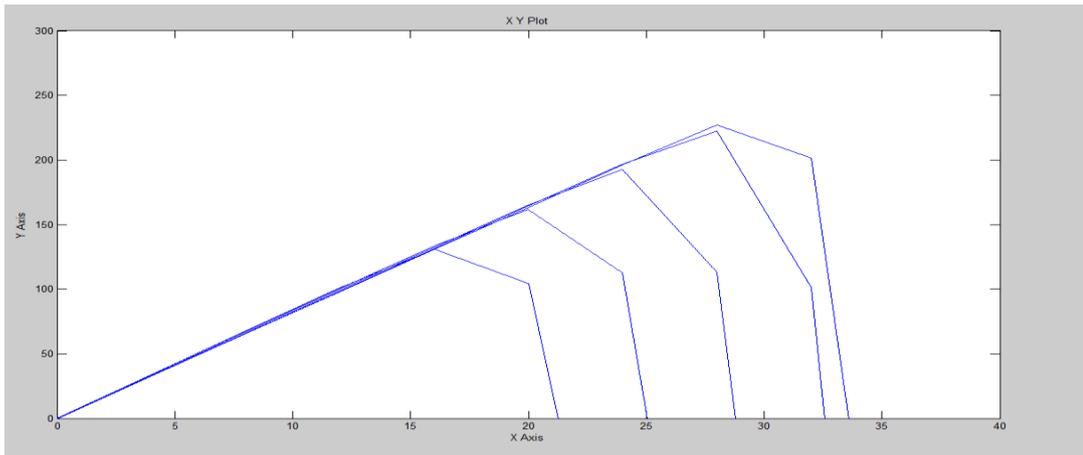


Figure 4.4: P-V characteristic curve with different PV cell temperature

4.3 Buck Converter Analysis

The result from the simulation of the buck converter in figure was collected and presented in graph.

Figure 4.5 shows the graph of output voltage ripple against PV cell temperature. The voltage ripple is quite small around 0.0003 to 0.0004. The voltage ripple gets higher at lower temperature and drops to 0.0003 at 60 which mean the voltage ripple is 0.0004 at higher voltage and the 0.0003 at lower voltage as the output voltage of PV module.

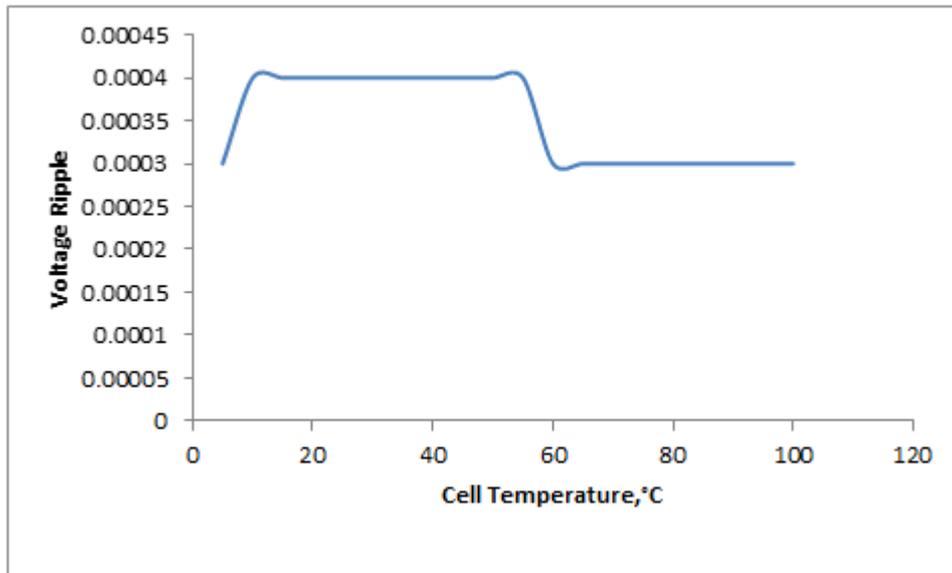


Figure 4.5: Voltage ripple against PV cell temperature graph

Figure 4.6 shows that the efficiency of buck converter decrease as the PV cell temperature increases. The efficiency of buck converter drops as the voltage drop and the efficiency of the buck converter is quite small about 34 to 35%.

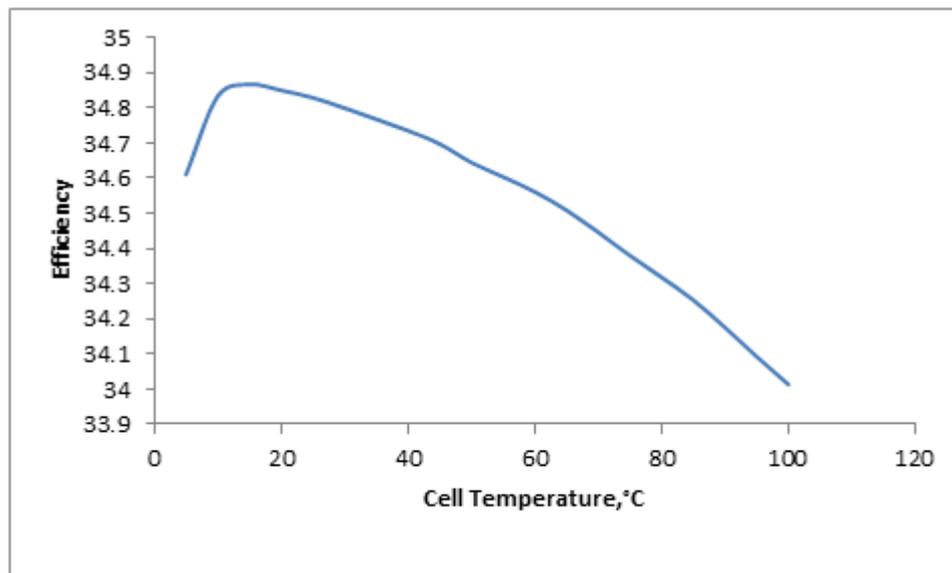


Figure 4.6: Efficiency against PV cell temperature graph

The output voltage ripples of the buck converter operated with various amount of irradiance are increasing as the irradiance increase however the output voltage ripple drops at 750 W/m² and rise again at 850 W/m² as shown in Figure 4.7

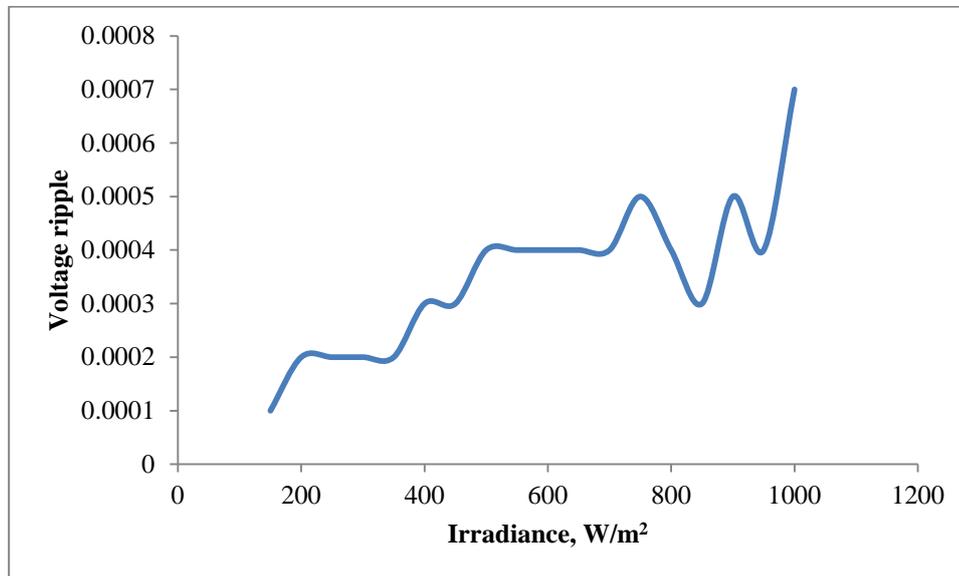


Figure 4.7: Output voltage ripple against irradiance graph

Graph in Figure 4.8 shows the increasing of the efficiency of the buck converter as the irradiance increase. The efficiency of the buck converter also small as the efficiency of the buck converter operated with various PV cell temperatures. The efficiency of the buck converter is around 30 to 35%.

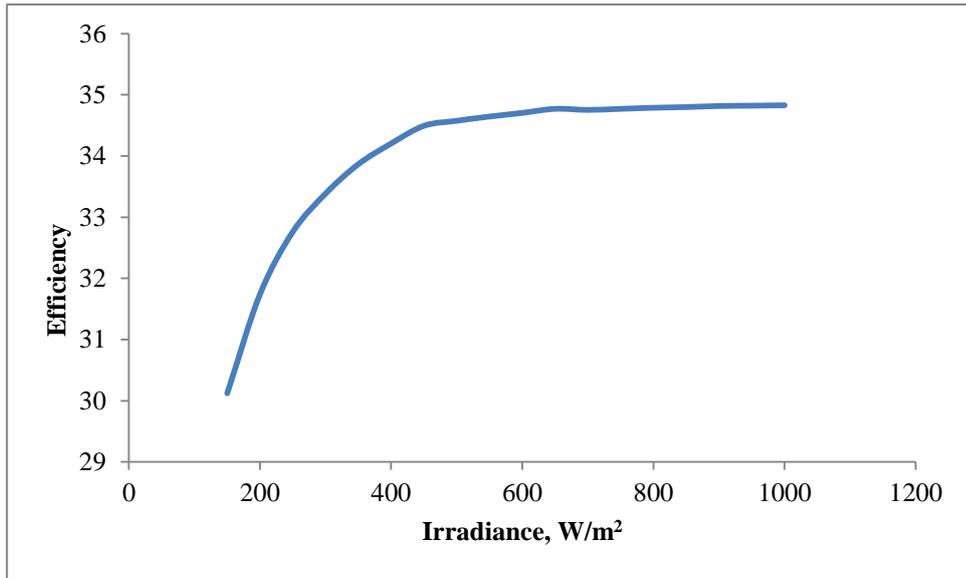


Figure 4.8: Buck converter efficiency against irradiance graph

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The main objectives of this project is achieved where the effect of irradiance and the temperature of PV panel to PV panel output was observed and studied from the simulation of PV panel mathematical modelling in MATLAB Simulink. The current output of PV panel is more affected than PV panel voltage output by the changes of the irradiance. The current output of PV panel increase as the irradiance increase. The Pmp was gained when the irradiance at 1000 W/m^2 . For the effect of PV panel temperature, the voltage output of PV panel are more effected than the current output of PV panel and the PV panel output voltage decrease as the PV panel temperature of PV panel increase. The maximum value of voltage, current and power was gained when the PV panel model tested at $25 \text{ }^\circ\text{C}$ and irradiance at 1000W/m^2 where V_{mp} , I_{mp} ,and P_{mp} is same as the data in PV panel datasheet from the manufacturer.

The analysis of the buck converter showed that the buck converter step down the input voltage from PV module. The output voltage ripple are small around 0.0004 for both sample of data with different PV cell temperature and irradiance. However the efficiency of the buck converter are small as with different PV cell temperature is around 34 % and decrease as the PV cell temperature increase. When the buck converter tested with different amount of irradiance, the buck converter efficiency also small around 30% to35% and the efficiency increase as the irradiance increase.

5.2 Future Recommendation

Absolutely, there are many improvements that can be applied to the project. Based on the project investigation, there are a few suggestions that may include into future research relating this project in order to have a better understanding and widening the knowledge about this project such as:

1. The power source of the project can be used with the other types of PV technologies or the other types of renewable energy to compare which one of the technologies is more efficient.
2. The full system of the project can be done in hardware to compare the result between the software and hardware results.
3. The efficiency of the buck converter can be increase by adjusting the parameter of the buck converter.

REFERENCES

- [1] S. Shaari, A. M. Omar, A. H. Haris, and S. I. Sulaiman, *Solar Photovoltaic Power : Fundamentals*. 2012.
- [2] H. Haberlin, *Photovoltaics : system design and practice*. West Sussex UK : Wiley, 2012.
- [3] R. Mayfield, *Photovoltaic design & installation for dummies*. Hoboken, NJ : Wiley, 2010.
- [4] G. Stapleton, S. Neill, G. Milne, C. Reardon, and C. Riedy, “Photovoltaic systems.” [Online]. Available: <http://www.yourhome.gov.au/energy/photovoltaic-systems>. [Accessed: 11-Oct-2016].
- [5] B. P. Solar and B. P. Solar, “BP 4175B.”
- [6] “Single Diode Equivalent Circuit Models.” [Online]. Available: <https://pvpmc.sandia.gov/modeling-steps/2-dc-module-iv/diode-equivalent-circuit-models/>. [Accessed: 13-Oct-2016].
- [7] M. G. Villalva, J. R. Gazoli, and E. F. Ruppert, “MODELING AND CIRCUIT-BASED SIMULATION OF PHOTOVOLTAIC ARRAYS,” vol. 14, no. 1, 2009.
- [8] M. G. Villalva, J. R. Gazoli, and E. R. Filho, “Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays,” vol. 24, no. 5, pp. 1198–1208, 2009.
- [9] H. Bellia, R. Youcef, and M. Fatima, “A detailed modeling of photovoltaic module using MATLAB,” *NRIAG J. Astron. Geophys.*, vol. 3, no. 1, pp. 53–61, 2014.
- [10] S. Sumathi, L. A. Kumar, and P. Surekha, *Solar PV and wind energy conversion systems : an introduction to theory, modeling with MATLAB/SIMULINK, and the role of soft computing techniques*. Springer, 2015.
- [11] E. R. C. Silva and M. E. Elbuluk, *Fundamentals of Power Electronics*. .

- [12] “AC-Equivalent Circuit Modelling,” 2015. [Online]. Available: <http://www.allaboutcircuits.com/technical-articles/ac-equivalent-circuit-modelling/>.
- [13] R. W. Erickson, “DC-DC Power Converters.”
- [14] J. Foutz, “Continuous (CCM) and Discontinuous Conduction Mode (DCM).” [Online]. Available: http://www.smpstech.com/mtblog/continuous_ccm_and_discontinuous_conduction_mode_dcm.html.

APPENDIX A1

DATASHEET OF KYOCERA-KC200GT PV MODULE



MODEL
KC200GT

THE NEW VALUE FRONTIER



KC200GT

HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE



LISTED

HIGHLIGHTS OF KYOCERA PHOTOVOLTAIC MODULES

Kyocera's advanced cell processing technology and automated production facilities produce a highly efficient multicrystal photovoltaic module. The conversion efficiency of the Kyocera solar cell is over 16%. These cells are encapsulated between a tempered glass cover and a pottant with back sheet to provide efficient protection from the severest environmental conditions. The entire laminate is installed in an anodized aluminum frame to provide structural strength and ease of installation. Equipped with plug-in connectors.



APPLICATIONS

KC200GT is ideal for grid tie system applications.

<ul style="list-style-type: none"> ● Residential roof top systems ● Large commercial grid tie systems 	<ul style="list-style-type: none"> ● Water Pumping systems ● High Voltage stand alone systems ● etc.
---	---

QUALIFICATIONS

● MODULE : UL1703 certified	● FACTORY : ISO9001 and ISO 14001
------------------------------------	--

QUALITY ASSURANCE

Kyocera multicrystal photovoltaic modules have passed the following tests.

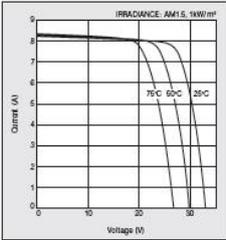
- Thermal cycling test ● Thermal shock test ● Thermal / Freezing and high humidity cycling test ● Electrical isolation test
- Hall impact test ● Mechanical, wind and twist loading test ● Salt mist test ● Light and water-exposure test ● Field exposure test

LIMITED WARRANTY

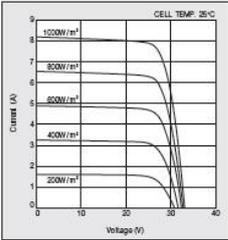
※1 year limited warranty on material and workmanship
 ※20 years limited warranty on power output: For detail, please refer to "category IV" in Warranty issued by Kyocera.
 (Long term output warranty shall warrant if PV Module(s) exhibits power output of less than 90% of the original minimum rated power specified at the time of sale within 10 years and less than 80% within 20 years after the date of sale to the Customer. The power output values shall be those measured under Kyocera's standard measurement conditions. Regarding the warranty conditions in detail, please refer to Warranty issued by Kyocera.)

ELECTRICAL CHARACTERISTICS

Current-Voltage characteristics of Photovoltaic Module KC200GT at various cell temperatures



Current-Voltage characteristics of Photovoltaic Module KC200GT at various irradiance levels



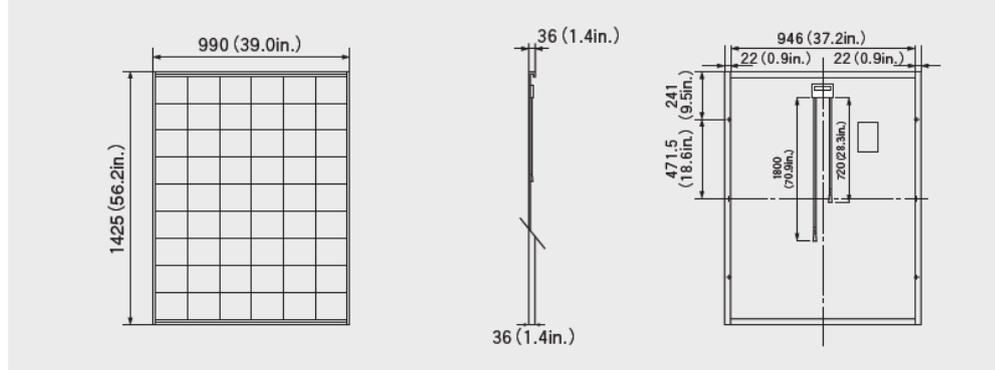
28

SPECIFICATIONS

KC200GT

Physical Specifications

Unit : mm (in.)



Specifications

Electrical Performance under Standard Test Conditions (*STC)	
Maximum Power (P _{max})	200W (+10%/−5%)
Maximum Power Voltage (V _{mpp})	26.3V
Maximum Power Current (I _{mpp})	7.61A
Open Circuit Voltage (V _{oc})	32.9V
Short Circuit Current (I _{sc})	8.21A
Max System Voltage	600V
Temperature Coefficient of V _{oc}	−1.23×10 ^{−1} V/°C
Temperature Coefficient of I _{sc}	3.18×10 ^{−3} A/°C
<small>*STC : irradiance 1000W/m², AM1.5 spectrum, module temperature 25°C</small>	
Electrical Performance at 800W/m ² , NOCT, AM1.5	
Maximum Power (P _{max})	142W
Maximum Power Voltage (V _{mpp})	23.2V
Maximum Power Current (I _{mpp})	6.13A
Open Circuit Voltage (V _{oc})	29.9V
Short Circuit Current (I _{sc})	6.62A
<small>NOCT (Nominal Operating Cell Temperature) : 47°C</small>	

Cells	
Number per Module	54
Module Characteristics	
Length × Width × Depth	1425mm(56.2in.)×990mm(39.0in.)×36mm(1.4in.)
Weight	18.5kg(40.7lbs.)
Cable	(+1720mm(28.3in.))(-1800mm(70.9in.))
Junction Box Characteristics	
Length × Width × Depth	1135mm(4.5in.)×76mm(3.0in.)×93mm(3.6in.)
IP Code	IP65
Reduction of Efficiency under Low Irradiance	
Reduction	7.8%
<small>Reduction of efficiency from an irradiance of 1000W/m² to 200W/m² (module temperature 25°C)</small>	

Please contact our office for further information



KYOCERA Corporation

KYOCERA Corporation Headquarters

CORPORATE SOLAR ENERGY DIVISION
6 Takeeda Tobadono-cho
Fushimi-ku, Kyoto
612-8501, Japan
TEL: (81)75-834-3476 FAX: (81)75-604-3475
<http://www.kyocera.com>

● KYOCERA Solar, Inc.
7612 East Acoma Drive
Scottsdale, AZ 85260, USA
TEL: (1)480-948-9003 or (800)223-9580 FAX: (1)480-483-8431
<http://www.kyocerasolar.com>

● KYOCERA Solar do Brasil Ltda.
Av. Guilnard 661, Loja A
22790-200, Recreio dos Bandeirantes, Rio de Janeiro, Brazil
TEL: (55)21-2437-8525 FAX: (55)21-2437-2338
<http://www.kyocerasolar.com.br>

● KYOCERA Solar Pty Ltd.
Level 3, 6-10 Talavera Road, North Ryde
N.S.W. 2113, Australia
TEL: (61)2-9970-3948 FAX: (61)2-9988-9589
<http://www.kyocerasolar.com.au/>

● KYOCERA Fineceramics GmbH
Fritz-Mueller-Strasse 107, 73730 Esslingen, Germany
TEL: (49)711-93934-999 FAX: (49)711-93934-950
<http://www.kyocerasolar.eu>

● KYOCERA Asia Pacific Pte. Ltd.

298 Tiong Bahru Road, #13-03/05
Central Plaza, Singapore 18730
TEL: (65)6271-0500 FAX: (65)6271-0600

● KYOCERA Asia Pacific Ltd.

Room 801-802, Tower 1 South Seas Centre, 75 Mody Road,
Tsimshatsui East, Kowloon, Hong Kong
TEL: (852)2-7237183 FAX: (852)2-7244501

● KYOCERA Asia Pacific Ltd. Taipei Office

10 Fl., No.66, Nanking West Road, Taipei, Taiwan
TEL: (886)2-2555-3609 FAX: (886)2-2559-4131

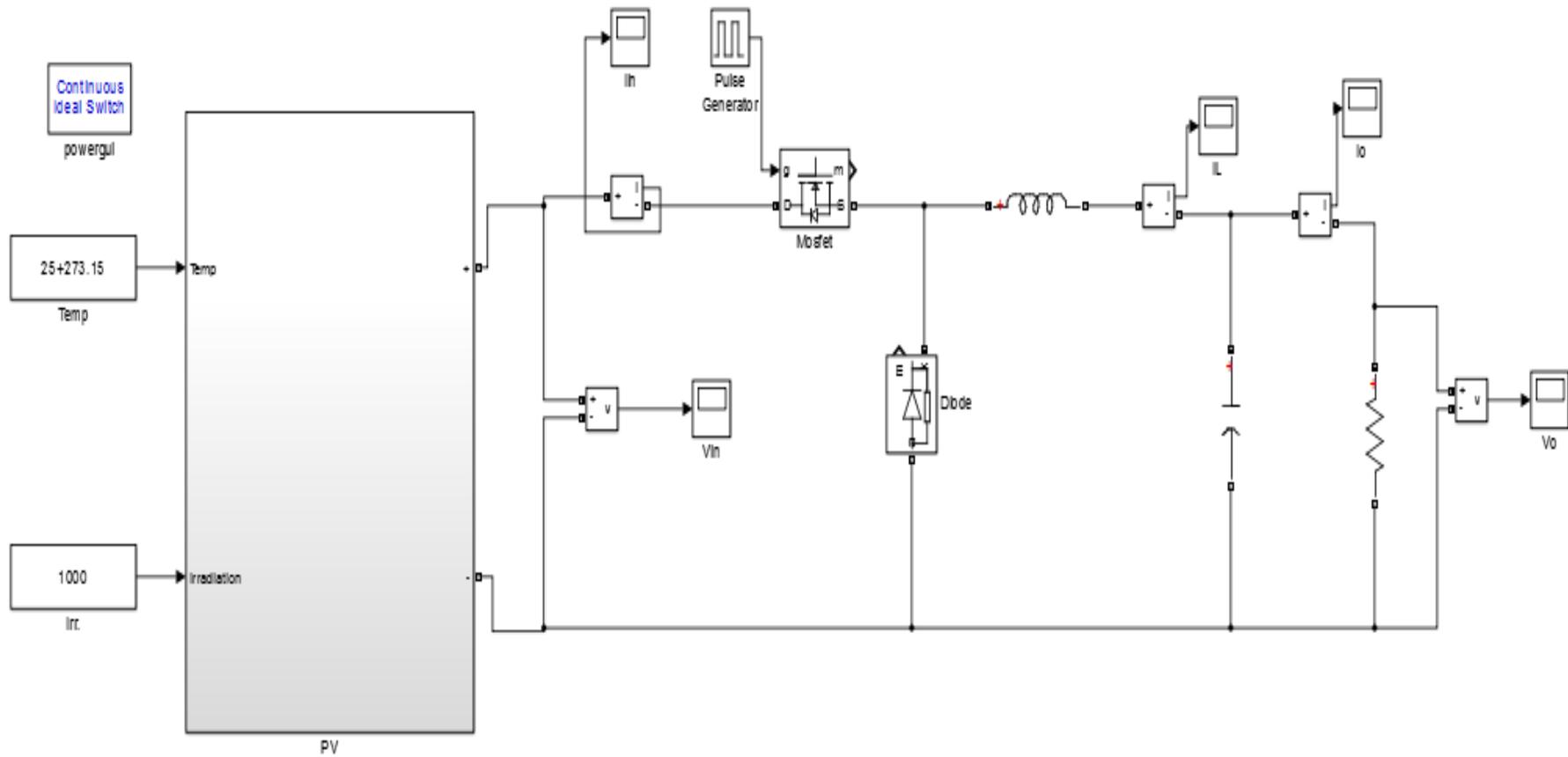
● KYOCERA (Tianjin) Sales & Trading Corporation

19F Tower C HeChao Building 8A Guanghua Rd.,
Chao Yang District, Beijing 100026, China
TEL: (86)10-6583-2270 FAX: (86)10-6583-2250

Kyocera reserves the right to modify these specifications without notice

LIE109M0703-SAGKM

APPENDIX B1 PV MODULE AND CONVERTER SYSTEM



APPENDIX B2 PV MODULE INSIDE SUBSYSTEM

