ANALYTICAL AND EXPERIMENTAL ANALYSIS OF BUCK-BOOST DC-DC CONVERTER IN PHOTOVOLTAIC (PV) MAXIMUM POWER POINT TRACKING APPLICATION

by

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Although I am indeed the sole author of this report, I am by no means the sole contributor. So many people have contributed to my report and it is now my great pleasure to take this opportunity to thank them.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

MATLAB	-	Matrix Labatory
MPPT	-	Maximum Power Point Tracking
MPP	-	Maximum Power Point
PV	-	Photovoltaic
DSP	-	Digital Signal Processors
R_{SH}	-	Shunt Resistances
R_S	-	Series Resistances

ANALITIKAL DAN ANALISIS EKSPERIMEN PENUKAR DC-DC BUCK-BOOST DALAM MENGESAN TITIK KUASA MAKSIMUM PADA PENGGUNAAN PHOTOVOLTAIK

ABSTRAK

Tenaga boleh diperbaharui sedang pesat membangun di seluruh dunia termasuk Malaysia. Salah satu daripada sumber tenaga boleh diperbaharui adalah tenaga solar di mana tenaga daripada solar (cahaya matahari) ditukar kepada tenaga elektrik. Walau bagaimanapun, tenaga elektrik yang dijana dari modul Photovoltaik (PV) tidak boleh dijamin untuk beroperasi pada kuasa maksimum jika modul PV yang disambungkan terus kepada beban. Untuk mengatasi masalah ini, kaedah yang dipanggil Maximum Power Point Tracking (MPPT) biasanya digunakan dalam sistem PV untuk memastikan pengeluaran kuasa maksimum. Kaedah MPPT terdiri daripada penukar DC-DC yang disambungkan di antara penjana PV dan beban. Titik operasi sistem kawalan dengan mengubah kitar tugas penukar. Dalam projek ini, penukar DC-DC Buck-boost bekerja sebagai pengesan MPP untuk memastikan pengeluaran berterusan kuasa maksimum daripada sistem PV di pelbagai keadaan alam sekitar. Penukar ini dipilih berdasarkan keupayaan untuk penyepadanan galangan modul PV tanpa dipengaruhi beban dan sinaran. Simulasi dan analisis eksperimen pada penukar Buck-boost DC-DC dilakukan pada tahap sinaran daripada 100 W/m^2 hingga 1000 W/m^2. A CHROMA PV Simulator (Model: 62100H-600S) digunakan untuk mencontohi 4 modul PV (MSX-60) disambung secara siri. EZDSP F28335 Pemprosesan Isyarat Digital bertindak sebagai pengawal untuk mengawal kitar tugas penukar. Keputusan menunjukkan bahawa penukar dibangunkan dapat mengesan MPP pada semua peringkat sinaran diuji. Keputusan simulasi dan eksperimen adalah hampir sama. Di samping itu ia membuktikan bahawa penukar Buck-boost dapat mengesan MPP dari 0 V kepada voltan litar buka, V_{oc}. Oleh itu ia dapat mencari MPP yang betul walaupun ketika berlakunya keadaan separa teduhan yang mana MPP yang betul tidak berada pada keadaan julat normal, iaitu 0.7-0.8 kali V_{oc}.

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ABSTRACT

Renewable energy has emerged throughout the world including Malaysia. One of the renewable energy sources is solar energy where the energy from solar (sunlight) is converted into electrical energy. However, the electricity generated from Photovoltaic (PV) module cannot be guaranteed to operate at maximum power if the PV modules or array are connected directly to the load. To overcome this problem, a method called Maximum Power Point Tracking (MPPT) is normally utilized in PV systems to ensure maximum power extraction. MPPT method consists of a DC-DC converter that is connected in between the PV generator and the load. The operating point of the system is controlled by varying the duty cycle of the converter. In this project, a DC-DC Buck-boost converter is employed as the MPP tracker to ensure continuous extraction of maximum power from a PV system at various environmental conditions. This converter is selected based on its ability to match the PV module impedance independence of the load and irradiance. Simulation and experimental analyses on the developed Buck-boost DC-DC converter is performed at irradiance level of 100 W/m^2 to 1000 W/m^2. A CHROMA PV Simulator (Model: 62100H-600S) is used to emulate 4 PV modules (MSX-60) connected in series. EZDSP F28335 Digital Signal Processing (DSP) is employed as a controller to control the duty cycle of the converter. Results showed that the developed converter is able to track the MPP for all irradiance levels tested. The simulation and experimental results are almost similar. In addition, it is proven that Buck-boost converter is able to trace the MPP from 0 V to open circuit voltage, V_{oc}. Hence it should be able to find the correct MPP even during the occurrence of partial shading (PS) conditions in which the correct MPP will not be at its normal range, i.e. 0.7-0.8 times V_{oc}.

CHAPTER 1

INTRODUCTION

1.1 Overview

Solar photovoltaic (PV) is one of the renewable energy source that has been growing rapidly around the world as well as Malaysia in the last a few years. Solar cell is a material or device that is capable of converting energy from solar to electrical voltage and current. The PV system installation requires higher initial cost with nil running cost. More over the return on investment (ROI) will be approximately five to ten years period depending upon the energy policy. The PV system mainly depends on the solar irradiance and temperature and hence direct connection between panels to load will not possible. The harnessing of solar energy using PV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the PV modules. A number of methods of how to track the maximum power point of a PV module have been proposed to solve the problem of efficiency and products using these methods have been manufactured and are now commercially available for consumers. A maximum power point tracker system (MPPT) is used for extracting the maximum power from the solar PV module and transferring that power to the load. As the market is now flooded with varieties of these MPPT that are meant to improve the efficiency of PV modules under various insulation conditions. The goal of the MPPT is to match the impedance of load to the optimal impedance of PV module. MPPT uses the DC-DC converter for a different purpose regulating the input voltage at the PV module's MPP and providing load matching for the maximum power transfer.

A DC-DC converter serves the purpose of transferring maximum power from the solar PV module to the load. A DC-DC converter consists of the Buck DC-DC converter, Boost DC-DC converter, Buck-boost DC-DC converter, Cuk DC-DC converter acts as an interface between the load and the PV module. By changing the duty cycle the load impedance as seen by the source is varied and matched at the point of the peak power with the source as to transfer the maximum power. Therefore MPPT techniques are needed to maintain the PV module operating at its Maximum Power Point (MPP). The MPPT techniques to extract optimum power from PV system namely are hill climbing method, Perturb and Observe (P&O) method, Incremental Conductance (INC), Neural Networks, Fuzzy Logic Controller, Particle Swarm Optimization, Genetic Algorithms and so on.

1.2 Problem Statement

Photovoltaic (PV) output power cannot be guaranteed at its maximum power point (MPP) if it is directly connected to the load. Therefore, a technique called Maximum Power Point Tracking (MPPT) is introduced. MPPT is an essential device which is employed to maximize the power flow from a photovoltaic (PV) module or array to a load. MPPT consists of PV module or array, the DC-DC converter and a load or another conversion stage.

If PV module or array is installed directly to the load without the installation of the DC-DC converter between PV module and a load, the operating point of the system cannot be guaranteed at its maximum power point due to variation in irradiance and temperature. The Buck-boost converter is the natural solution in MPPT applications

1.3 Objectives

The objectives of this project are:

1. To design and develop a Buck-Boost DC-DC converter for MPP Tracker Application using MATLAB/Simulink®.
2. To develop a Buck-boost DC-DC converter hardware for MPPT application.
3. To analyze the performance of PV system with direct load connection and PV system with MPP tracker at different level of irradiance.
4. To analyze the MPP tracker with Buck-Boost DC-DC converter performance in terms of conversion efficiency and tracking capabilities.

1.4 Project Scope

The scopes of project are as follows:

1. The designed DC-DC Buck-boost converter is based on MSX-60 PV module connected in 4 ×1 connection.
2. Modeling and simulation of DC-DC Buck-boost converter using MATLAB at irradiances level of 900 W/m^2 to 1000 W/m^2 and temperature 25°C.
3. The experimental analysis of DC-DC Buck-boost converter using the PV simulator at irradiance level of 100 W/m^2 to 1000 W/m^2 and temperature 25°C.
4. The experiment is conducted in two parts: (1) PV is directly connected to the load and (2) PV is connected to the load with DC-DC Buck-boost converter.
5. The EZDSP F28335 Digital Signal Processing (DSP) is used as a controller to control the duty cycle of the converter by using MATLAB embedded target function.

1.5 Summary

This chapter presented the introduction about PV system, the MPPT technique, DC-DC converter and included the four objective with the project scope to achieve the performance of this works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Photovoltaic (PV) converts solar energy into direct current electricity using semiconducting materials that exhibit a photovoltaic effect. A PV system employs solar panels composed of a number of solar cells to supply usable solar power. However, the power flow (solar power) from the PV panels still cannot ensure the optimization, since the outputs current and voltage are strongly depending on the temperature and irradiance. To provide the maximum power flow from the PV panel, the Maximum Power Point Trackers (MPPT) system is used to maximize the power flow from a PV module to load. A Maximum Power Point Tracker is an electronic essential device DC to DC converter that optimizes the matches between the photovoltaic module (array) and the battery bank or load.

2.2 Maximum Power Point Tracking (MPPT)

A basic diagram of MPPT method consists of PV Module, DC-DC converter, MPPT controller and load is shown in Figure 2.1. MPPT controller uses certain algorithm to control the duty cycle of the DC-DC converter in order to track the maximum power point from PV module/array. The operating point of the PV system on the I-V characteristic curve is changing with the duty cycle of the converter is shown in Figure 2.2.

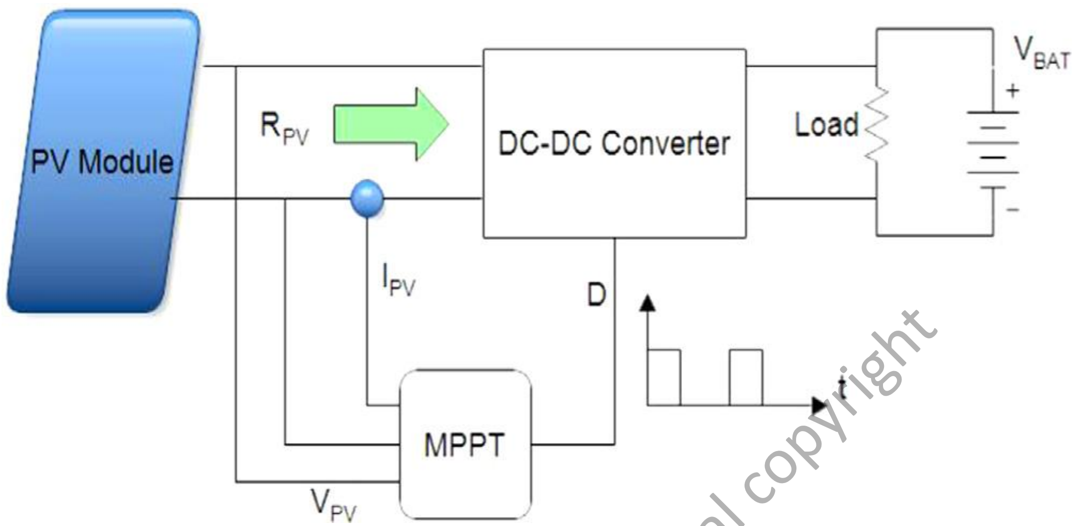

Figure 2.1: Basic diagram of MPPT method.

(Başoğlu*, M.E., & Çakır.B. (2016))

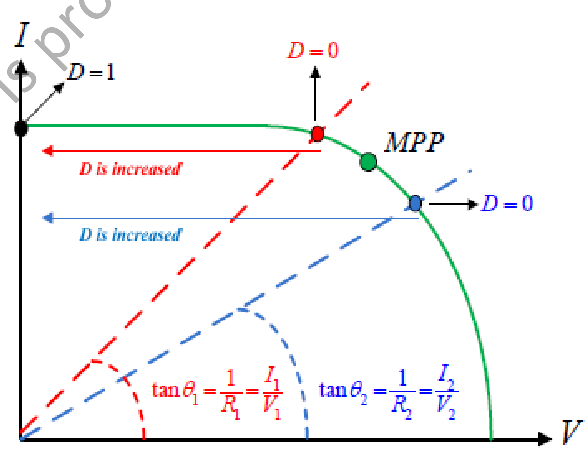

Figure 2.2: The changing duty cycle to track the MPP in the I-V curve.

2.3 PV Cell, Module and Array

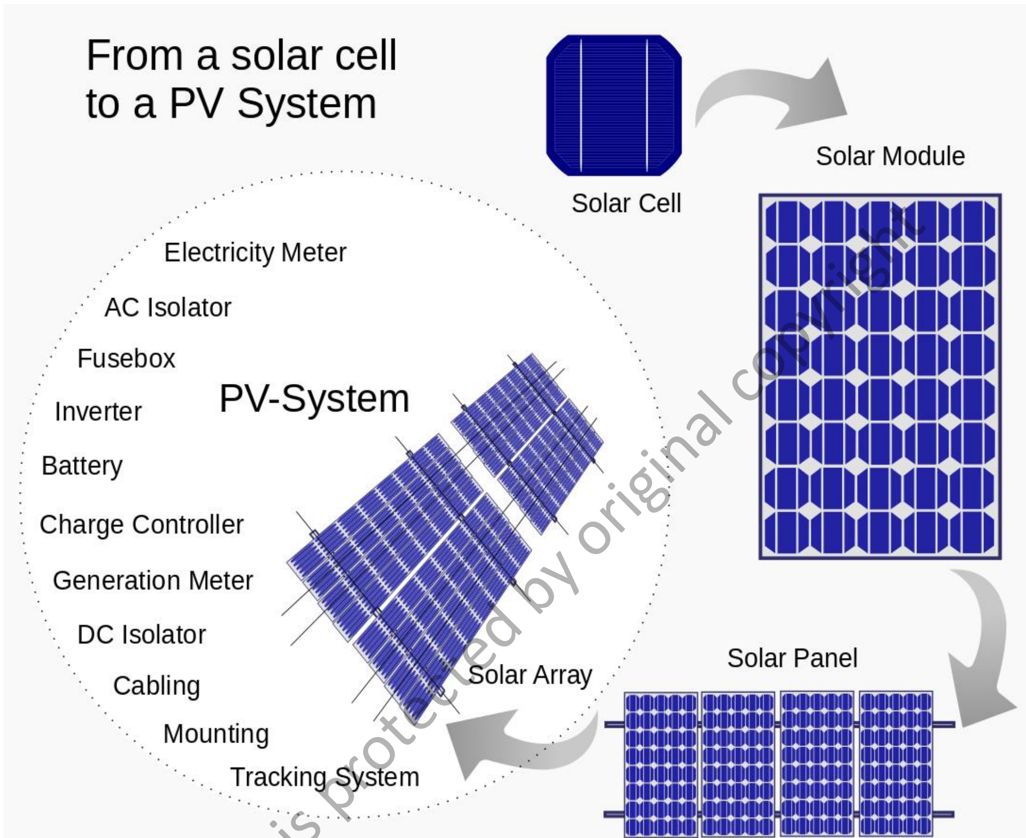

Figure 2.3: Configuration from solar cell to PV system.

Figure 2.3 shows the configuration of PV system, which starts from a solar cell to solar array. A PV cell is a specialized semiconductor diode that converts the light to direct current (DC) and can generate power ranging from 2-5W. Arrangement of solar cells in series forms to produce a solar module that can generate power up to 300W. Combination of solar modules in series to produce solar panel that can generate power about 1000W and connection solar panel in parallel to form a solar array and generate about more than 1000W.

2.4 Basic PV Module Model

A basic model for PV module consists of semiconductor diode (D), shunt resistances, R_{SH} and series resistances, R_S is shown in Figure 2.4.

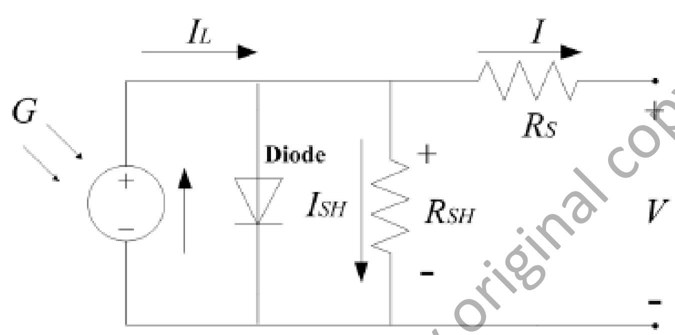

Figure 2.4: Basic circuit of PV cell

Figure 2.5: Photovoltaic System Technology

Figure 2.5 shows the system technology and method of generating electrical power by converting solar irradiance into direct current electricity using semiconductors that exhibit the photovoltaic effect. The photovoltaic effect refers to photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current. The photovoltaic effect was first observed by Alexandre-Edmond Becquerel in 1839 (J.M. Enrique, E. Duran, M. Sidrach-de-Cardona and J.M. Andujar). The first practical application of photovoltaic was to power orbiting satellites and other spacecraft.

2.5 Maximum Power Point Tracker

There are many techniques and analysis done by researchers to bring solutions to maximize the output power from photovoltaic system. Coelho, R.F., Concer, F.M., & Martins, D.C. (2010a) presented that methods to optimize the output power are normally grouped in two categories. The first one relates to the DC-DC converter optimization, focusing on the methods to choose the suitable DC-DC converters to operate as MPPT and the second one refers to the maximum power point tracking algorithm.

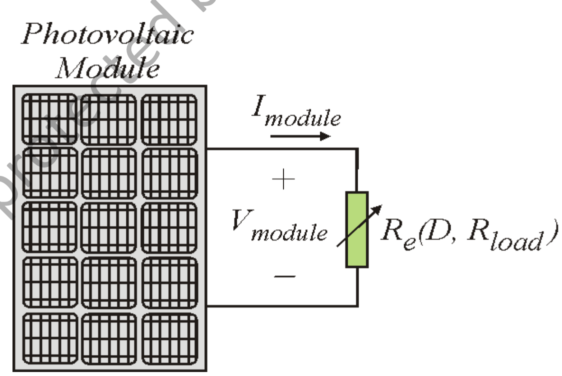

Figure 2.6: Photovoltaic (PV) panel connected to a load.
(Coelho, R.F., Concer, F.M., & Martins, D.C. 2010a)

Figure 2.6 shows the basic circuit for photovoltaic (PV) system, in which (PV) panel is connected directly to the load.

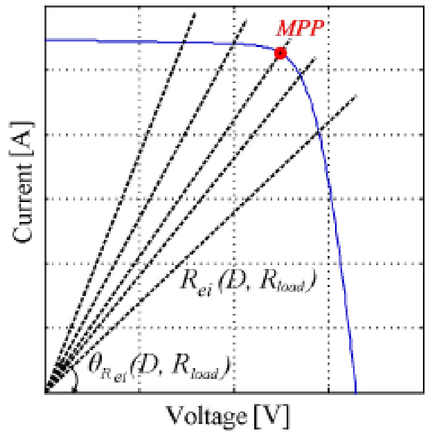

Figure 2.7: Operation point for *I-V curve.*
(Coelho, R.F., Concer, F.M., & Martins, D.C. 2010a)

Figure 2.7 shows the operation point I-V curve for PV connected directly to the load. The maximum power point (MPP) of energy extracted from the photovoltaic (PV) panel to the load. However, the MPP value varies with the different load which is influenced by temperature and irradiance.

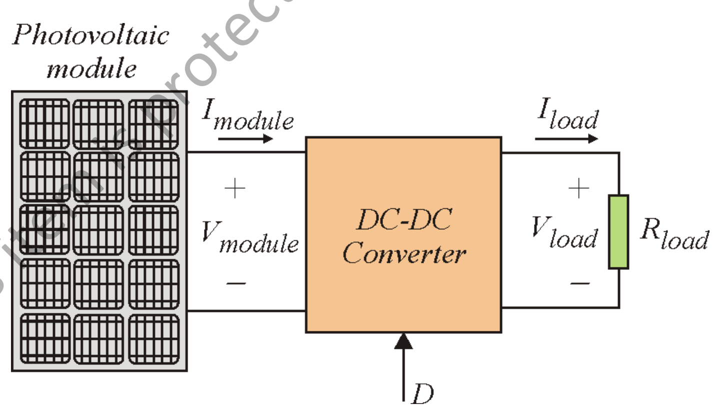

Figure 2.8: Photovoltaic (PV) panel connected to a load through DC-DC converter.
(Coelho et al., 2010a)

To ensure the MPP of energy extracted from the PV panel is at optimal value for different load, temperature and irradiance, DC-DC converter is normally utilized in between the PV module and the load as shown in Figure 2.8.

2.6 Non-isolated DC-DC Converter as MPP Tracker.

The non-isolated DC-DC converter consist of Buck, Boost, Buck-boost, Zeta, Cuk and Sepic converter. Buck-boost converter has characteristics similar to Sepic, Zeta and Cuk. Selection of non-isolated DC-DC converter as Maximum Power Point tracker between the photovoltaic (PV) panel and the load should be evaluated in accordance to the characteristic of each DC-DC converter. Evaluation and testing are important so that the selection of DC-DC converters are appropriate based on the characteristic of the DC-DC converter to be used as MPPT.

Coelho et al., (2010a) presented the theory DC-DC converter Buck, Boost and Buck-Boost type operates as a Maximum Power Point Trackers (MPPT), with static transfer characteristic given by D / (1-D), is a fundamental solution in MPPT.

2.6.1 Buck Converter as MPP Tracker

From the Buck converter static characteristic, equation (2.1) can be written as equivalent load resistant at maximum power from PV module.

$$R_e(D, R_{load}) = \frac{R_{load}}{D^2} \tag{2.1}$$

Convert the equation (2.1) to equation (2.2) as Inclination angle, for calculation range of operational region graph for Buck converter by substituting value of duty cycle (D) between 0 and 1.

$$\theta_{Rei}(D, R_{load}) = atan\left(\frac{D^2}{R_{load}}\right) \tag{2.2}$$

Substituting duty cycle (D) equal to 0 into Inclination angle equation (2.3)

$$\theta_{Rei}(0, R_{load}) = atan\left(\frac{0}{R_{load}}\right) = 0° \tag{2.3}$$

Substituting duty cycle (D) equal to 1 into Inclination angle equation (2.4)

$$\theta_{Rei}(1, R_{load}) = atan\left(\frac{1}{R_{load}}\right) \tag{2.4}$$

The equation (2.5) is the results of operational region graph for Buck converter. The Buck converter able to operate from 0° to $atan\left(\frac{1}{R_{load}}\right)$ in operational region and not able to operate in non-operational region that shows in Figure 2.9.

$$0° < \theta_{Rei}(D, R_{load}) < atan\left(\frac{1}{R_{load}}\right) \tag{2.5}$$

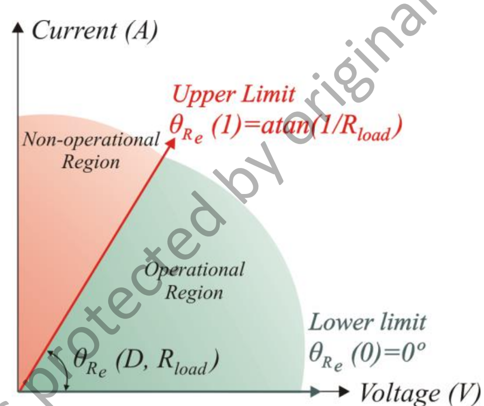

Figure 2.9: Operational Region and Non-operational Region for Buck type. (Coelho et al., 2010a)

Figure 2.9 shows that the Buck converter cannot operate at high temperature (low voltage) and high irradiation (high current), because at high temperature (low voltage), the value of voltage decreased to 0 and at high irradiation (high current), the value of current increased to 1. When the voltage decreased to 0 and current increased to 1, MPP of Buck converter is located into the non-operational region that proves the Buck converter cannot operate at high temperature (low voltage) and high irradiation (high current).

2.6.2 Boost Converter as MPP Tracker

From the Boost converter static characteristic, equation (2.6) can be written as equivalent load resistant at maximum power from PV module.

$$R_{ei}(D, R_{load}) = (1-D)^2 R_{load} \tag{2.6}$$

Convert the equation (2.6) to equation (2.7) as Inclination angle, for calculation range of operational region graph for Boost converter by substituting value of duty cycle (D) between 0 and 1.

$$\theta_{Rei}(D, R_{load}) = atan\left[\frac{1}{(1-D)^2 R_{load}}\right] \tag{2.7}$$

Substituting duty cycle (D) equal to 0 into Inclination angle equation (2.8).

$$\theta_{Rei}(0, R_{load}) = atan\left[\frac{1}{R_{load}}\right] \tag{2.8}$$

Substituting duty cycle (D) equal to 1 into Inclination angle equation (2.9).

$$\theta_{Rei}(1, R_{load}) = atan\left[\frac{1}{0}\right] = 90° \tag{2.9}$$

The equation (2.10) is the results of operational region graph for Boost converter. The Boost converter able to operate from $atan\left(\frac{1}{R_{load}}\right)$ to 90° in operational region and not able to operate in non-operational region that shows in Figure 2.10.

$$atan\left[\frac{1}{R_{load}}\right] < \theta_{Rei}(D, R_{load}) < 90° \tag{2.10}$$