DESIGN AND SIMULATION OF CONTROLLERS FOR STANDALONE AND GRID CONNECTED SOLAR PV SYSTEM

A Dissertation submitted in

partial fulfillment of the requirements for the award of the

Degree of

Master of Technology

in

Energy System and Management

Submitted by

Gaurav Mishra

Sch. No. 202118114

Under the Guidance of

Dr. Archana Soni

Energy Centre

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL, MADHYA PRADESH, INDIA 462003

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Declaration

I, **Gaurav Mishra** hereby declare that the work which is being presented in this dissertation entitled **“DESIGN AND SIMULATION OF CONTROLLER FOR STANDALONE AND GRID CONNECTED SOLAR PV SYSTEM”**, submitted in partial fulfilment of the requirement for the award of the degree of “**Master of Technology”** in “**Energy System And Management”**, has been carried out at **Maulana Azad National Institute of Technology, Bhopal** and is an authentic record of my own work carried out under the esteemed guidance of **Dr. Archana Soni, Associate Professor, Department of Energy, Maulana Azad National Institute of Technology, Bhopal**. The matter embodied in this thesis has not been submitted by me for any other degree or diploma.

Place: Bhopal

Date: 27th April, 2022

Signature of Candidate

(Gaurav Mishra)

CERTIFICATE

This is to certify that the dissertation work entitled **"Design and Simulation of Controllers for Standalone and Grid Connected Solar PV system"** is a bonafide record of the work done by **Gaurav Mishra (Sch.No. 202118114)** and submitted in the partial fulfilment of the requirements for the award of degree of **Master of Technology** in Energy with specialization in **Energy System And Management** in **Energy Centre** of **Maulana Azad National Institute of Technology**, is record work carried out by his under my supervision and guidance, The matter presented in this report has not been presented elsewhere for any degree or diploma.

To the best of our knowledge project work embodies work of candidate. The project work is of standard both in report of content and language being presented to external examiner.

Project Supervisor Signature: …………………………

Dr. Archana Soni,

Associate Professor,

Dept. of Energy (Energy Centre) M.A.N.I.T., Bhopal

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Gaurav Mishra

(202118114)

Table of Content

List of Figures

List of Table

NOMENCLATURE

AC: Alternating current.

DC: Direct current.

MPPT: Maximum Power Point Tracking.

P&O: Perturb and Observe.

PV: Photovoltaic.

P,I,V: Power, Current, Voltage, resp.

V_s or V_{in}: Supply voltage of Chopper.

Vo/Vout: output voltage of chopper.

Io/Iout: Load current.

L, C, R: Inductor, Capacitor, Resistor.

I_L, I_C: Inductor current, capacitor current.

D: duty cycle of chopper.

T, T_{ON}, T_{OFF}: Total time, ON time of chopper, OFF time of chopper.

K_P: proportional constant.

K_D: Derivative constant.

K_I: Integral constant.

P_{PV}/P_$_{PV}$: output power of PV panel.

V_{PV}/V_$_{PV}$: output voltage of PV panel.

MPP: Maximum Power Point.

V_{MPP}: MPP at output voltage of PV panel.

$MPPT_{eff.}$: efficiency of MPPT algorithm.

$P_{PVideal}$: ideal power delivered by PV panel.

$P_{PVactual}$: actual power delivered by PV panel.

ABSTRACT

Solar photovoltaic (PV) system made a great attention in the electrical power generation due to its advantages. This dissertation contains the design, simulation and analysis for the PV system with DC – DC Boost converter controlled by different controllers and the the study of various protection scheme of grid connected solar PV system. The project contains the comparative study of the with and without controlled mechanism used in the feedback of the PV system with DC – DC boost converter. And also compare the different controllers (like P, PI, PID used as control mechanism) output when controllers are tuned by using tuning mechanism called as Ziegler – Nichol’s method (for optimize the output of the controllers) and untuned. The output of the DC – DC boost converter enhance by using the MPPT algorithm. The Boost converter model’s simulation done by using MATLAB/SIMULINK software demonstrate that controllers can improve the feedback system’s transient response, also enhance the system output and efficiency.

CHAPTER 1

INTRODUCTION

Undoubtedly, Solar photovoltaic (PV) systems have play the key role in electrical power generation. It can overcome the scarcity of demand and also provide energy security. Hence, become the next generation energy resources. The various advantages of PV system are that it is pollution free, source is inexhaustible and many more. India who's aim will become net carbon zero upto 2070. So, such countries have to shift their power generation from fossil fuel to renewable energy resources like solar, wind, biomass, etc.

Many challenges occur when solar PV system connected to existing power system such as Temperature and irradiance variation, non-linearity in PV characteristics, non-linearity in power electronic components like harmonics, stability, reliability. Some other challenges occur at the time of the fault occur on the standalone and grid connected solar PV system.

There are different models used for the study of the solar pv system such as the single diode model (SD) and double diode model (DD) and Triple diode model. Apart from all single diode model is used for study due to its simplicity. The classification of the solar PV system such as the on the basis of the system configuration such as standalone PV system, grid connected system, hybrid system and many more.

In recent years, different optimization techniques have been introduced to estimate the parameters of PV such as: the Genetic Algorithm (GA), iteration technique, Whale optimization algorithm (WOA), Simulated Annealing (SA), Ziegler Nichols, etc. However, these algorithms still require some modification to obtain the most optimized parameter for different solar PV modules.

The Maximum Power Point Tracking (MPPT) algorithm with charge controller is used for extraction of more power from the solar PV. MPPT tests the performance of the PV module and compares it with the battery voltage. It adjusts the optimum power that the PV module can provide to charge the battery and converts it to the optimum voltage providing the highest current for the battery.

There are different methods to enhance the performance of the MPPT controller such as the constant voltage method. But the most popular method is PI or PID controllers integrate with charge controller.

The system block contains the solar PV modules, DC – DC Boost converter with MPPT charge controller, various controllers like P, PI, PID. These all help to enhance efficiency, reliability, response, accuracy of the system.

The standalone system is installed where the grid is unavailable due to difficult terrain like hilly areas. That why reliability is main concern if we not using hybrid solar PV system. While the grid connected (solar PV system installed with grid) is more reliable because in day time solar PV system is able to give its output but not in night time. So, in night time local grid delivers electrical power.

1.1 Solar Modules

It is the assembly of number of PV cells which is comprise of a modest layer of tremendous Si or a thin Si film joined with electrical ports. From daytime when the sunlight falls on the surface of the solar cell the electron – hole pair generated which results the flow of the electric current through the solar cell. This instrument mainly depends on the 2 things. They are

(1) on the type of semiconductor material and

(2) on the occurrence light's benefit.

Depending on the material used for fabrication of the junction, they are classified as:

1. Monocrystalline (single crystal) silicon cell
2. Multi crystalline silicon cell
3. Amorphous silicon (a-Si)
4. Gallium arsenide solar (GaAs)
5. Organic PV cell

1.1.1 Difference between Crystalline and Amorphous Silicon

Table 1: Crystalline Silicon vs Amorphous Silicon

	Crystalline Silicon	Amorphous Silicon
1.	The constituent particles are orderly arranged.	The constituent particles are randomly arranged.
2.	It has definite geometry shape with definite edge.	It has not such specific geometry in their shapes.

3.	Such Silicon have sharp melting point.	Such Silicon have not sharp melting point.
4.	Chemical nature of such Silicon are Isotropic it means the materials are direction independent.	Whereas such Silicon are Anisotropic means direction dependent.

1.1.2 Monocrystalline Silicon Cell

The Silicon cell which is made up by single crystal of silicon that is homogeneous structure. Such cell is called Monocrystalline Silicon Cell.
The crystal having constant size, orientation, electronic properties and lattice parameter.

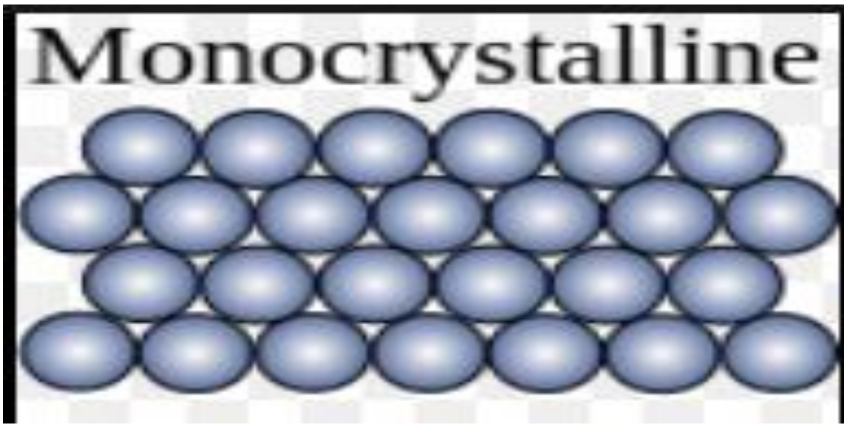


Figure 1.1 Crystal Structure of Monocrystalline (Source: Baranlab)

1.1.2 Multi - Crystalline / Poly - Crystalline Silicon Cell

The Silicon cell which is made up by numbers of Silicon crystal which are not similar in size, orientation, electronic properties and Lattice parameter. Such cell is called Polycrystalline Silicon Cell.

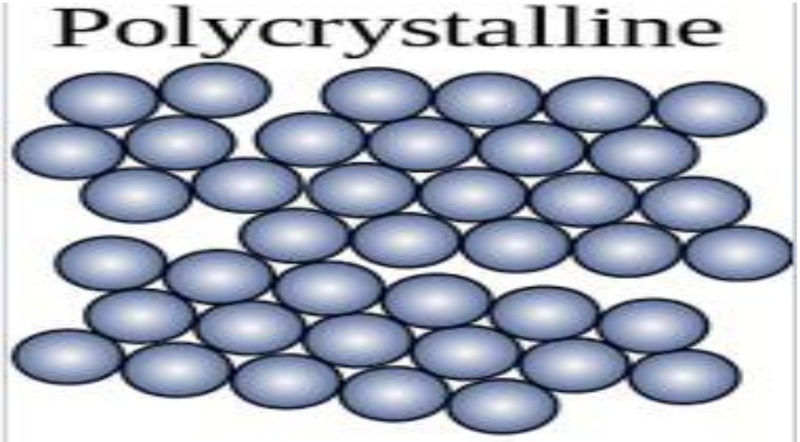


Figure 1.2 Crystal Structure of Polycrystalline (Source: Baranlab)

1.1.3 Amorphous silicon (a-Si) Solar Cell

The Amorphous Silicon Solar Cell have randomly arranged constituent particles. It has not such specific geometry in their shapes. Such Silicon have not sharp melting point. Whereas such Silicon are Anisotropic means direction dependent. It has high efficiency and low cost. It is used in calculator, etc.

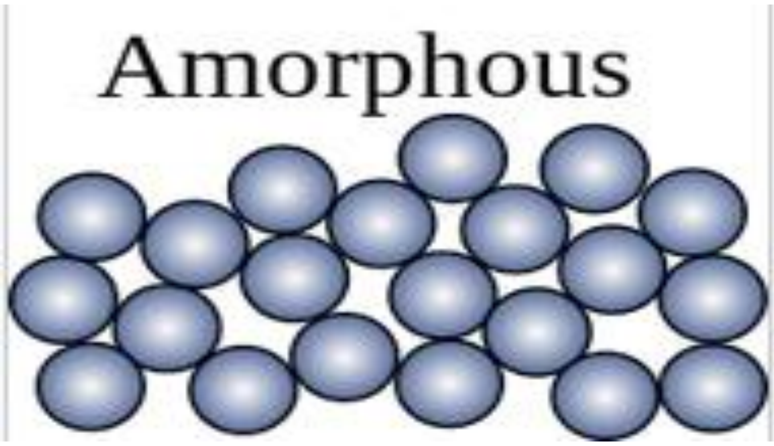


Figure 1.3 Crystal Structure of Amorphous Solid (Source: Baranlab)

1.1.4 Gallium Arsenide Solar Cell

GaAr used in solar cell due to its high absorption capability of incident solar energy. The cost and efficiency of the cell is high.

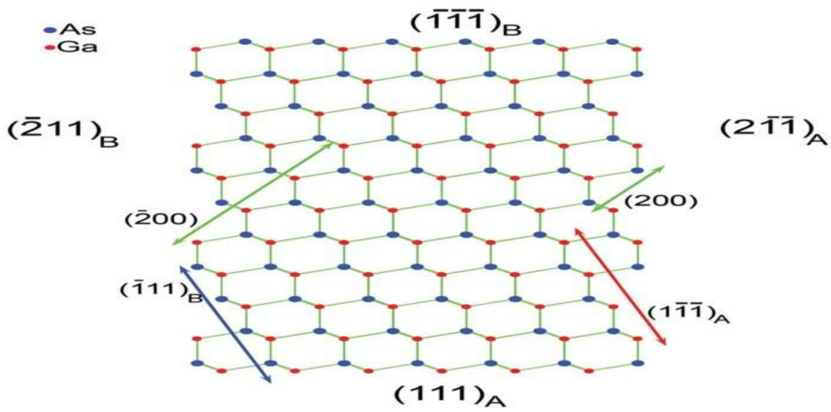


Figure 1.4 Atomic Structure of Gallium Arsenide (Source: Research gate)

1.1.5 Organic PV Cell

It is also known as the Plastic Solar cell in which organic electronic (a branch of electronics that deals with conductive organic polymers or small organic molecules,) is used , for light absorption and charge transport to produce electricity from sunlight by the PV effect.

Compare to Silicon based solar cell it is light weighted, inexpensive to fabricate, and flexible, etc. Some Organic photovoltaic materials are polyacetylene, poly (phenylene vinylene) and many more.

Acceptor organic material PCBM ([6,6]-Phenyl-C_{71}-butyric Acid Methyl Ester (mixture of isomers), etc. Donor organic material P3HT (Poly(3-hexylthiophene)), etc.

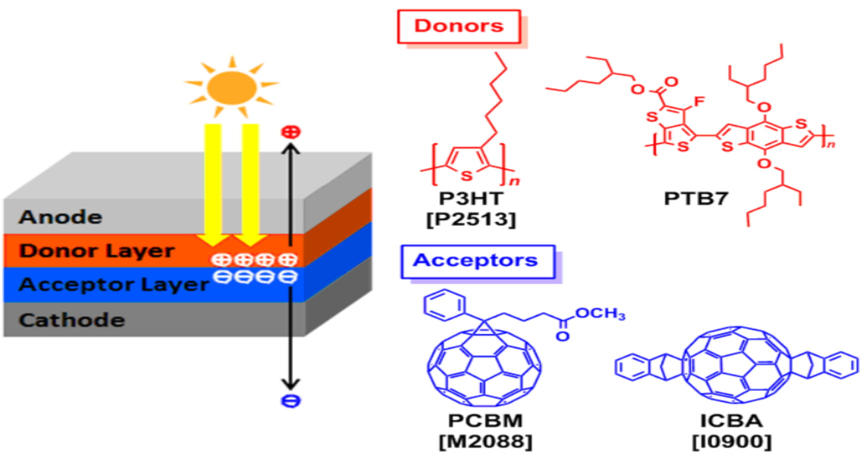
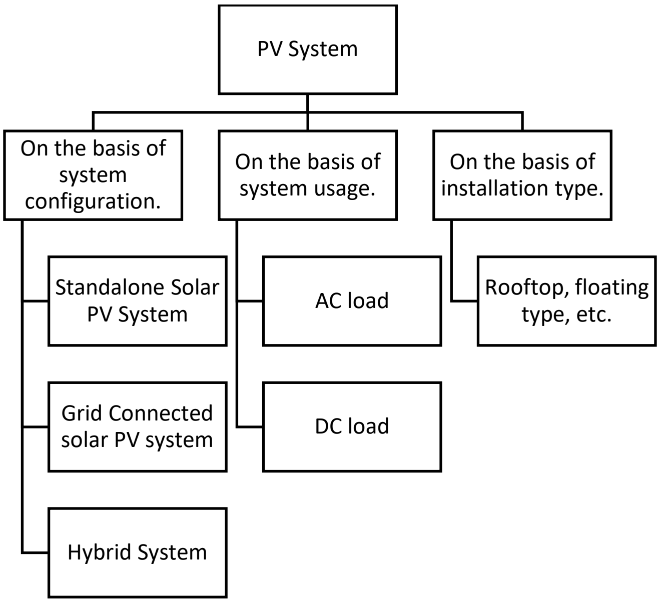


Figure 1.5 Block diagram of Organic PV Cell (Source: TCI chemicals)

1.2 Classification of PV System:



1.2.1 Standalone Solar PV system:

This **is** the system basically installed where grid is unable to reach due to difficult terrains such as Hilly areas, etc. This system consists solar PV modules, DC – DC converter, MPPT controller, Inverter, Battery bank, and load. Daytime or night time it is able to run the load because of battery bank, without taking any power from the grid. But the grid connected is coming to more usage because of expensive batteries and also less durable battery.

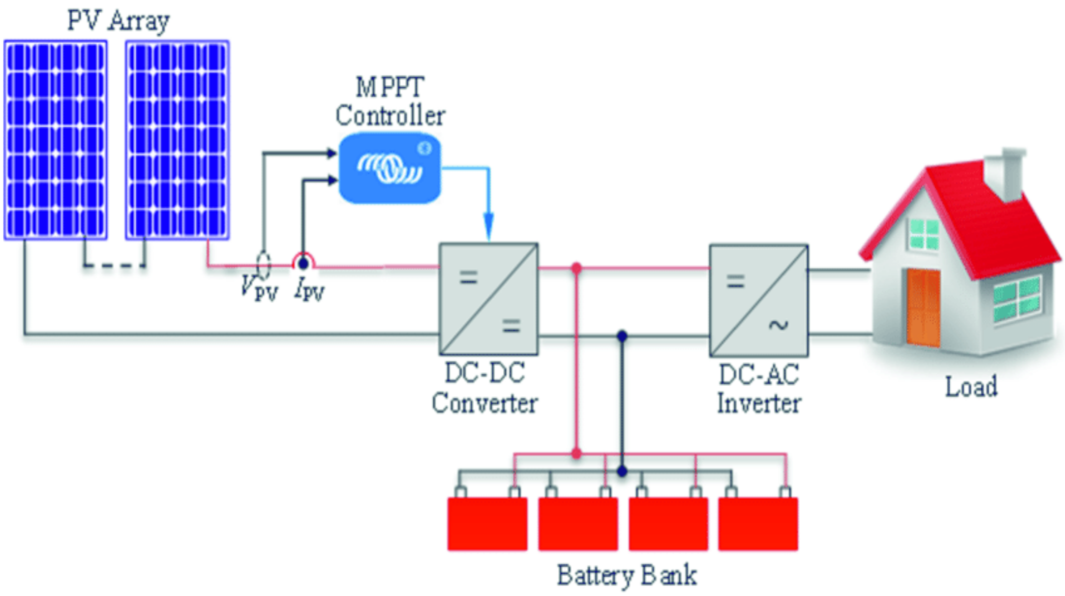


Figure 1.6 Block diagram of Standalone PV System. (Source: Research gate)

1.2.2 Grid Connected Solar PV System:

This system consist of solar PV, DC – DC converter, Inverter, power modelling component and grid – connected component. This system has no storing losses. It is self-regulating means during daytime load takes power from solar PV and at night time it takes power from grid. It also has net metering facilities means if you have excess amount of power generation through solar PV and sell it to grid which gives you compensation on your electric monthly bill.

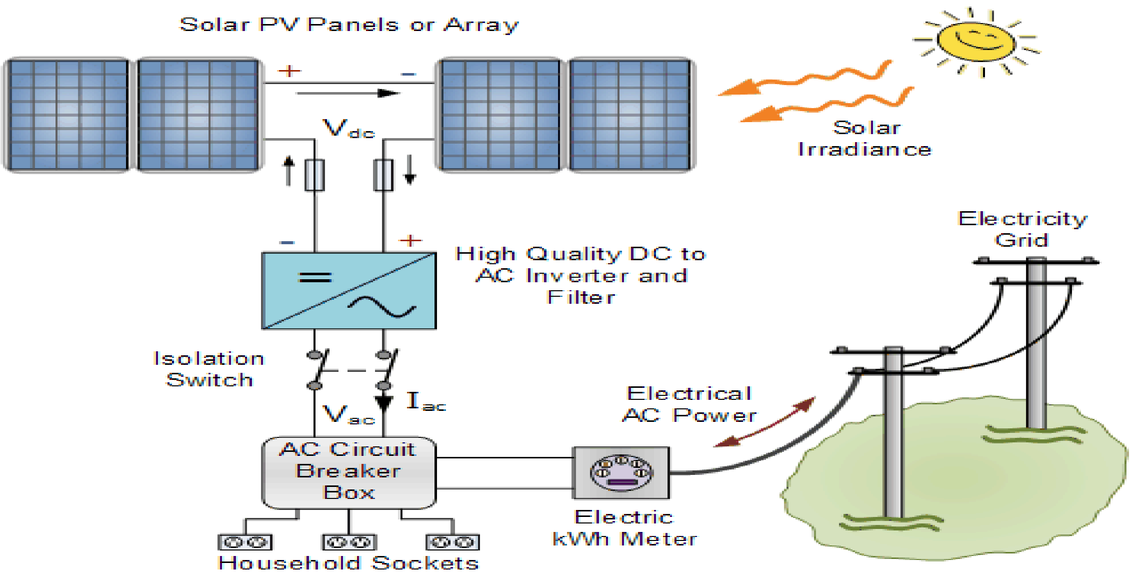


Figure 1.7 Block diagram of Grid connected solar PV system. **(**Sources: Alternative energy tutorials**)**

Table 2: **Difference between Standalone and Grid Connected Solar PV System**

	Standalone PV System	**Grid Connected Solar PV System**
1.	It is installed at the remote area where grid is unable to reach. E.g., hilly areas.	Directly connected to public grid because very easy to install in plain surface.
2.	It is design according to load size of the certain area.	Whether it is not design according to load size.
3.	It is expensive and less reliable.	While it less expensive and more reliable due to presence of public grid.

4.	There is no grid if pv system having surplus energy generation for sell power to public grid and take profit. Also, if power is less than the demand then no grid is there for delivering power.	There is a grid for dispatch surplus power from solar PV system. And also, there is grid if solar PV is unable to generate power.

CHAPTER 2

2.1 Literature Survey

Barun K. Das et al. (2021) reviewed on the Paper of economic and environmental benefits of stand-alone and grid integration thoroughly analyzed with different system configurations of a PV/Wind/Diesel/Battery based hybrid energy system (HES). And also study of sell back power to grid through net metering.[1]

Ceren Ceylan et al. (2021) review the paper which consist of simulation of proton exchange membrane fuel cell (PEMFC) / electrolyzer coupled with standalone pv system. This paper shows that PV/Electrolyzer/PEMFC hybrid power system provides an alternate option for powering stand-alone system in a self-sustainable way.[2]

Djaafar Toumi et al. (2021) review the paper which consist of block diagram of the construction of Autonomous photovoltaic stations .It also proposes a method for selecting the parameters of the main components of an autonomous photovoltaic (PV) stations. Different system configuration analyzed by using MATLAB.[3]

Laurentiu Faraa et al. (2017) review the paper which explains the necessity of stand alone system in difficult terrain. Mathematical modelling stand-alone PV system. Simulation of standalone pv system done by MATLAB.[4]

Munipally Bhavani et al. (2021), The main purpose of this paper is to observe the effect on pv system due to the variation of solar temperature and irradiance on different conditions. Also study of inverter output for a grid-connected system.[5]

National Grid Report (2015) This paper is about fault ride through(FRT) mechanism by the help of which we can avoid the blackout. So by using FRT we can drive the fault point by injecting the power generated by solar, wind power plant. This also aims at integration of solar pv system with electrical network using converters and inverters. [6]

M. Lokesh Reddy et al. (2017) the authors mainly focused to implement series, shunt, and combined series and shunt controller. To develop this charge controller authors considered

MOSFET’s as the switch which can reduces the switching power losses. The charge controller has been modelled by MATLAB/SIMULINK. The proposed charge controller is developed with cost effective solution and reduce the switching loses. [7]

Ayman Alhejji et al. (2020) This paper has introduced an application of the adaptive reference PI controller on the inverter gate pulses that integrates the PV system into the electrical utility. A comparison between the proposed ARPI controller and optimal PI controller optimized by HS has been presented. The proposed control approach aims the integration of solar PV with grid by achieving the MPPT. and also reduce the fluctuation due to LVRT and smoothing the output.[8]

Hossam A. Abd el-Ghany et al. (2021) this paper consists of about different types of fault occur on the grid connected solar PV system such as string to string fault, cell to cell fault, shadow abnormal, pole to pole faults. The authors also propose a new technique to detect and discriminate the abnormal states of the grid-connected photovoltaic (PV) solar system based on the rate of change of voltage and current trajectory. The design of the PV system is developed by implementation of only one diode in every PV string. The diode prevents the reverse direction of the fault current in case of faulty strings. On the other hand, the installation of a diode reduces the ability of faults detection and diagnosis depending on currents in each string. The fault detection model built based on the solar PV system parameters such as temperature and irradiance. [9]

Santiago Silvestre et al. (2014) in this paper author proposes the new automatic detection of main faults by evaluation of Thresholds current and voltages where thresholds mean the parameter determine by keeping in mind of the number of strings and modules in the solar PV system. [10]

Kambiz Arab Tehrani and Augustin Mpanda (2014) This paper give the information about the types of feedback system that is positive and negative feedback system. The authors basically work on the controller like P, PI, PID to enhance the controllability of the system. Paper contains thorough description of the every controllers including their block diagram, pole zero location, and their analog circuit diagram. This paper also contain the different tunning methods of the controller in which The Ziegler–Nichols tuning method is efficient.[11]

Ahmed T. Mohamed et al. (2021) This paper consist the comparative study of the controllers like P, PI, PID. Also compare the output when MPPT is installed and when not. The paper is divided into two parts: The first part's objective function is to search a five-parameter (PV voltage, PV current, MPPT efficiency, load current, load voltages) model based on the data-sheet given by commercial PV modules for a single-diode (SD) model. In the second part of the study, a detailed comparison is executed versus P, PI, PID, and FOPI controllers showing the effect of implementing Fractional order controllers on the results.[12]

Chen Qi et al. (2012) In this paper, a one-diode equivalent circuit-based versatile simulation model in the form of masked block PV module is proposed. By the model, it is allowed to estimate behavior of PV module with respect changes on irradiance intensity, ambient temperature and parameters of the PV module. The paper also consist how to increase the output of the system by using MPPT charge controller.[13]

Deepak Renwal et al. (2015), In this paper design and simulation of feedback controller is done for regulate the output voltage and current. The circuit is modelled by MATLAB. It is found that among Fuzzy logic controllers (FLC) and FLC tuned by PI controller, FLC tuned PI controller is superior because of fast transient response, minimum steady state error and good disturbance rejection under various variation of the operating condition.[14]

Chandrakant Dondariya et al. (2018) This paper focus on the working, design and simulation of rooftop grid connected solar pv system.The study focuses on the use of various simulation software, PV*SOL, PVGIS, SolarGIS and SISIFO to analyze the performance of a grid-connected rooftop solar photovoltaic system. The study assesses the energy generation, performance ratio and solar fraction for performance prediction of this solar power plant. So it is found that PV*SOL is easy, fast, and reliable software tool for the simulation of a solar PV system.[15]

Maria C. Argyrou et al. (2021) This paper aims the modelling, design and simulation of the grid connected solar PV system with battery – supercapacitor hybrid energy storage. Also the detailed small – signal stability analysis is considered for design of the current controllers for the bidirectional converters of the battery and supercapacitor. Maily paper is focus on the detailed small signal AC analysis was performed for the designing of the current controllers for Bidirectional DC – DC converters. Detailed study of the converters, controllers, Inverters. [16]

Olusola Charles Akinsipe et al. (2020) This paper focuses on examining the feasibility of deploying an off-grid PV system to drive the electricity consumption of a residential building. The paper adopts a mathematical modelling method for designing and analyzing the entire PV systems to drive the power consumption of the households. There is also the analysis of solar intensity of the particular area. It also contains the designing of the solar PV system that is the number of panels, strings, inverters, and many more. Also the cost estimation of the installation of standalone PV system. It also consist the calculation of different parameters such as average PV array area, peak PV power of array, battery storage capacity. Also sizing of the charge controller. [17]

Browh Serge Tekpeti et al. (2018) This paper proposes a method for fault analysis with Overcurrent relay (OCRs) consideration to discuss relays faults currents fluctuations in time against PV fluctuations. The paper also contain the fault analysis of PV connected distributed systems (DSs). Their is also the explaination of the working performance of DSs with Battery energy storage system (BESS). By using BESS we can reduce the fault current which can makes the system more stable and reliable. The simulated PV fluctuations are short time dynamic high and low irradiations fluctuations and PV connection and disconnection based PV-dominated feeders. It also include the design and simulation of grid connected solar PV system using PSCAD software. It is found that PVs connection and disconnection have significant influence on OCRs maximum faults currents and, for that reason, LVRT with PV must be reinforced. Relays faults currents depend on PVs locations and the higher the PV penetration the higher the fault currents.[18]

Manoj et al. (2009) this paper discusses a control method based on fuzzy reasoning for single PV system. The fuzzy reasoning produces output power command for smoothing PV system's power fluctuations considering insolation and power utility conditions. The authors also energy storage based method is proposed. Here, PV output power fluctuations are leveled through battery charge/discharge action and the optimal size of the battery is calculated to minimize the system cost. Thirdly, a simple coordinated control method is proposed for multiple PV systems clustered in different locations.it also gives the comparative study of the fuzzy logic and MPPT control. [19]

Bahador Fani et al. (2017) This study presents a novel offline, quick, applicable and cheap solution which guarantees protection coordination for any penetration and location of PV units. There is certain steps given by the authors to protect the overcurrent relay from penetration. first, under different PV penetration levels and locations, the conventional protection performance is studied to discover the worst mis-coordination cases. Next, according to relays standards, the characteristic curve of the back-up relay is modified such that it can maintain coordination in all worst cases. This study also have brief discussion about the relays and other protection schemes.[20]

2.2 Research Gap

It is realized after reviewing the various research papers that there is less research done on the

- *Different configuration of controllers used to enhance the power output in the Solar PV system.*
- *And comparative study of performance parameters after using the controller.*
- *Also, tunning of controller using the Ziegler Nichol's algorithm.*
- *Also, performance analysis of different controller configuration for different type of Irradiances i.e. for cloudy and sunny days irradiance.*

CHAPTER 3

3.1 OBJECTIVES

- Design the parameters of Boost Converter.
- Simulation of Boost converter with different Controllers using MATLAB Software.
- Comparative study of different configuration of controllers.
- Study of protection schemes for Grid connected solar PV System.

Firstly, after the collection of data of solar PV, we have to design parameters of Boost converter like Inductor (L), Input Capacitor (Cin), Output Capacitor (Co) and Load Resistance (Ro). Second by using the MATLAB, we simulate the Boost Converter for different configuration of controller that is input or output side. Then after we make comparative study using the performance parameters like input current or I_PV, input voltage or V_PV, output current (Io), Input current or (I_PV), Input Power or P_PV, Output Power or Po, etc.

3.2 METHODOLOGY

These are the following steps which author follow:

- Collection of data i.e., rating of components of system.
- Calculation of the parameters of the DC – DC converter.
- Design the MPPT Charge Controller.
- Simulation of converter without MPPT algorithm using MATLAB.
- Simulation of converter with MPPT algorithm using MATLAB.
- Simulation of converter with MPPT Charge Controller and PI controller and
- Tunning of PI controller using the Ziegler Nichols Algorithm.
- Simulation of converter with MPPT Charge Controller and using PID controller using MATLAB.
- Tunning of PID controller using the Ziegler Nichols Algorithm
- Comparative study of results of different controller on the basis of different

Irradiance and with & without tunning of Controllers.

- Calculation of performance parameters.
- Study of Various protection system used in power system.

For the designing and simulation of controllers for the standalone and grid connected solar PV system, first we have to know installation capacity of PV system. Here the solar PV system has 165 kWp capacity. Then after we have to design the parameters of DC – DC Boost Converter using experimental formulae's taken directly from the research paper. In next step we have to design the MPPT charge Controllers using different Internet resources. After that we have to see what is the variation comes when we not used MPPT controller and when we use, these all analyze by using the MATLAB software. Thirdly we simulate the different controllers like P, PI, PID and analyze their output with tuned controllers. Then after comparative study of different controllers for solar PV system with Boost controller done on the basis of outputs of simulation in terms of PV voltage, PV current, output current, output voltage, Input Power or P_PV, Output Power, efficiency. After all of the above, study of different protection schemes such as circuit breaker and relay.

CHAPTER 4

Controllers

*Definition: I*t is a mechanism of the system which can reduces the difference between actual value and the desired value.

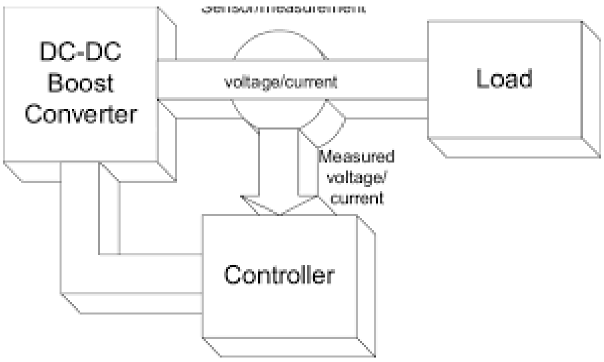


Figure 4.1 General block diagram of Controller used in feedback of DC – DC Boost converter. (Source: Research gate)

4.1 Types of Controllers

4.1.1 Proportional or P – Controller

The Output of this controller is proportional to actuating signal which is the input of the controller.

$$u(t) \propto e(t)$$

$$\Rightarrow u(t) = K_P e(t)$$

Apply Laplace transform on both the sides –

$$U(s) = K_P E(s)$$

$$U(s)/E(s) = K_P$$

Therefore, the transfer function of the proportional controller is K_P

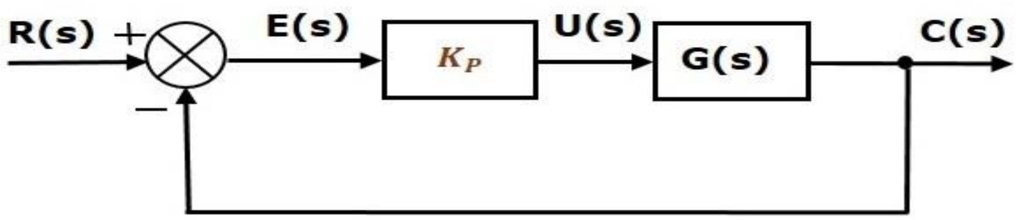


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Figure 4.2 Block diagram of Proportional controller used in plant. (Source: Tutorial point)

Features:

- The settling time will not be change.
- The peak overshoot is Increased.
- The damping frequency is increases.
- The steady state error reduces.
- Relative stability is unaffected because distance from imaginary axis is unchanged.

4.1.2 Differential Controller

The output of this controller is proportional to derivative of its input.

$$u(t)=K_D * de(t)/dt$$

Apply Laplace transform on both sides.

$$U(s)=K_D s E(s)$$

$$U(s)/E(s)=K_D s$$

Therefore, the transfer function of the derivative controller is $K_D s$.

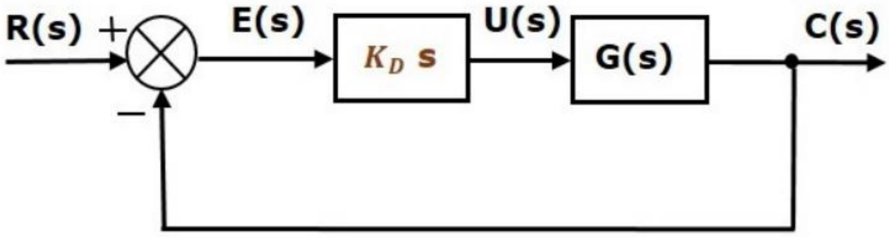


Figure 4.3 The block diagram of the unity negative feedback closed loop control system along with the derivative controller. (Source: Tutorial point)

Where, K_D is the derivative constant.

Features:

- It introduces a zero at origin.
- The type is reduce by 1 so steady state error increases.
- The order is reduce by 1 so the stability of system is improved.
- Due to derivative action, transient response of the system is improved.

4.1.3 Integral Controller

The integral controller produces an output, which is integral of the error signal.

$$u(t)=K_I \int e(t)\, dt$$

Apply Laplace transform on both the sides -

$$U(s)=K_I E(s) / s$$

$$U(s) / E(s)=K_I / s$$

Therefore, the transfer function of the integral controller is K_I / s.
Where, K_I is the integral constant.

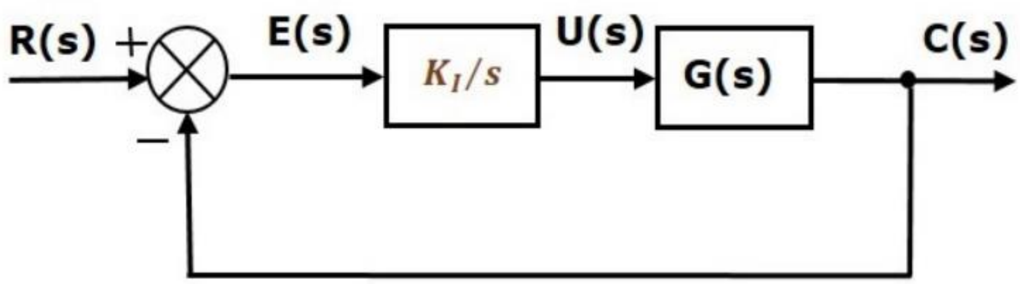


Figure 4.4 The block diagram of the unity negative feedback closed loop control system along with the integral controller. (Source: Tutorial point)

Features:

- It introduces a pole at origin.
- The type of the system is increased which can improve the steady state error.

- But order of the system also increases which reduces the stability of system.

4.1.4 Proportional & differential or PD Controller

The proportional derivative controller produces an output, which is the combination of the outputs of proportional and derivative controllers.

$$u(t)=K_P e(t)+K_D \frac{de(t)}{dt}$$

Apply Laplace transform on both sides -

$$U(s)=(K_P+K_D s)E(s)$$

$$U(s) / E(s)=K_P+K_D s$$

Therefore, the transfer function of the proportional derivative controller is $K_P+K_D s$

.

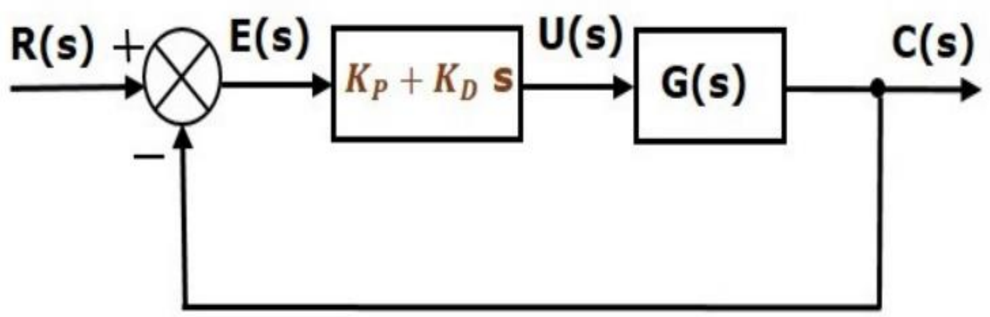


Figure 4.5 The block diagram of the unity negative feedback closed loop control system along with the proportional derivative controller. (Source: Tutorial point)

Features:

- It introduce a zero on LHS of s – plane.
- It improves the transient response of the system by increasing the speed of system.
- It behaves like a lead compensator.
- It behaves like a high pass filter (HPF).

4.1.5 Proportional & Integral or PI Controller

The proportional integral controller produces an output, which is the combination of outputs of the proportional and integral controllers.

$$u(t)=KP \,.\, e(t)+KI \int e(t)dt$$

Apply Laplace transform on both sides -

$$U(s)=(KP+KI\,/\,s)E(s)$$

$$U(s)E(s)=KP+KI\,/\,s$$

Therefore, the transfer function of proportional integral controller is $KP+KI\,/\,s$.

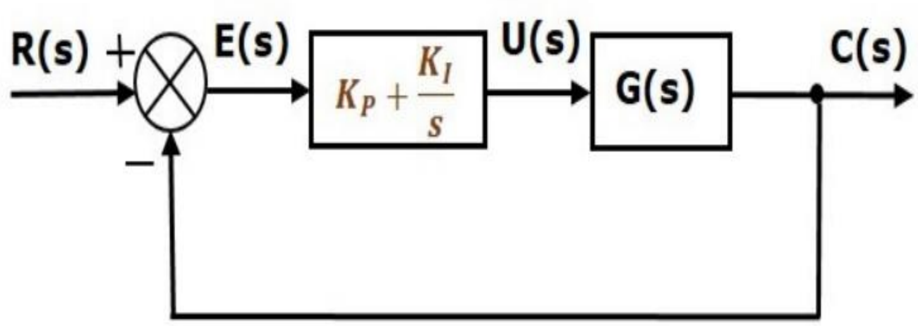


Figure 4.6 The block diagram of the unity negative feedback closed loop control system along with the proportional integral controller. (Source: Tutorial point)

Features:

- It introduces a pole at origin and a zero at left hand side of the s – plane.
- It behave like a lag compensator.
- It reduces the steady state error of the system so steady state response is improved.
- It behave as a LPF.

4.1.6 Proportional –Integral –differential or PID Controller

It produces an output, which is the combination of the outputs of proportional, integral and derivative controllers.

$$u(t)=K_P\, e(t)+K_I \int e(t)dt+K_D\, de(t) / dt$$

Apply Laplace transform on both sides -

$$U(s)=(K_P+K_I / s+K_D s)E(s)$$

$$U(s) / E(s)=K_P+K_I / s+K_D s$$

Therefore, the transfer function of the proportional integral derivative controller is $K_P+K_I / s+K_D s$.

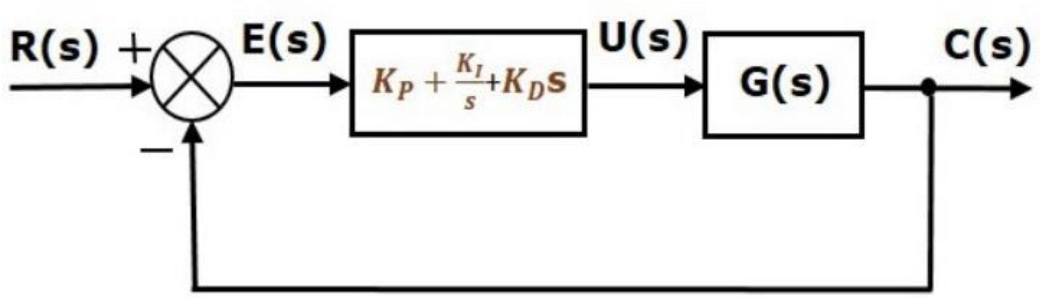


Figure 4.7 The block diagram of the unity negative feedback closed loop control system along with the proportional integral derivative controller. (Source: Tutorial point)

Features:

- It improves the steady state as well as the transient response of the system.
- It behaves like a lead – lag compensator.

4.2 MPPT Charge Controller

We know that temperature and irradiance changes from morning to evening so under all operating condition it is desirable to transfer maximum power from a PV panel to the load. In order to receive maximum power, the load must adjust itself accordingly to track the maximum power point. In order to ensure the operation of PV modules for maximum power transfer a special method called Maximum Power Point Tracking (MPPT) is employed in PV systems.

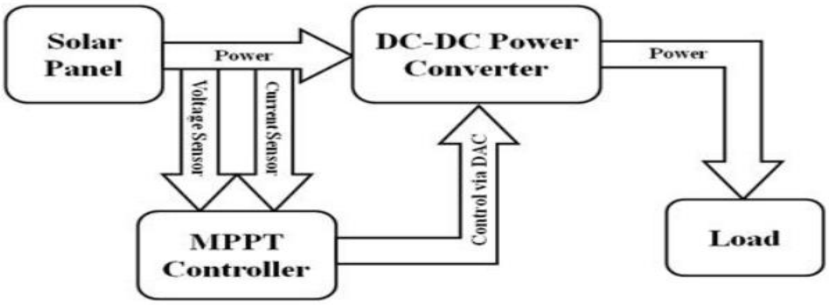


Figure 4.8 Block diagram of the MPPT controller. (Source: Bryan Buckley)

The power from the solar PV module can be calculated by measuring the voltage and current of PV. This power is an input to the algorithm which then adjusts the duty cycle of the switch, resulting in the adjustment of the reflected load impedance according to the power output of PV module. So, for design the MPPT controller, we are using Perturb and Observe algorithm (P&O).

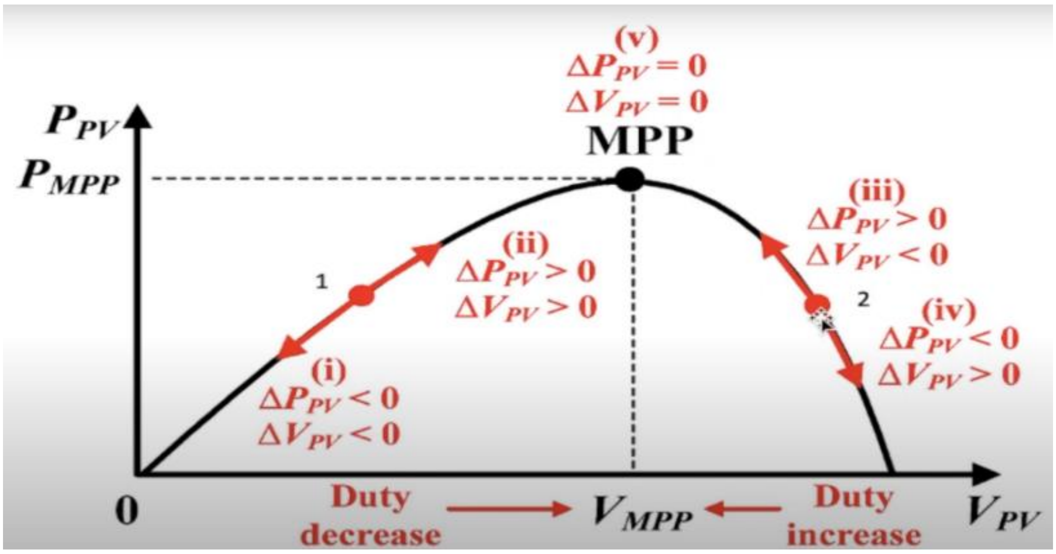


Figure 4.9 Concept of P&O algorithm. (Source: How to project)

The Explanation of Fig.22 is divided into 4 cases:

Case 1: [P,V<1]

In this interval it is observe that when Voltage of PV panel (V_{PV}) is decreases, the output power of PV (P_{PV}) also decreases. Duty cycle increases in this interval.

Case 2: [1<P,V<MPP]

In this interval it is observe that when V_{PV} is increases, the P_{PV} also increases. So in this case we can extract the maximum power from the PV panel. And also, Duty cycle decreases in this interval.

Case 3: [2<P<=MPP , V_{MPP}=V<2]

In this case we when V_{PN} is reduces from point 2 to V_{MPP}, P_{PV} increases. And we extract the maximum power from the solar PV module. And in this case duty cycle increases.

Case 4: [P,V> 2]

In this interval V_{PV} increases but P_{PV} decreases. We not getting power close to P_{MPP}. Here, duty cycle decreases.

CHAPTER 5

Protection Schemes and Tunning Method

5.1 Various Protection devices for power system

Power system which is consist of Generation, Transmission and Distribution unit. It helps to transmit the electrical power from generation unit to load center with maintain reliability and makes economical. Hence for reliability, we have to take care of faults which can interrupt the power, by proper Protection mechanism. Since, faults are widely 2 types that is Open Circuit and Short Circuit. Open circuit is less frequent while Short circuit is more frequent.

There are numbers of protection devices used in power system some are Circuit breaker, different relays, Tripping Circuit and many more.

5.1.1 Circuit breaker

It is a switching device which operate either manually or automatically for controlling and protecting the power system. Due to short circuit fault, a heavy fault current drawn through the circuit which may damage the power system. This current interrupted by disconnection of fault circuit through healthy circuit using circuit breaker.

Working Principle of Circuit Breaker:

The circuit breaker (CB) basically contain two type of contact, one, moving contact and second, Fixed contacts. In the Normal condition, the CB always ON except any maintenance work is not going on. But, in case of any fault condition like short circuit, heavy faulty current drawn through the power system which can be make collapse of power system. At this time those 2 contact comes into picture because these contacts close due to applied mechanical pressure on the moving contact. There is an arrangement which stored potential energy in the operating mechanism of CB which is released if the switching signal is given to the breaker. There are different ways to stored potential energy like deforming metal spring, by compressed air, or hydraulic pressure. All the circuit breaker having the tripping circuit energized by switching pulse and plugger, which is connected through operating mechanism of CB, displaced, as a result mechanically stored potential energy in the breaker mechanism is released in forms of kinetic energy , which make the moving contact to move and disconnect the circuit.

Types of Circuit Breaker

According to the arc quenching by the medium can be categorized as:

- Oil C.B.
- Air C.B.
- SF_6 C.B.
- Vacuum C.B.

According to Voltage level of installation types of C.B. are referred as:

- High Voltage C.B.
- Medium Voltage C.B.
- Low Voltage C.B.

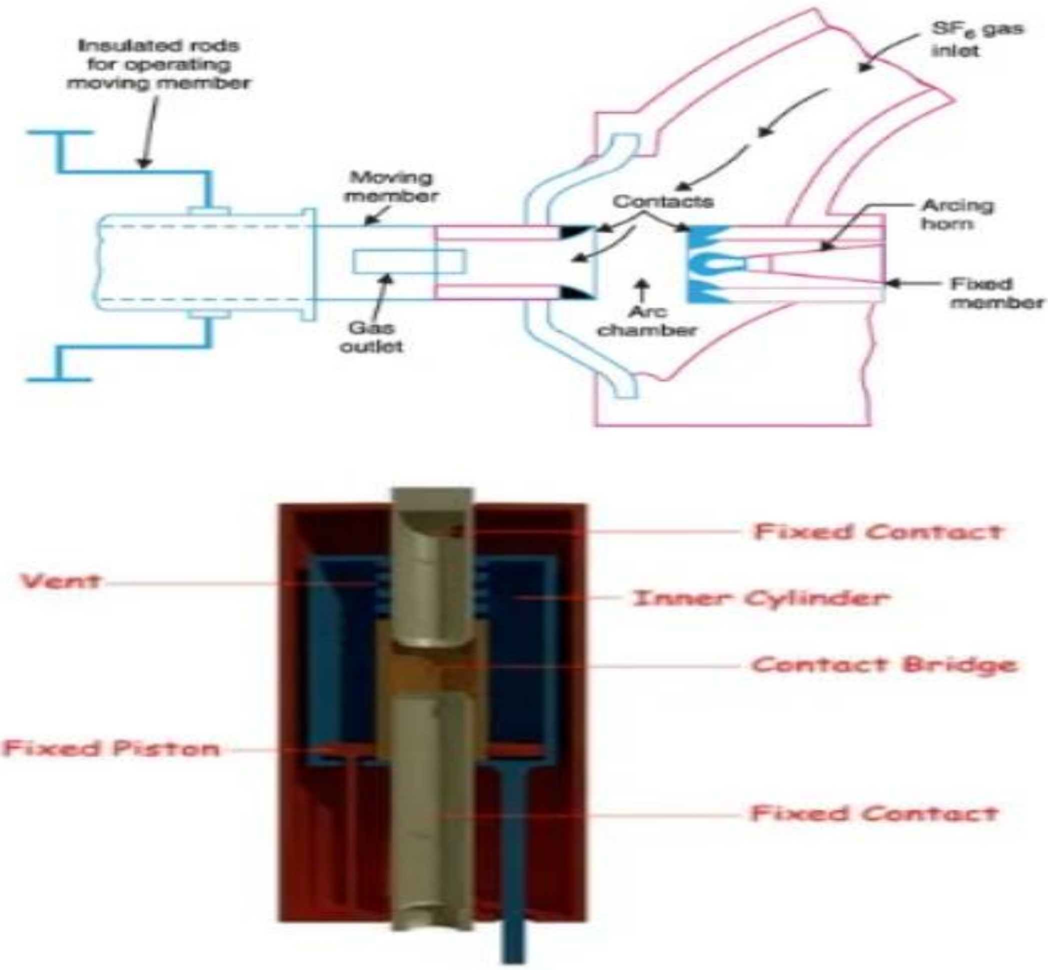


Figure 5.1 Diagram of SF_6 Circuit Breaker. (Source: Electrical4u)

5.1.2 Protection Relays

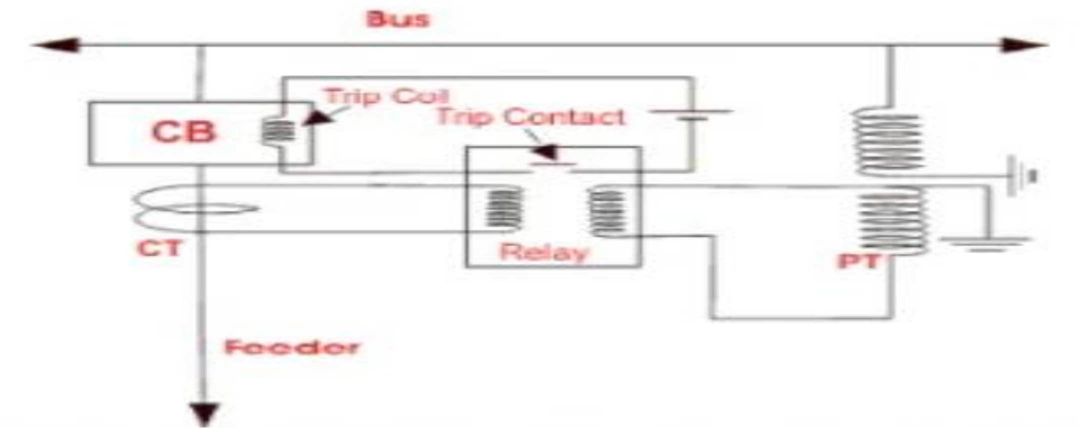


Figure 5.2 Basic connection diagram of protection relays. (Source: Electrical4u)

Definition and working of Relay:

It is the automatic device which can sense the abnormal condition and closes its contact which can complete the circuit of tripping circuit and responsible to break the contacts of circuit breaker. By the help of which we can disconnect the faulty circuit through the healthy section of power system.

Types of Relays

- Directional relay
- Overcurrent relay
- Overvoltage relay
- Loss of excitation relay
- Over fluxing relay and etc.

5.2 Tunning method of Controller

5.2.1 Ziegler - Nichols Method

This method is best use for tuning of P, PI and PID controllers. In this method we first zeroing the integral and differential gains and then raise the proportional gain until the system is unstable. The value of K_P at the point of instability is called K_{MAX};
the frequency of oscillation is f_0.

The method then backs off the proportional gain a predetermined amount and sets the integral and differential gains as a function of f_0. The P, I, and D gains are set according to Table.

Table 3 - Settings for P, I, and D Gains According to the Ziegler–Nichols Method

	K_P	K_I	K_D
P controller	0.5 K_{MAX}	0	0
PI controller	0.45 K_{MAX}	1.2 f_0	0
PID controller	0.6 K_{MAX}	2.0 f_0	0.125/f_0

5.2.2 Algorithm of Ziegler – Nichols Method

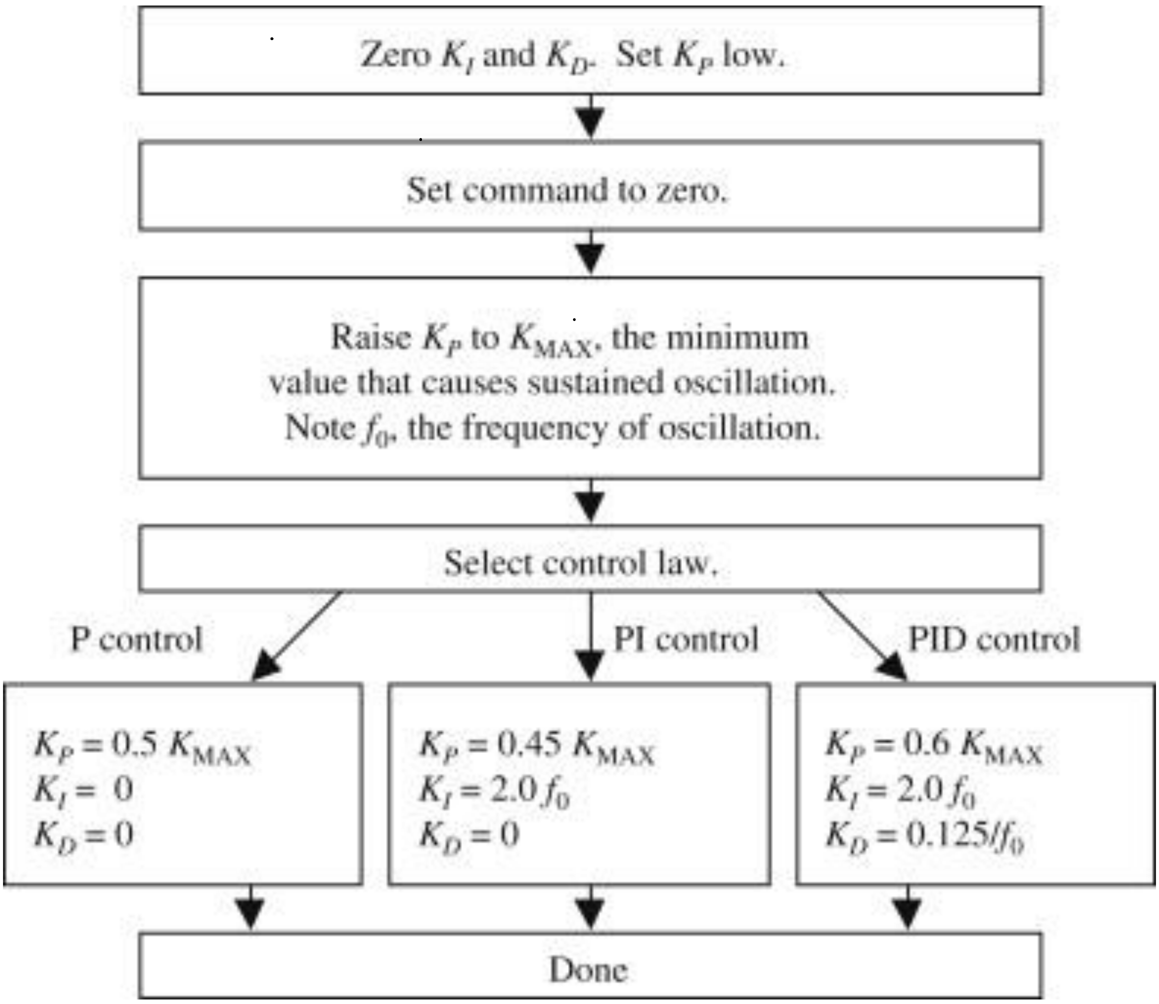


Figure 5.3 Algorithm of Ziegler Nichols Method. (Source: Science Direct)

Advantages :-

- This method is easy to apply for tunning the P, PI, PID Controllers.
- Very simplify steps.
- Focus on to reduce the harmonics of the waveforms.

Disadvantages :-

- Due to number of iterations, it takes lot of time to get desired values.
- Controller setting are aggressive due to which it gives large overshoot and oscillatory responses.
- It is similar to heat and trial method, so we don’t know whether the calculate value is exact value or not.
- Error is more as compare to other methods like generic algorithm, etc.

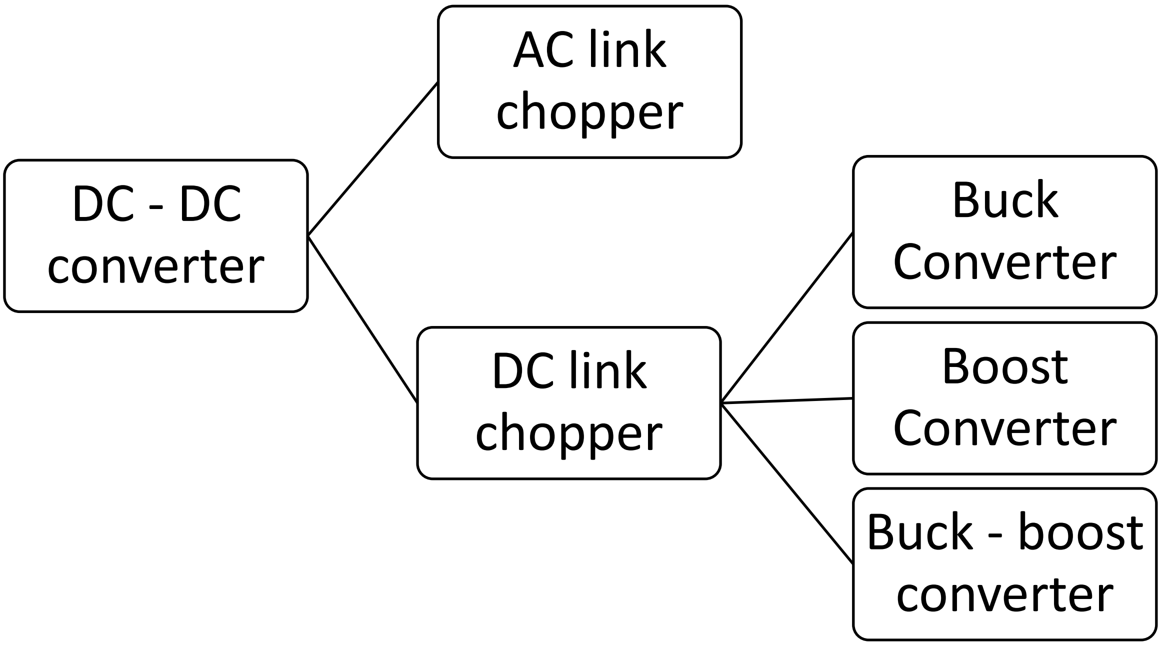
CHAPTER 6

DC – DC Converters / Chopper and Designing of Boost Converter

6.1 DC – DC Converters / Chopper

A Chopper is the power electronic devices which can convert the fixed DC into variable – output. It is also known as DC – DC Converter.

6.2 Classification of DC – DC Converter



6.2.1 AC Link Chopper

In the case of an ac link chopper, first dc is converted to ac with the help of an inverter. After that, AC is stepped-up or stepped-down by a transformer, which is then converted back to DC by a diode rectifier. Ac link chopper is costly, bulky and less efficient as the conversion is done in two stages.

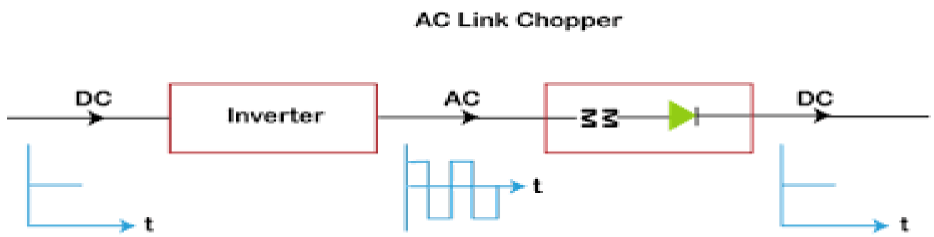


Figure 6.1 Block diagram of AC link Chopper. (Sources: javatpoint)

6.2.2 DC link Chopper

Chopper is semiconductor device along with turning ON and turning OFF circuit.

Figure 6.2 Block Diagram of DC link Chopper. (Source: Circuittoday)

6.3 Buck Converter / Step down chopper

It reduces the input DC voltage to a specified DC output voltage.

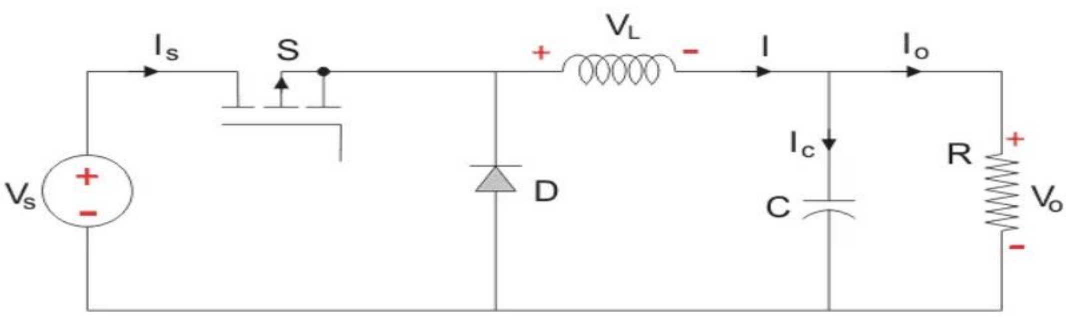


Figure 6.3: Circuit diagram of buck converter. (Sources: electrical4u)

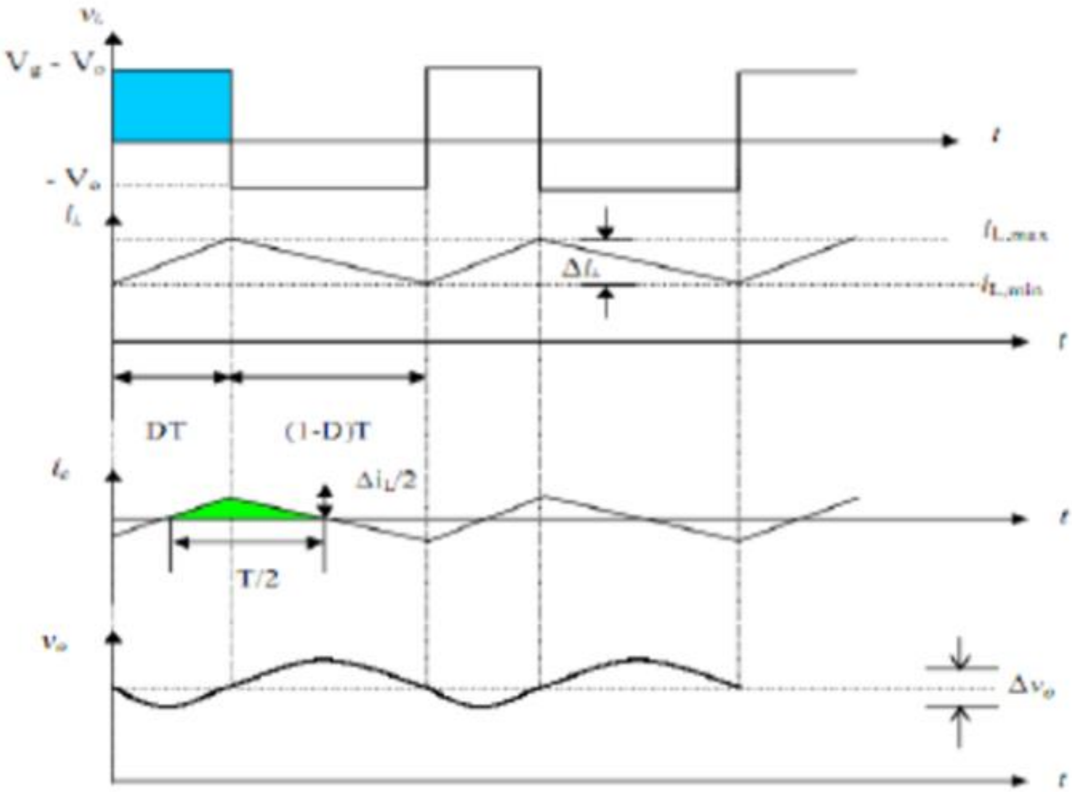


Figure 6.4 Waveform of Buck Converter. (Sources: electrical4u)

Average Voltage:

$$\frac{Vo}{Vin} = D \qquad \text{where,} \quad D = \frac{Ton}{T}$$

Ripple Current:

$$\Delta iL = \left(\frac{Vin - Vo}{L}\right) DT$$

6.4 Boost Converter / Step Up Chopper

It increases the input DC voltage to a specified DC output voltage.

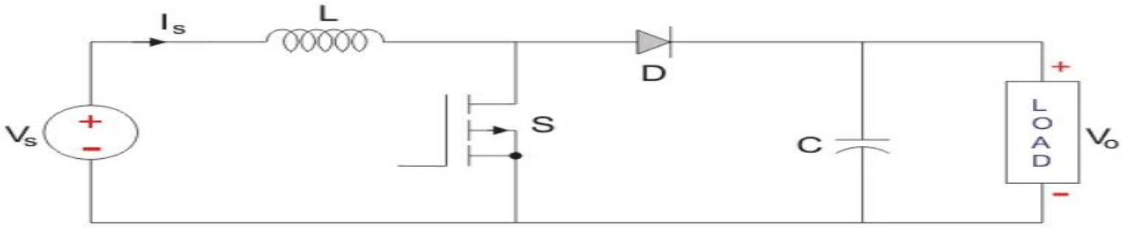


Figure 6.5 Circuit diagram of boost converter. (Source: electrical4u)

Average Voltage:

$$\frac{Vo}{Vs} = \frac{1}{(1-D)} \qquad \text{where,} \quad D = \frac{Ton}{T}$$

Ripple Current:

$$\Delta I = \frac{Vs*D}{Lf} \qquad \text{Where ,} \quad T = Ton + Toff = \frac{1}{f}$$

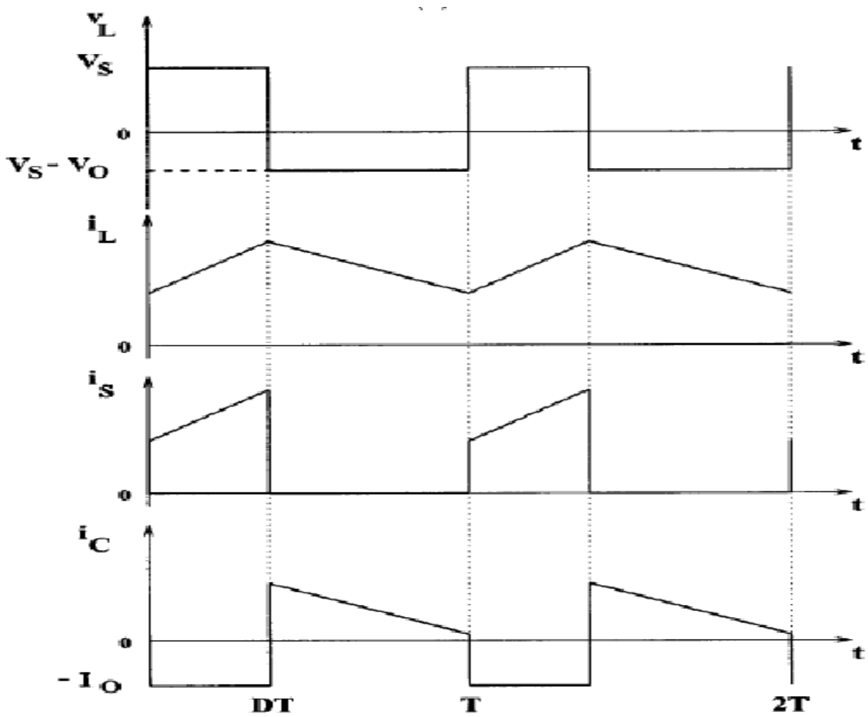


Figure 6.6 Waveform of boost Chopper. (Source: electrical4u)

6.5 Buck – Boost Converter

The buck–boost converter is a type of DC-to-DC converter (also known as a chopper) that has an output voltage magnitude that is either greater than or less than the input voltage magnitude.

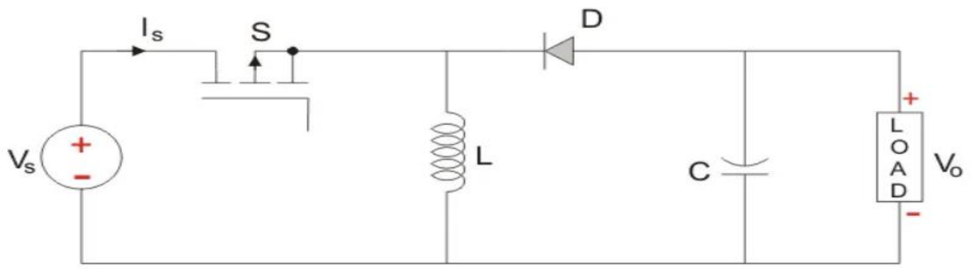


Figure 6.7 Circuit Diagram of Buck – Boost Converter. (Source: electrical4u)

Average Voltage:

$$Vo = \frac{D*Vs}{(1-D)} \qquad \text{where,} \quad D = \frac{Ton}{T}$$

Ripple Current:

$$\Delta I = \frac{D*Vs}{fL} \qquad \text{Where ,} \quad T = Ton + Toff = \frac{1}{f}$$

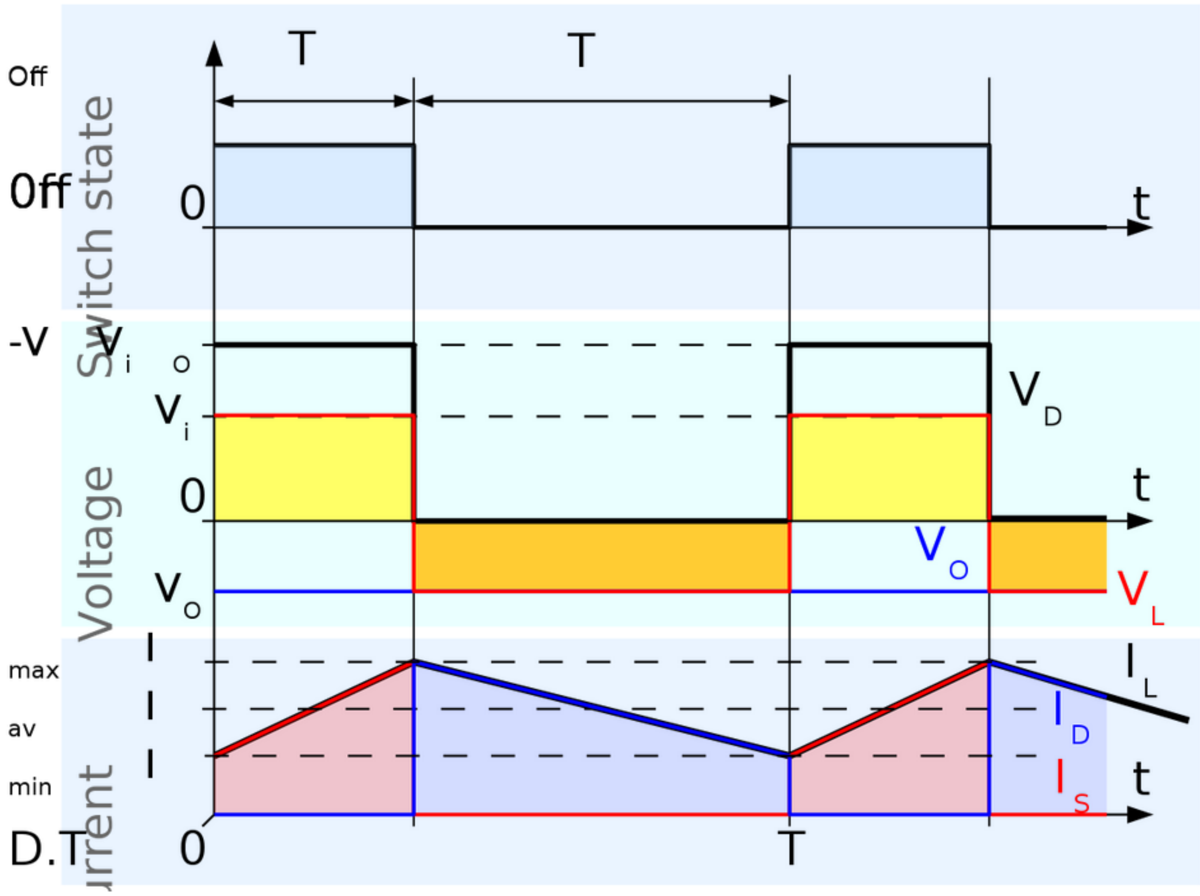


Figure 6.8 Waveform of buck – Boost Converter (Sources: Researchgate)

6.6 Designing of Boost converter

Let us assume STCs i.e. 1000 W/m^2 & 25°C

Worst condition i.e. 50 W/m^2 & 25°C

1. **PV array specifications:-**

At 1000 W/m^2 & 25°C :-

V_{mp} = 522 V, P_{mpp} = 165kWp, I_{mp} = 316.10 A

At 50 W/m^2 & 25^{o}C :-

V_{mp} = 90 % of V_{mp} at 1000 W/m^2 & 25^{o}C

= 0.9 * 522 = 469.80 V

P_{mp} = 5% of P_{mp} at 1000 W/m^2 & 25^{o}C

= 0.05 * 165 * 10^3

= 8250W

I_{mp} = P_{mp} / V_{mp}

= 8250 / 469.80

= 17.56 A

2. **Switching frequency of boost converter =** 25 kHz

3. **Define current and voltage ripples specification**

i.e. Δ V = 0.2 % of V & Δ I = 40 % of I

4. **To calculate the internal resistance of PV array at MPP, Rmp = Vmp / Imp**

At 1000 W/m^2 & 25^{o}C :-

R_{mp} = 522 / 316.1

At 50 W/m^2 & 25^{o}C :-

R_{mp} = 469.80 / 17.56

$= 1.6513\ \Omega$ $= 26.754\ \Omega$

5. Calculation of the load resistance (Ro)

Ro = 2.50 * Rmp at 50 W/m^2 & 25^{o}C

= 2.50 * 26.754

= 66.885 Ω

6. Calculate value of D at MPP :-

$$Dmp = 1 - \sqrt{\frac{Rmp}{Ro}}$$

At 1000 W/m^2 & 25^{o}C :-

$$Dmp = 1 - \sqrt{\frac{1.6513}{66.885}} = 0.84287$$

At 50 W/m^2 & 25^{o}C :-

$$Dmp = 1 - \sqrt{\frac{26.754}{66.885}} = 0.3675$$

7. Calculate values of Vo & Io :-

$$Vo = \frac{VI}{(1 - D)} \quad \& \quad Io = \frac{Vo}{Ro}$$

At 1000 W/m^2 & 25^{o}C :- **At 50 W/m^2 & 25^{o}C :-**

$V_o = 522 / (1 – 0.84287)$ $\quad$ $V_o = 469.8 / (1 – 0.3675)$

$= 3322.1\ V$ $\quad$ $= 742.7667\ V$

$I_o = 3322.1 / 66.885$ $\quad$ $I_o = 742.7667 / 66.885$

$= 49.668\ A$ $\quad$ $= 11.105\ A$

8. Calculate ripple voltage and current i.e. Δ V and Δ I

$\Delta V_I = 0.002 * V_I = 0.002 * 522 = 1.044\ V$

$\Delta V_o = 0.002 * V_o = 0.002 * 3322.10$ (at 1000 W / m^2) $= 6.6442\ V$

$\Delta I_o = 0.4 * 11.105$ (at 50 W / m^2) $= 4.442\ A$

9. Calculate reflected Input Resistence (R_{IN}) at i/p & PV array :-

$R_I = R_o (1 – D^2)$

$= 66.885 (1 – 0.84287^2)$

$= 19.368\ \Omega$

10. Put all calculated values in following equation and Calculate values of C_{IN} , C_o And L :-

$$C_I = \frac{4 * Vmp * Dmp}{\Delta VI * RI * fs}$$

$$= \frac{4 * 522 * 0.84287}{1.044 * 19.368 * 25000}$$

= 3500 **µF** (approx)

$$\mathbf{Co} = \frac{\mathbf{2 * \mathit{Vo} * \mathit{Dmp}}}{\Delta\ \mathrm{Vo} * \mathrm{Ro} * \mathrm{fs}}$$

$$= \frac{\mathbf{2 * 3322.1 * 0.84287}}{\mathbf{6.6442 * 66.885 * 25000}}$$

= 510 µF (approx)

$$\mathrm{L} = \frac{Vmp * Dmp}{2 * \ \Delta\ \mathrm{I} * \mathrm{fs}}$$

$$= \frac{469.8 * 0.3675}{2 * 4.442 * 25000}$$

= 0.77736 mH

= 1 mH

CHAPTER 7

SOFTWARE & SIMULATION

7.1 MATLAB Software

MATLAB was invented by Dr. Cleve Moler (Mathematician and Computer Programmer). This is the programming plateform designed for engineers and scientists to analyze and design systems and products. We can do Analyze data, develop algorithms and Create models and applications with the MATLAB R2020a. MATLAB consist of SIMULINK where we create the model. It consist of directory which have components from various engineering streams like Electrical, Mechanical, Robotics, Aerospace Engineering and many more.

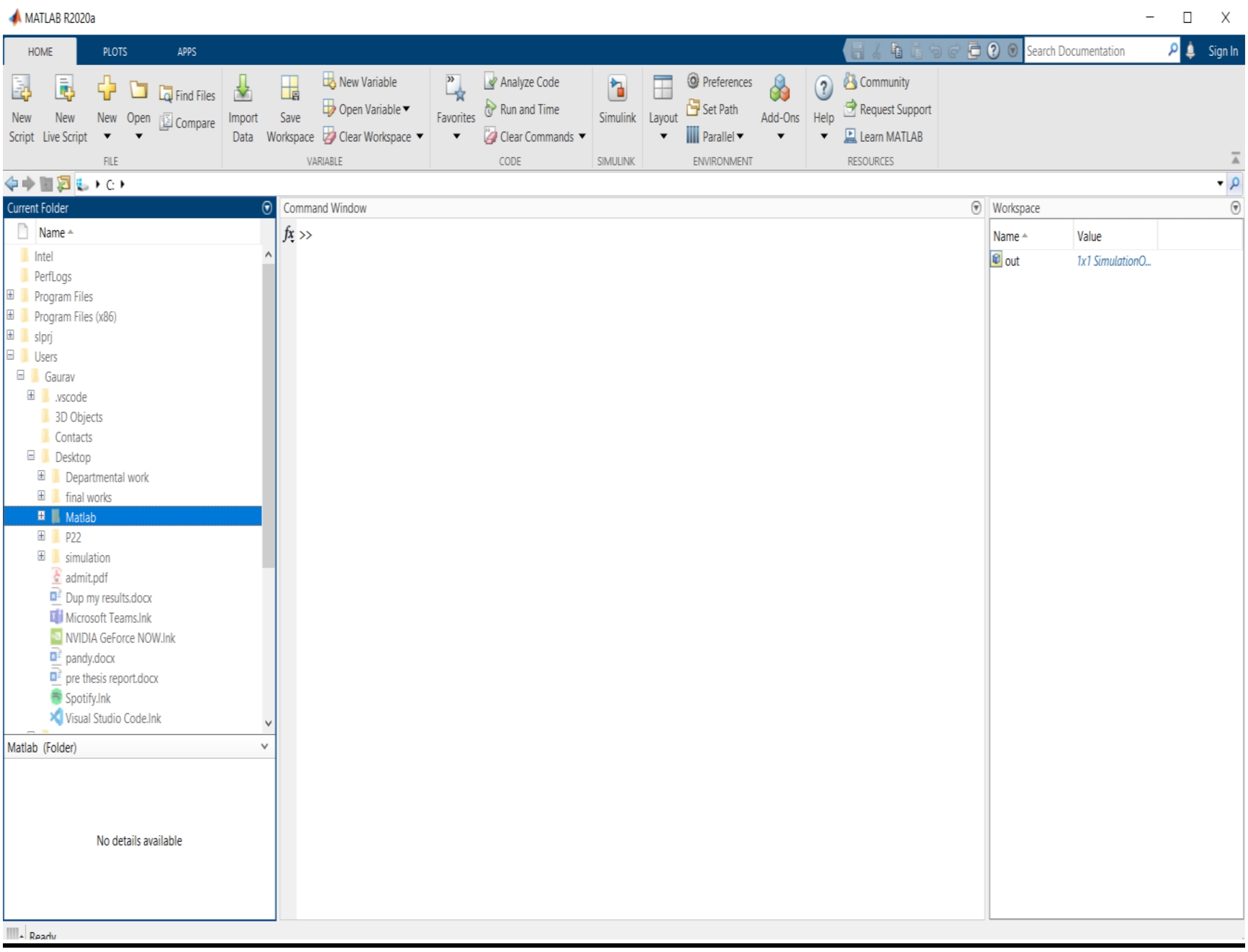


Figure 7.1 Opening Screen of MATLAB

Version of MATLAB: MATLAB R2020a

Toolbox: there is number of toolboxes using which we can analyze different system. Some are:

- Symbolic Math Toolbox
- Predictive Maintenance Toolbox
- Optimization Toolbox and etc.

MATLAB basically consist two important plateform

1. Script – it is the window in which we can do coding in MATLAB.
2. SIMULINK – it provides the window in which we design and simulate the various systems using its directory and Analysis the output using GUI (Graphical User Interface).

In figure 7.1 the Opening window of the MATLAB contains features like SIMULINK option, New script, Command window, Import Data and many more. In SIMULINK we can design and simulate the technology related things like simulation of solar PV system whether it is Grid connected or anything.

By the help of New Script we can do coding in MATLAB which is similar to C/C++ coding and run and easily analyze that code. While MATLAB also help us to tackle the big matrix for analysis.

Now comes to MATLAB file extension for saving the SCRIPT we use **".m"** and for SIMULINK we use **".slx".**

7.2 Simulation of Types of Controller

Simulation Process

Author in this sub chapter explains all about simulation process. Firstly, author designed the polar PV panel that is rating and all. After that by using the 6.6 Sub – chapter that is designing of Boost converter, simulate the boost converter and integrate with solar PV panel. Then, integrate the MPPT charge controller after designing and coding of MPPT algorithm which trigger the IGBT in such a way that we got maximum power output at that specified irradiance at that time. Next, now author can integrate different controller that is P, PI, PID one by one in the forward path of MPPT. Then after by using scope author generate the waveforms of different parameter and analyze according to their need.

7.2.1 Ratings of solar PV panels

Project for “Simulation of Controller for different Solar PV system” Solar PV having following specification :-

Module: - 1Soltech 1STH-215-P

Parallel Strings – 43

Series – connected modules per string – 18

Maximum output power per module – 213.35 W

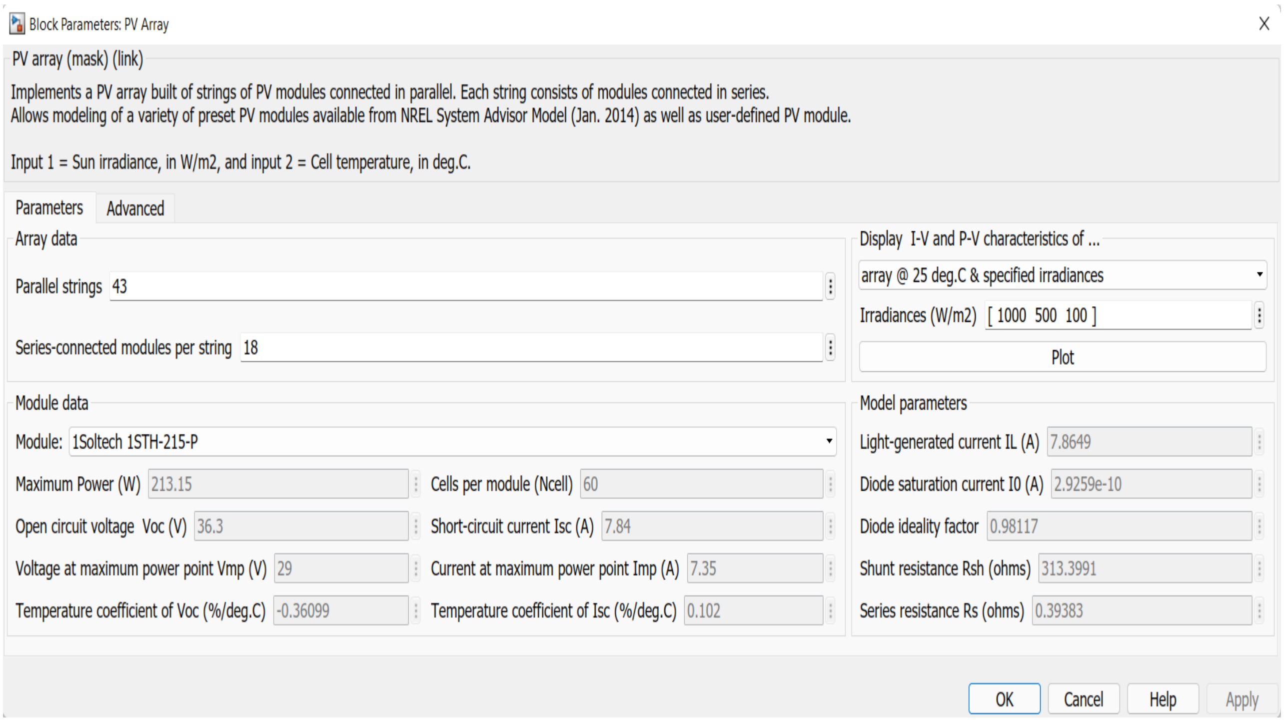


Figure 7.2 Parameter Interface window of Solar PV module

Figure 7.2 is the window setting of PV Array. It contains Array setting, Module data setting, display of I – V and P – V characteristics and Module parameter. In Array setting we can set number of Parallel strings in solar PV system and Series connected modules per string.

In Module data having two types of data feeding, one is user define and other one is different companies simulated solar PV module inbuilt in MATLAB.

Display of I-V and P-V characteristics for different cases like specified temperature @ 25°Cwith varying Irradiance and specified Irradiance @ 1000 W/ m^2 with varying temperature.

Last part is module data, in which modules series resistance, shunt resistance , diode saturation current and many more information we can get from this window.

7.2.2 P-V and I- V characteristics of solar PV system generated by using MATLAB software.

Figure 7.3 is obtained for specified array temperature @25^{o}C with variable irradiance that is for 1000 W/m^2 , 500 W/m^2 and 100 W/m^2. By using these graph, we can measure the Power, Voltage and Current at Maximum point for extreme point that is @1000 W/m^2 and @50W/m^2 . This data is used for designing of Boost Converter in sub chapter 6.6.

- ➢ These graph shows that at 1 KW/m^2 Irradiance,
  maximum power given by solar PV is 165 kWp,
  output PV voltage = 522V and
  current deliver by PV = 316.1A.
- ➢ It is also observed in P-V curve that when the irradiance increases from 0.1 to 1 kW/m^2 , output of the panel also increases.

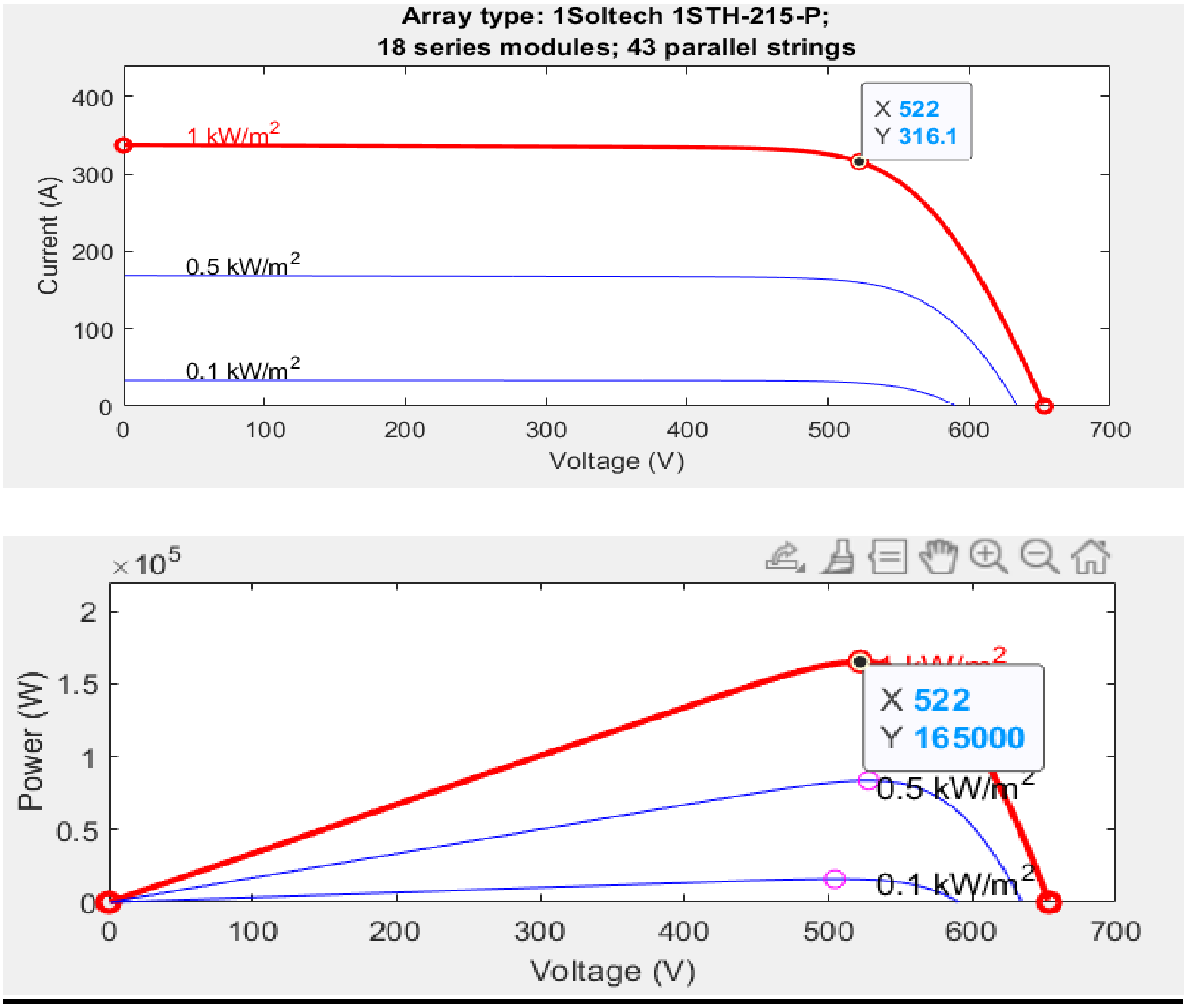


Figure 7.3 P-V and I-V characteristics of PV system for different Irradiance.

7.2.3 P&O Algorithm of MPPT Charge Controller for extraction of maximum power from the solar PV system.

Editor - Block: chopperpwmgen/MPPT*

MPPT*

```
function D = Pand0(Vpv,Ipv)

persistent Dprev Pprev Vprev

if isempty(Dprev)
    Dprev = 0.7;
    Vprev = 190;
    Pprev = 2000;
end

deltaD = 125e-6;

%calculate measured array power
Ppv = Vpv*Ipv;

% Increase or decrease duty cycle based on conditions
if (Ppv-Pprev) ~= 0
    if (Ppv-Pprev) > 0
        if (Vpv-Vprev) > -3
            D = Dprev - deltaD;
        else
           D = Dprev + deltaD;
        end
    else
       if (Vpv-Vprev)> 0
           D = Dprev + deltaD;
       else
           D = Dprev - deltaD;
       end
    end
else
    D = Dprev;
end
% Update internal values
Dprev = D;
Vprev = Vpv;
Pprev = Ppv;
```

Figure 7.4: MPPT algorithm

The P&O algorithm in figure 7.4 for the Maximum power point tracking (MPPT). The algorithm aim is to fire the IGBT in such a way that we got maximum Power output means this code gives optimize Duty cycle.

The designing and performance analysis of controller is divided, on the basis of the 2 type of irradiance, one is repetitive and other one is continuous.

Type 1 Irradiation :-

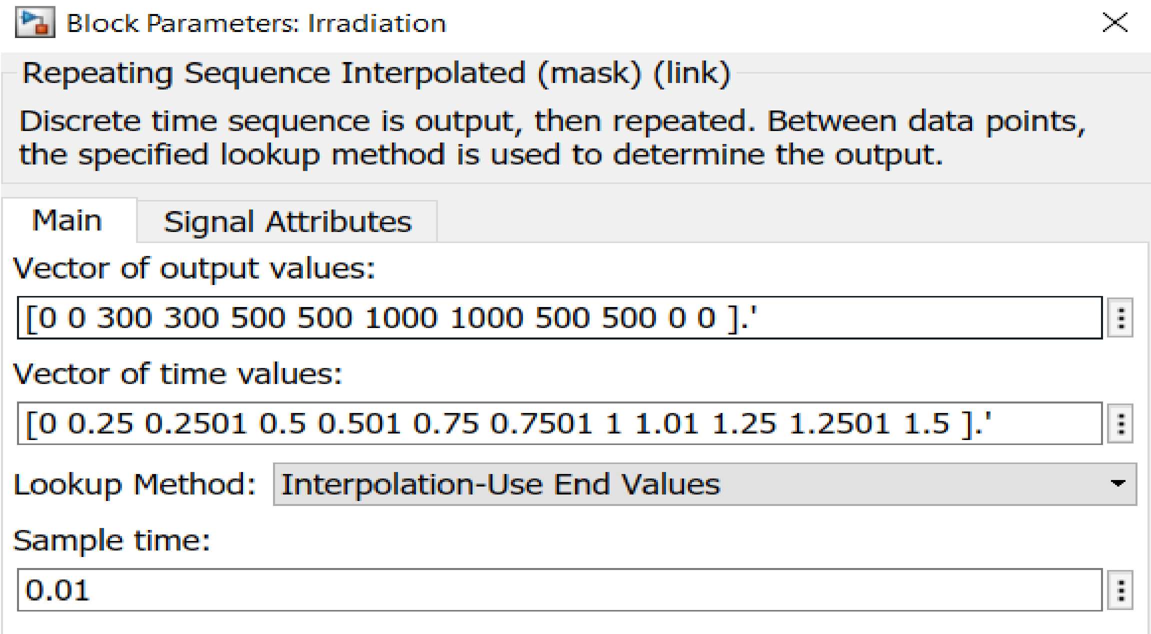


Figure 7.5 Input interface of Repeating Sequence Interpolated

The repetitive irradiance is achieved by using the interpolation of different Irradiance range from 300 – 1000 W/m^2 with the single pulse having 1.5 sec width. This irradiance is for the 10 sec of the time which is also known as the step time.

Type 1 Irradiance similar to Cloudy day or Repetitive.

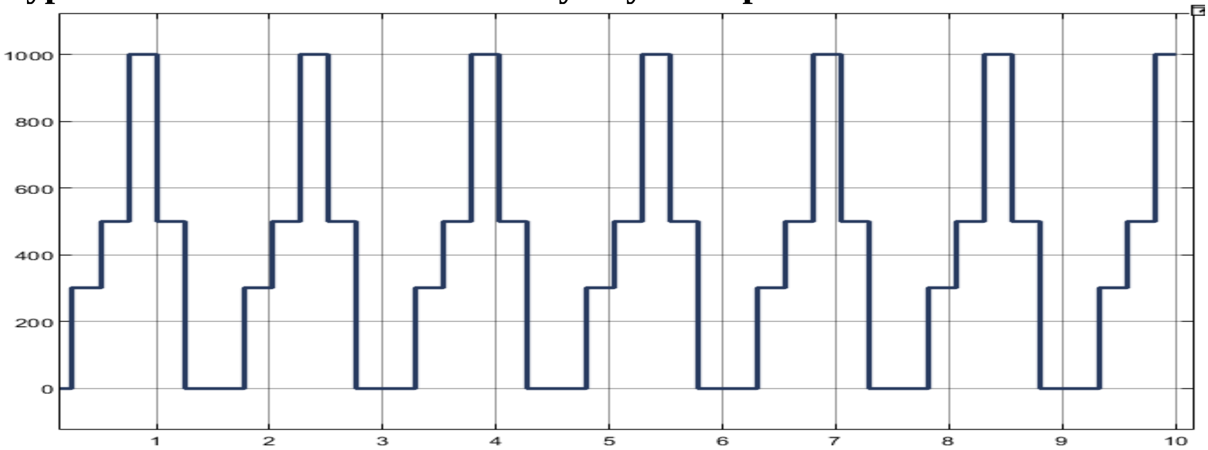


Figure 7.6 Generated by using MATLAB

This irradiance gives similar analysis of at the time of the cloudy climate in which irradiance varying number of times due to

1. Boost Converter without MPPT controller

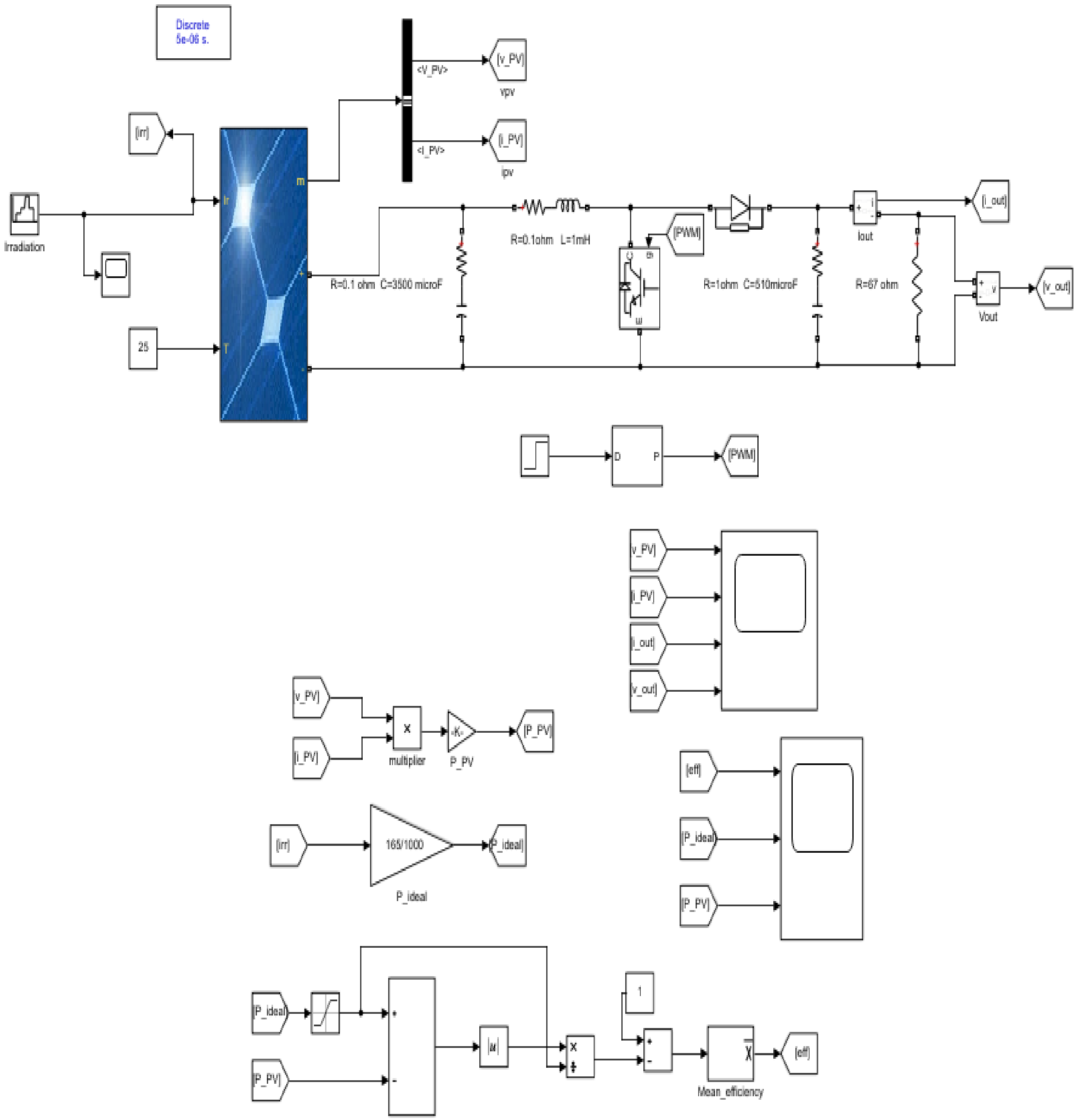


Figure 7.7 Circuit diagram of Boost Converter without MPPT.

In figure 7.7 IGBT is trigger by using PWM generator.

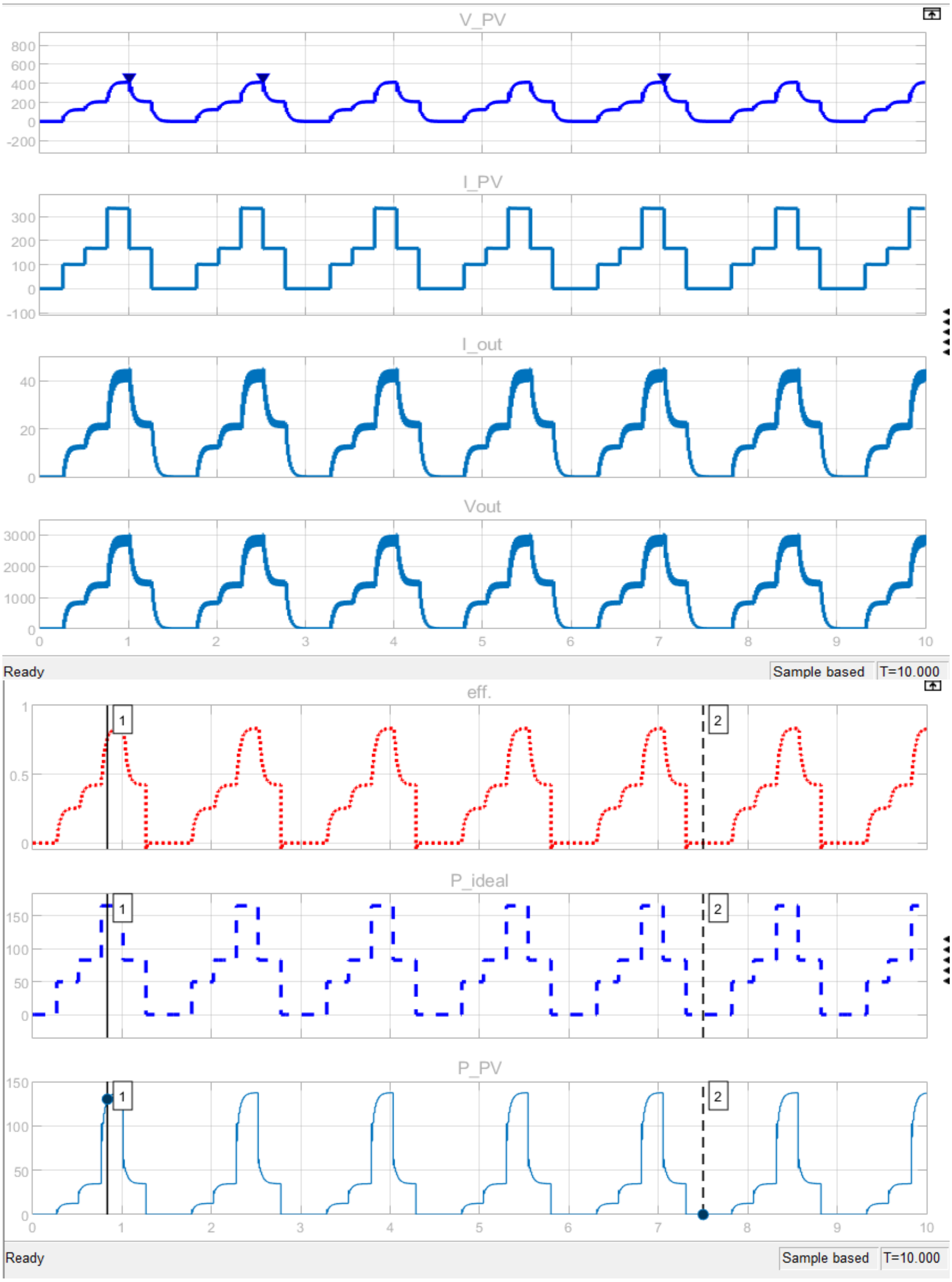


Figure 7.8 waveforms of all the parameter of Boost Converter without MPPT.

2. Boost Converter with MPPT Controller

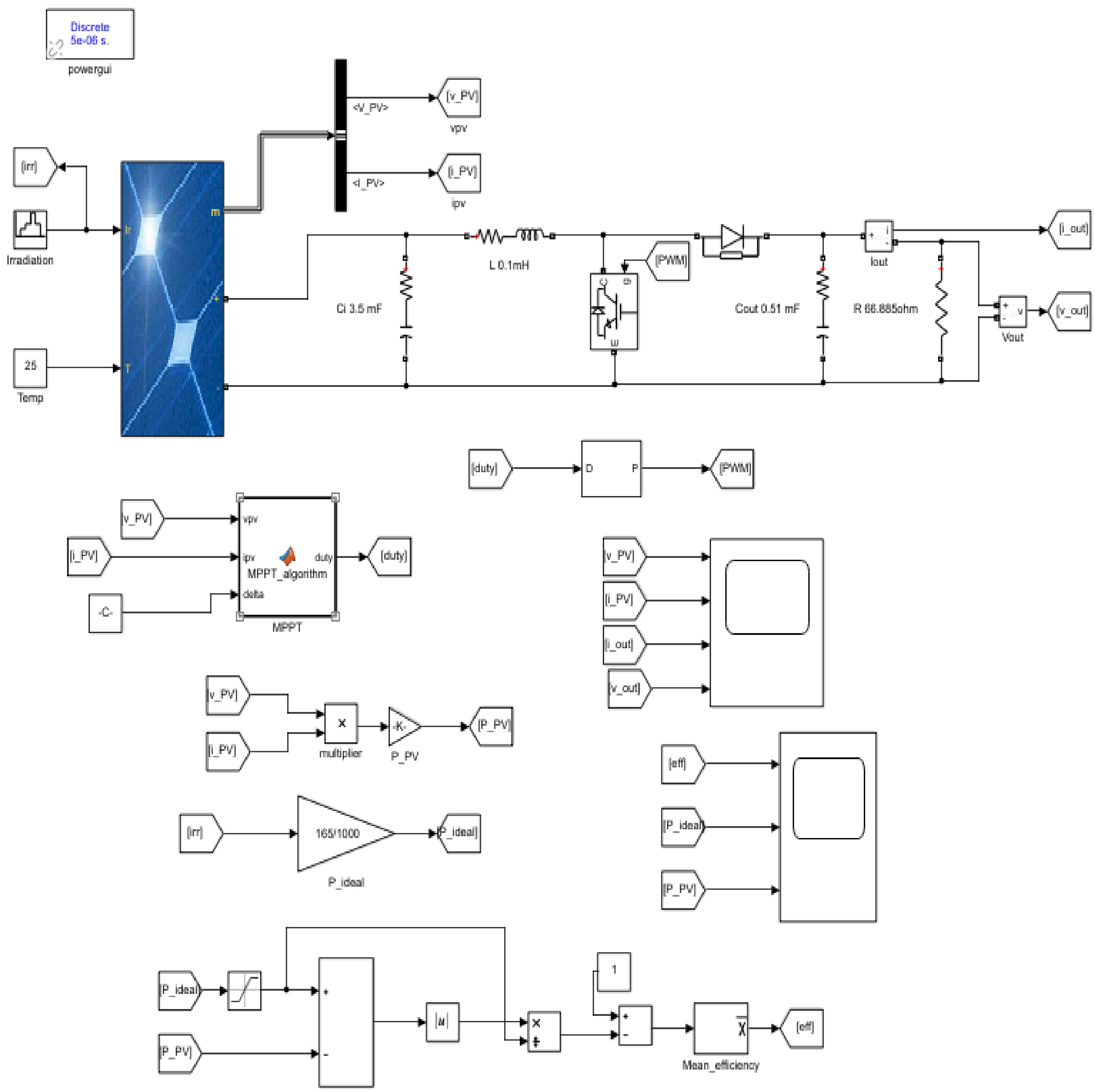


Figure 7.9 Circuit diagram of Boost Converter with MPPT Charge Controller

The circuit consist MPPT charge controller which can now decide the duty cycle of IGBT.

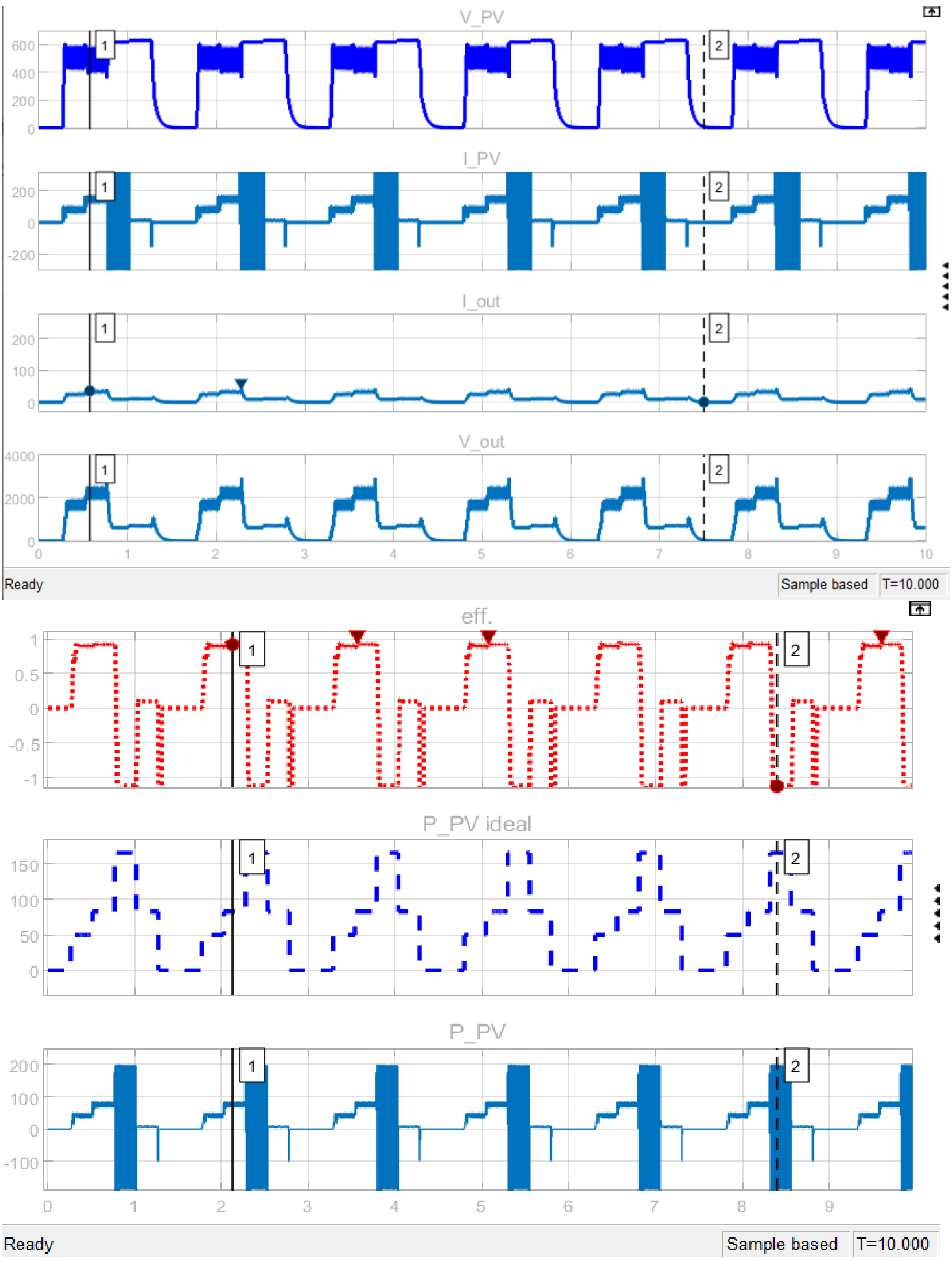


Figure 7.8 Waveform of all the parameter of Boost Converter with MPPT Controller

3. Boost Converter with MPPT with PI controller (without & with tunning)

I. PI controller at input side

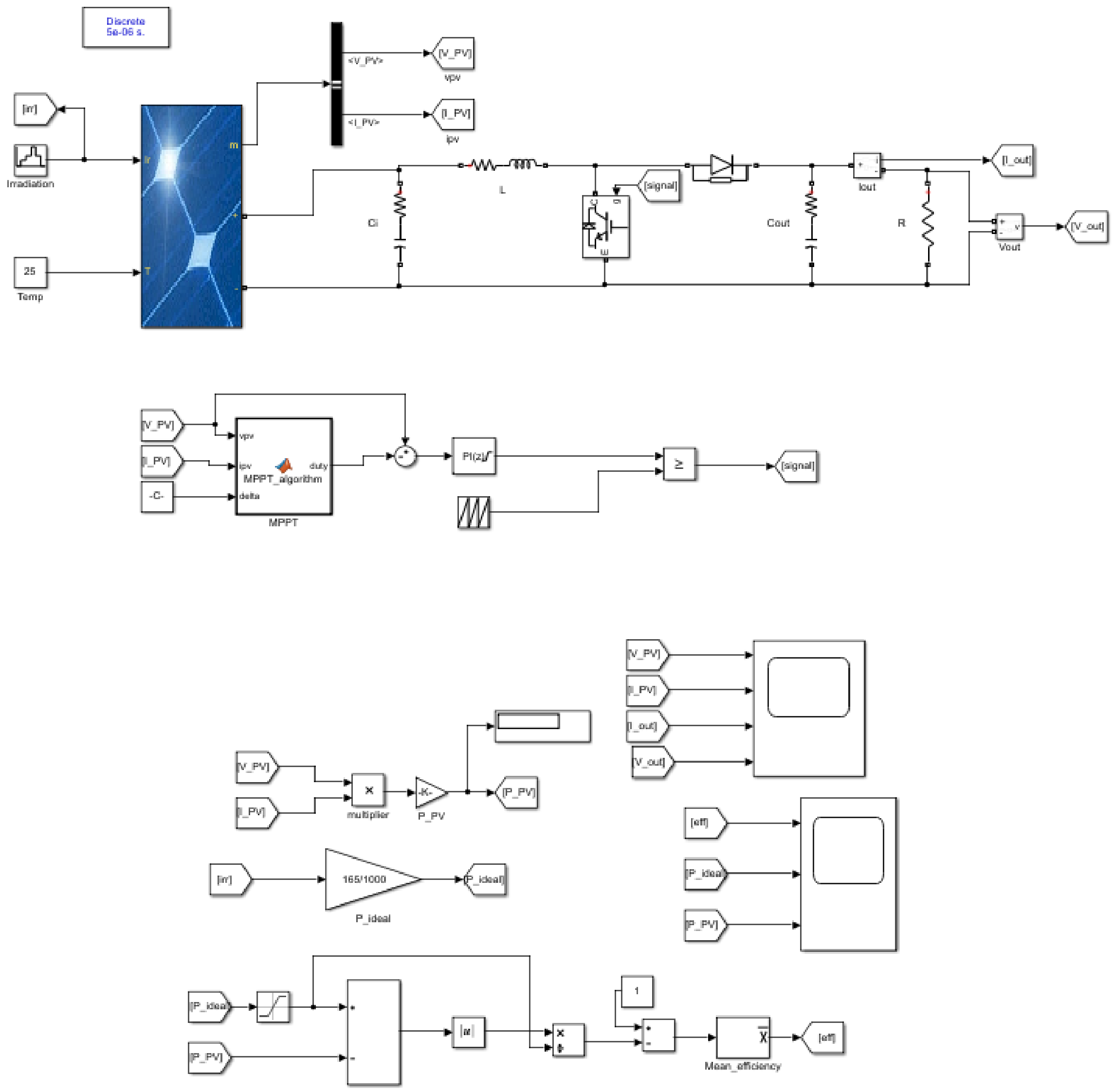


Figure 7.9 Circuit diagram of Boost Converter with MPPT and PI controller at input side.

The author design this circuit in which PI controller is at input side means it takes input response in terms of V_PV and I_PV indirectly from MPPT charge controller. Then at comparator 2 signals compare, one is output of PI controller and other one is from repeating signal block which have reference switching frequency of f = 25 kHz. This single circuit is used for generating waveforms for different parameters for both Untuned and Tuned PI controller.

a. Without tunning where kp = 0.55 and ki = 1200

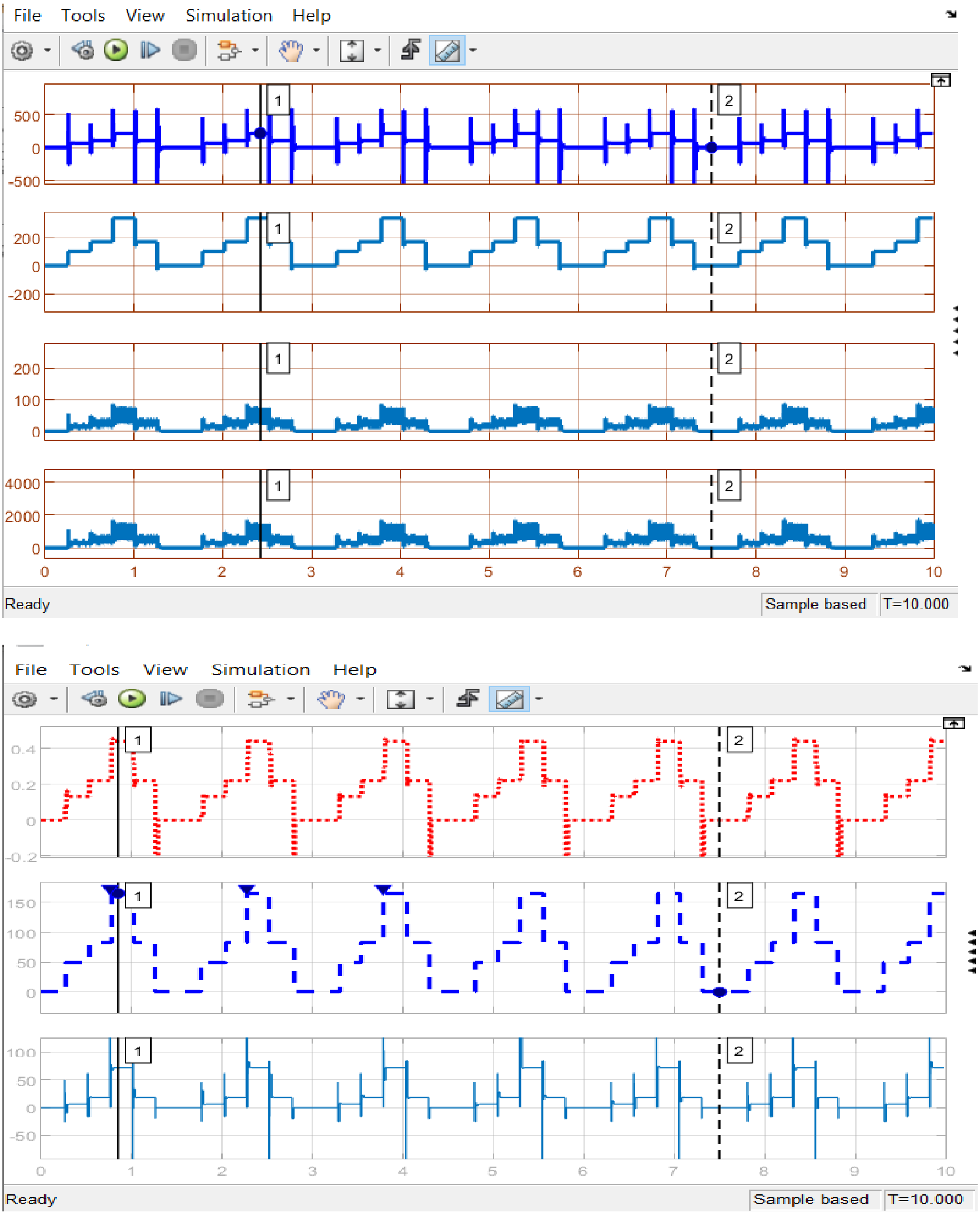


Figure 7.10 Waveform of parameters for boost converter with MPPT controller connected with untuned PI controller.

b. With tunning where Kp = 0.405 and ki = 4860

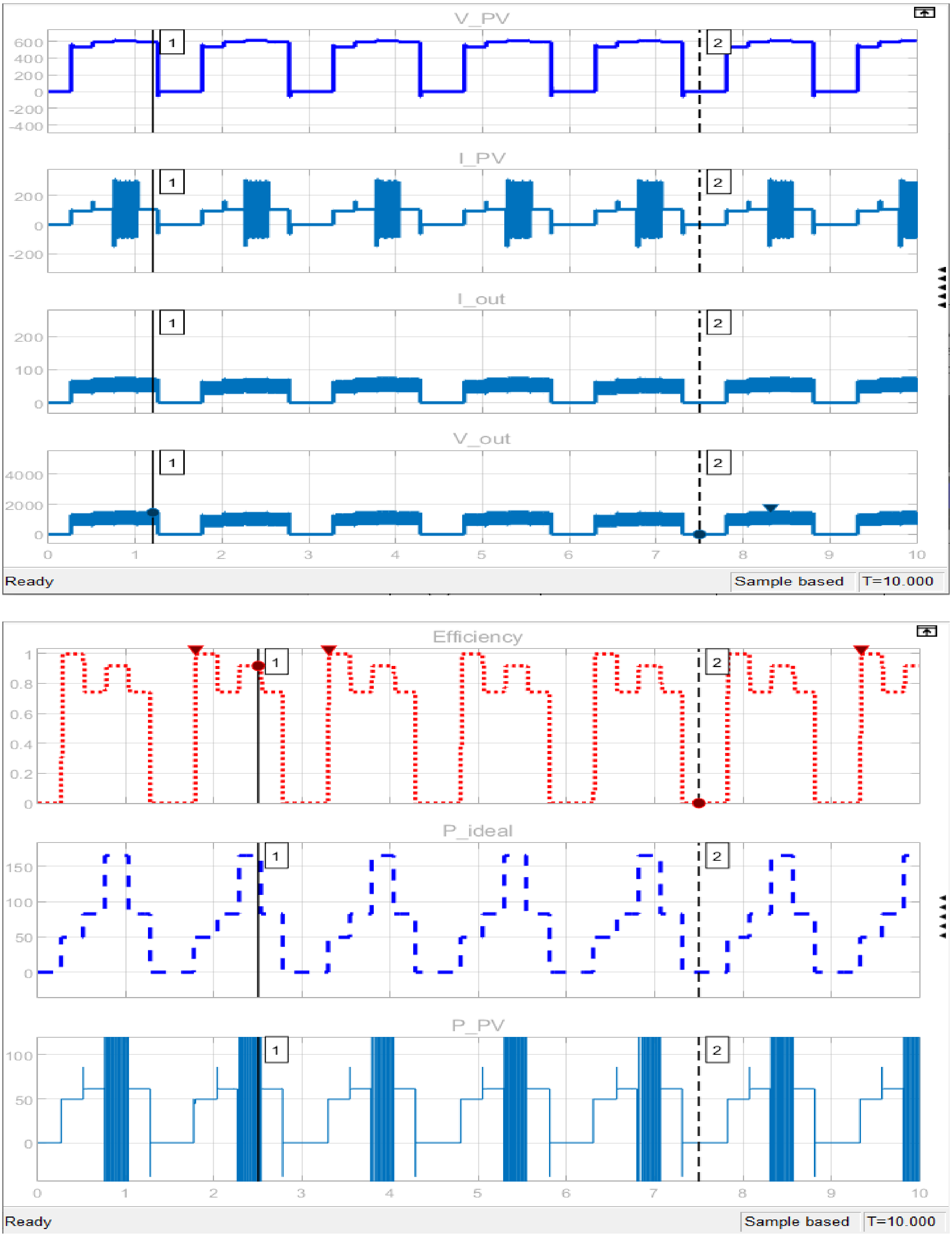


Figure 7.10 Waveform of parameters for boost converter with MPPT controller connected with tuned PI controller.

After tunning we clearly observe the waveforms of parameter where the amplitude of voltages, current increases, harmonics reduces and efficiency increases as compare to untuned.

II. PI controller at output side

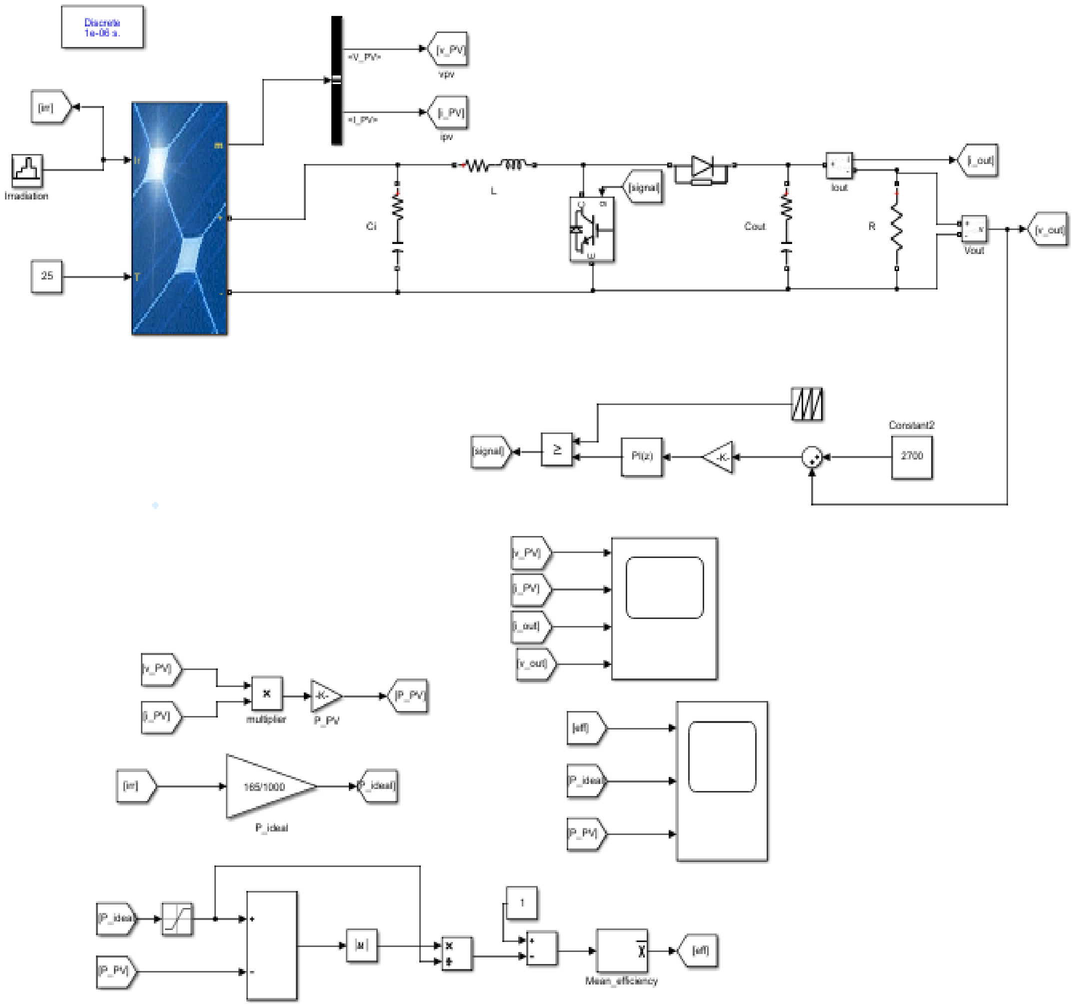


Figure 7.11 Circuit diagram of Boost converter with PI controller at output side.

The circuit is design in such away that PI controller got input from output side of Boost converter that is Voltage across the load (Vo). Two signals given to sum point, one is output voltage and other one is constant voltage of 2700 V. After this signal is go through gain block of value 1/2500. Then it pass through PI controller. After all of these it trigger the IGBT after comparison between signal from PI controller and repeating signal block.

a. Without tunning with kp = 0.45 and ki = 54

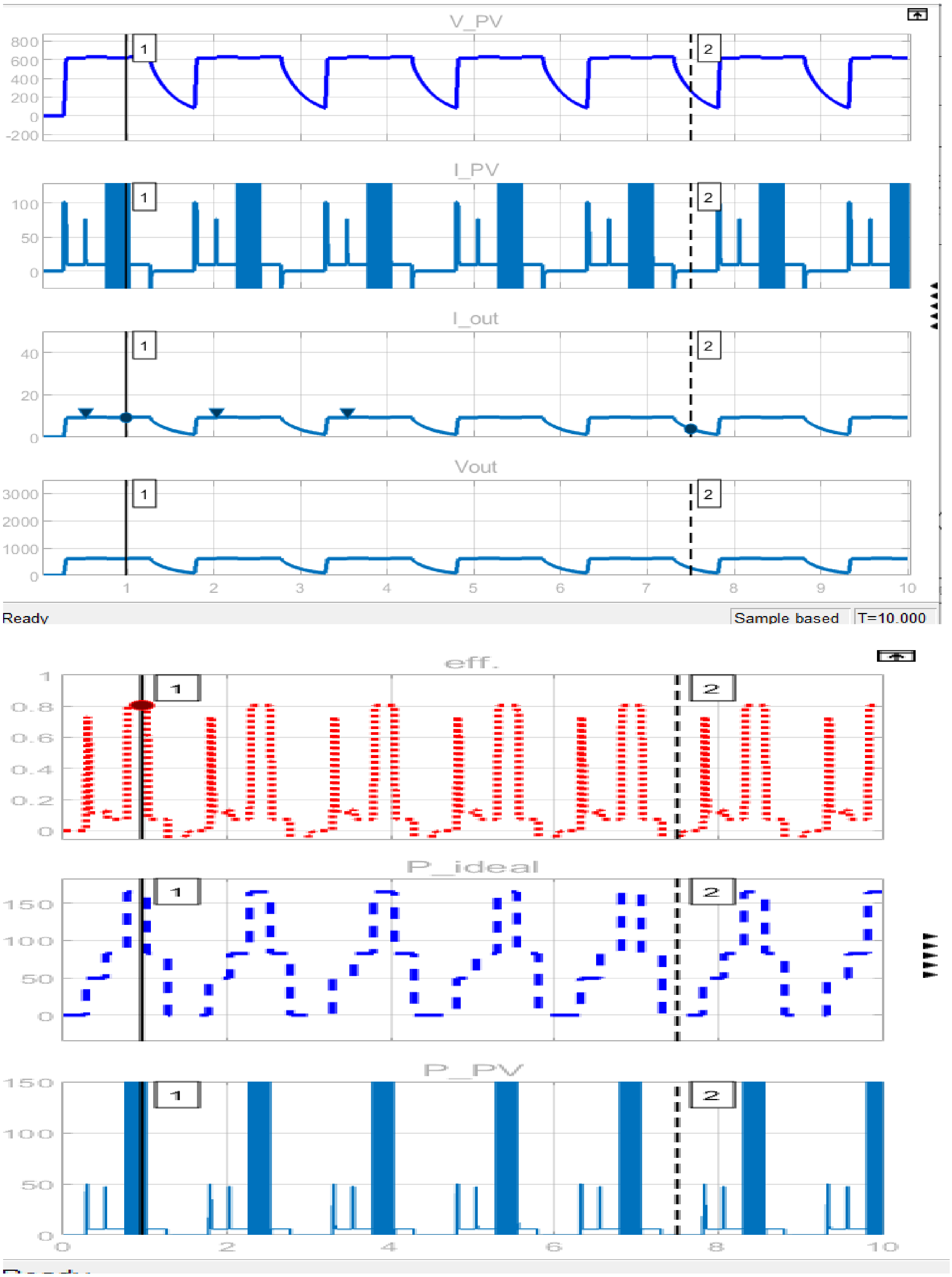


Figure 7.12 Waveforms of parameters of Untuned PI controller at output side.

b. With tunning with kp = 0.270 and ki = 6480

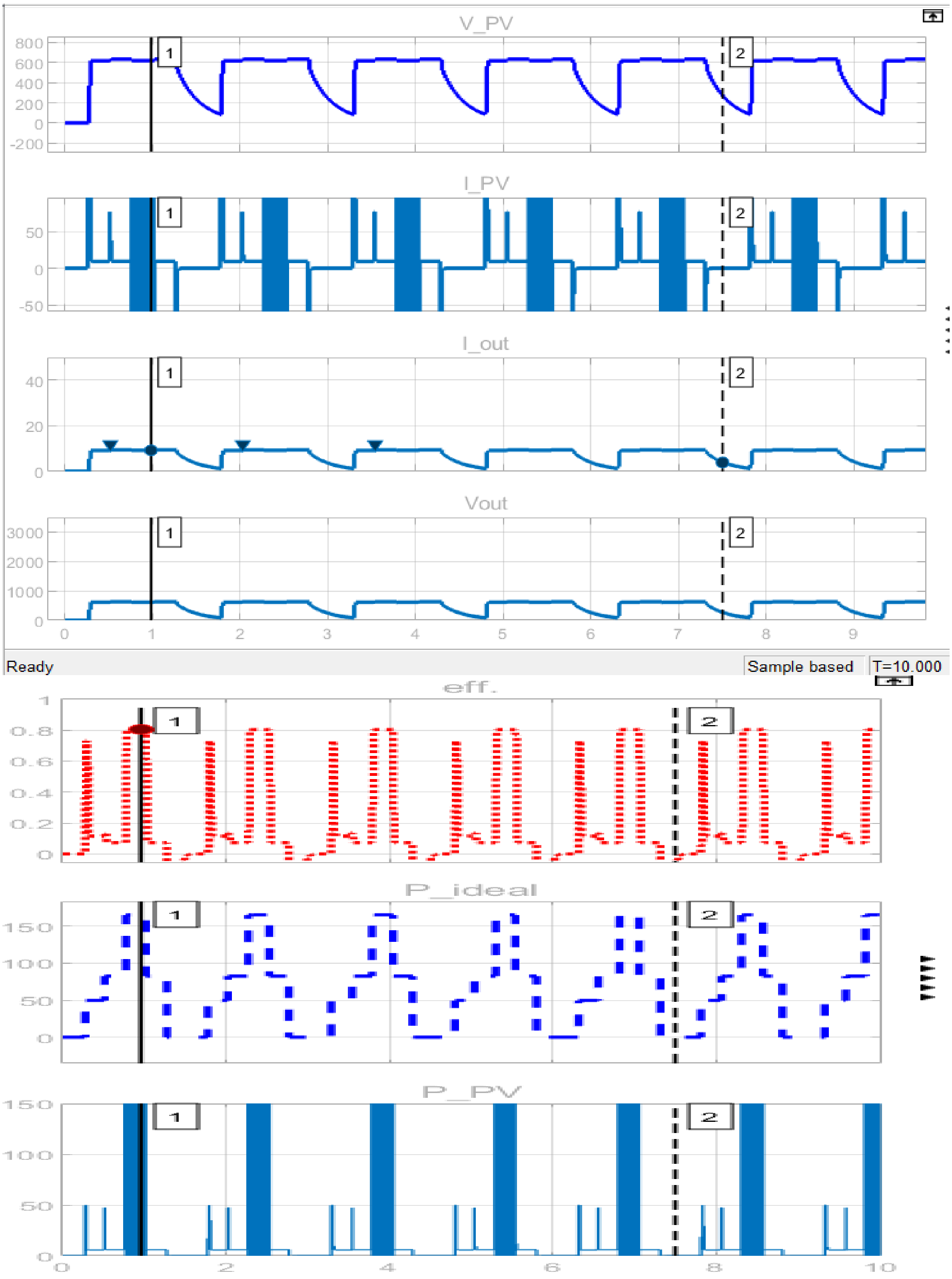


Figure 7.13 Waveforms of parameters of tuned PI controller at output side.

III. PI controller at input - output side

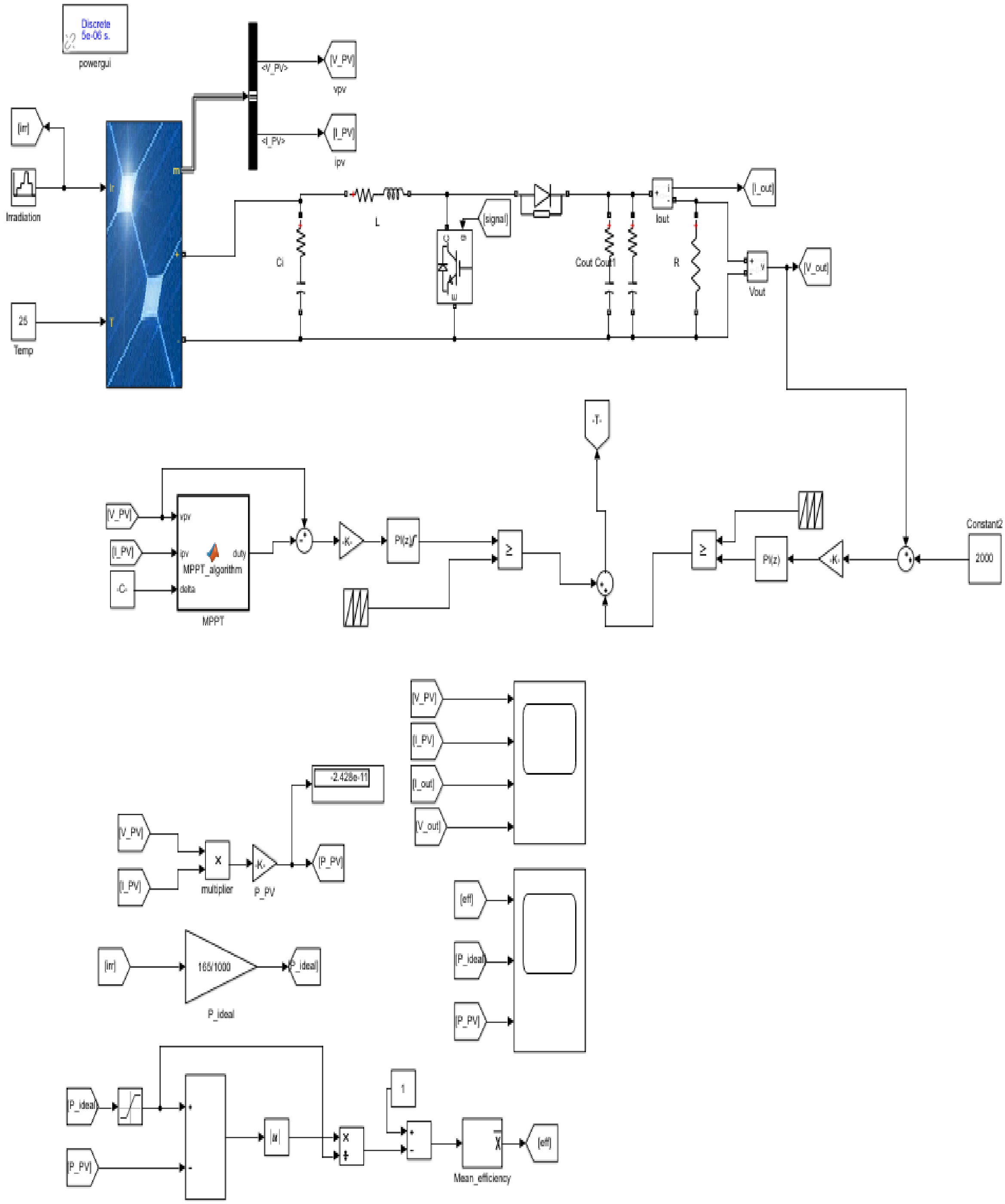
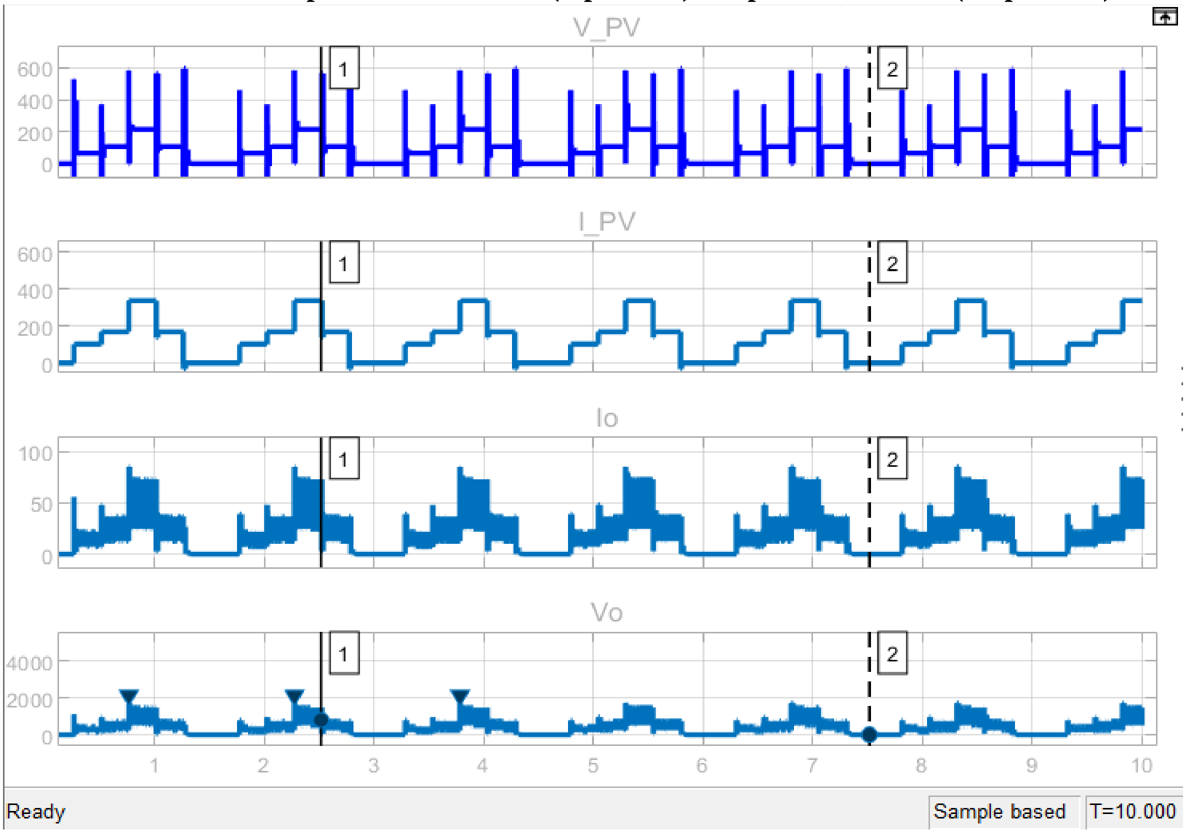


Figure 7.14 Circuit diagram of Converter with PI controller both input and output side.

a. Without tunned at kp = 0.55 , ki = 1200 (input side) & kp= 0.45 , ki = 54 (output side)



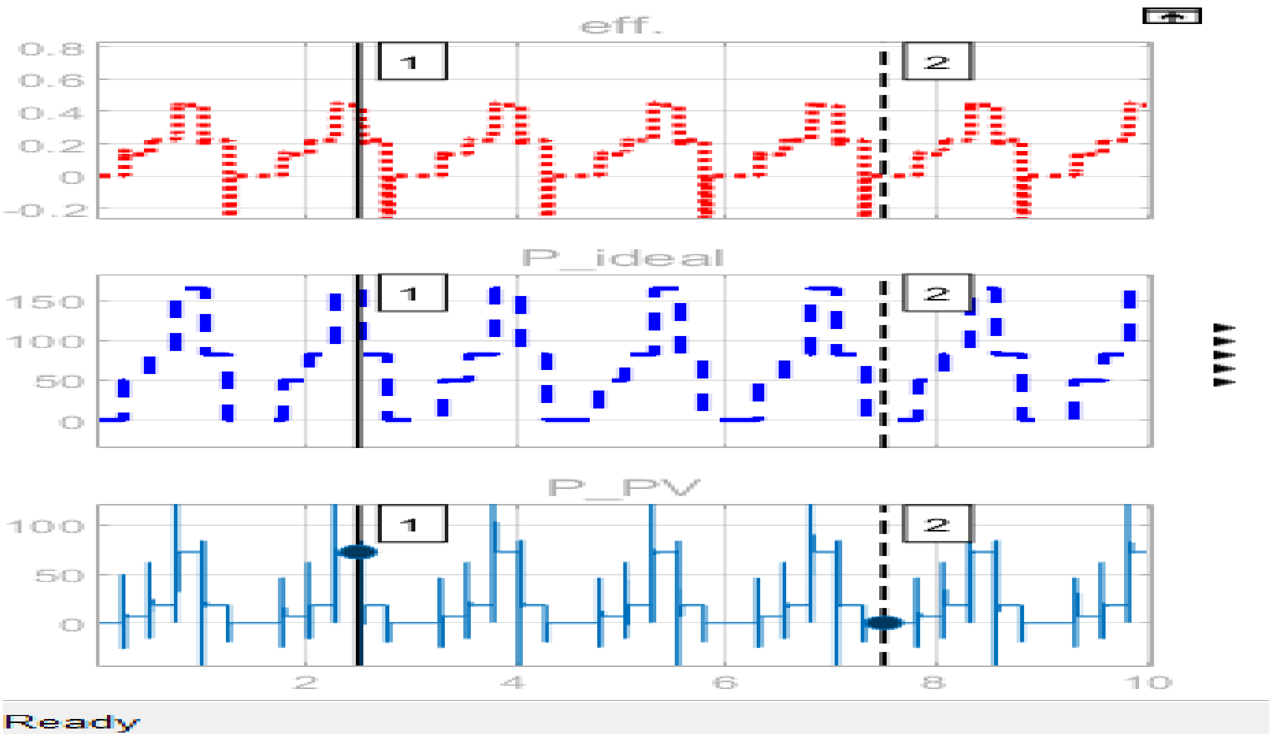


Figure 7.15 Waveforms of parameters of untuned PI controller both at input and output side.

b. With tunned at kp = 0 , ki = - 200000 (input side) & kp= 0.2025 , ki = 243 (output side)

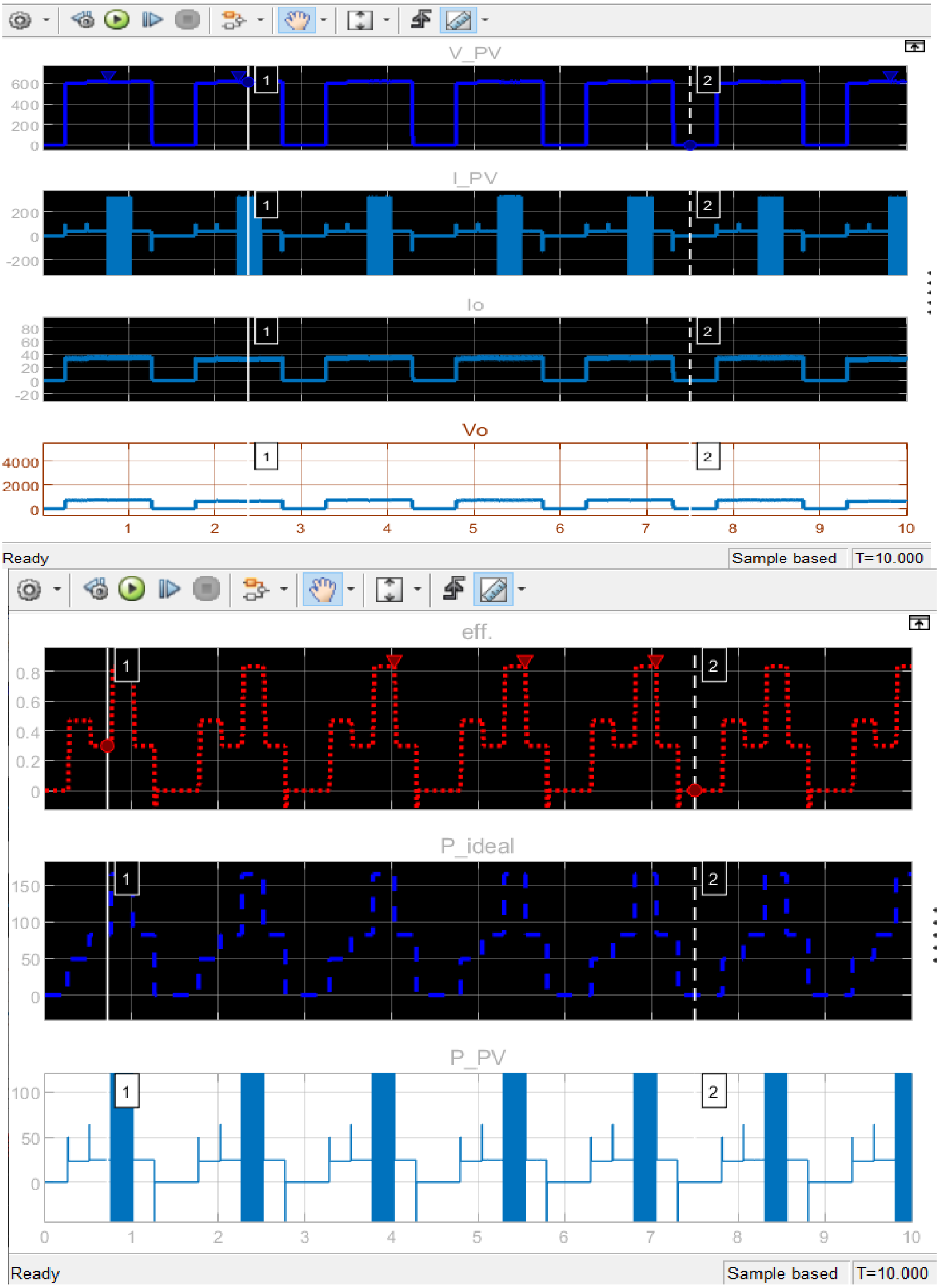


Figure 7.16 Waveforms of parameters of tuned PI controller both at input and output side.

By comparing Untuned and tuned response of PI controller, we observe that tuned response is good in compare of amplitude, less harmonics, high efficiency.

4. Boost Chopper with MPPT with PID controller (without or with tunning)

I. PID controller at input side

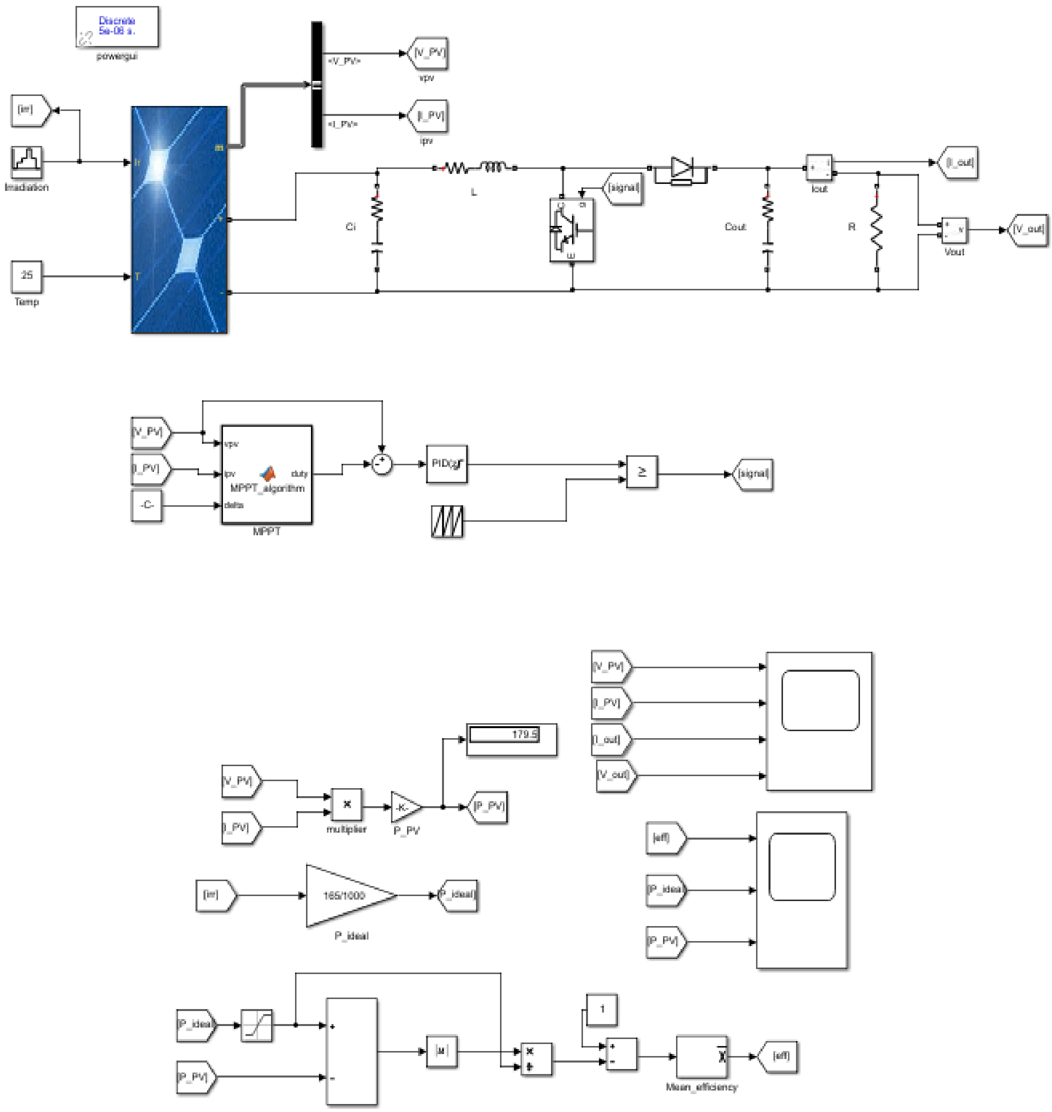


Figure 7.17 Circuit diagram of the Boost converter with PID controller at input side.

In figure 7.17 the PI controller is replaced by PID controller. The PID controller is used to improve the both transient stability and steady state stability. The author simulate above circuit which work in both untuned and tuned manner.

a. Waveforms when PID controller is Untunned with kp= 0.45 , ki = 0.01 & kd = 540

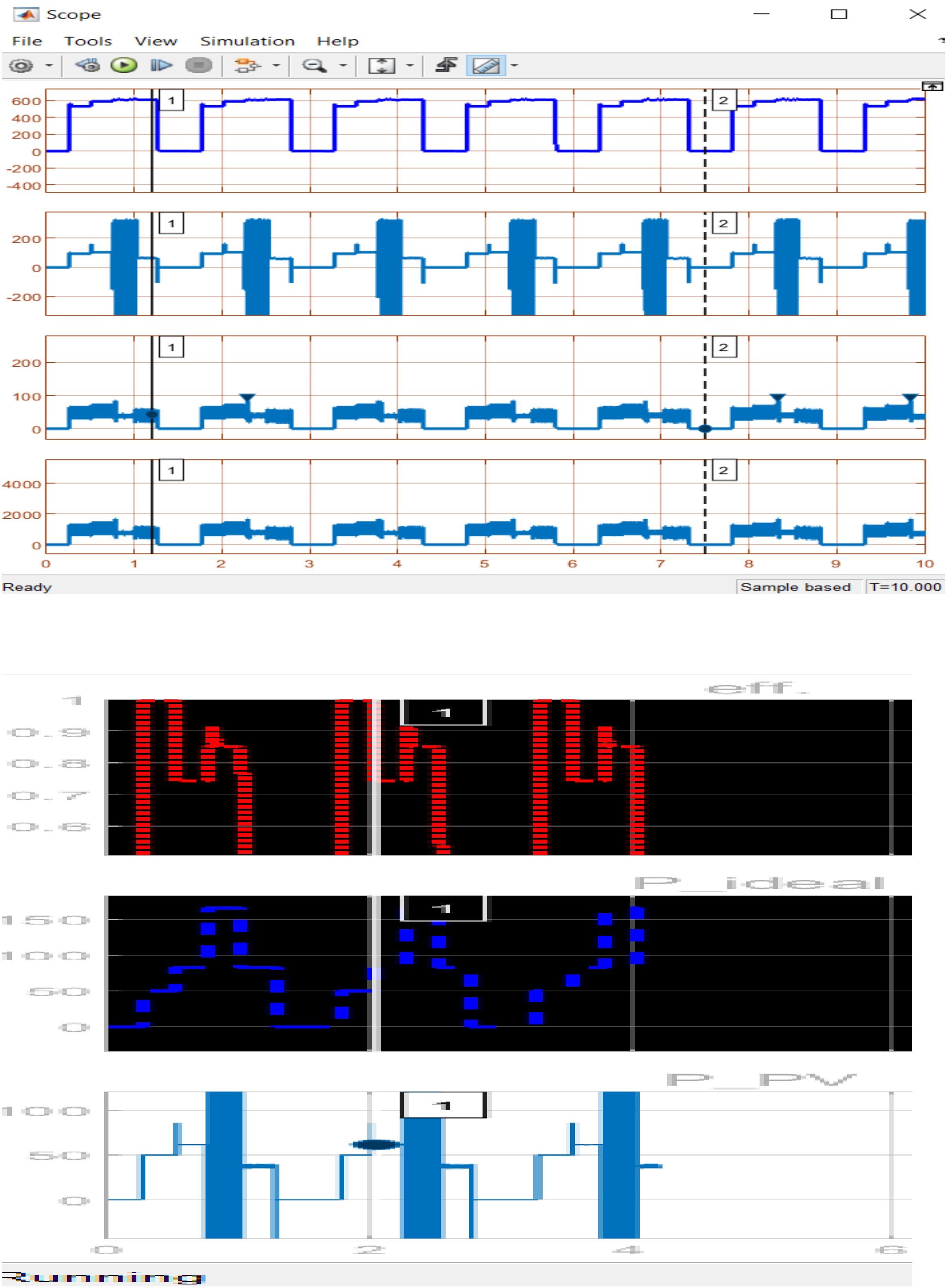


Figure 7.18 Waveform of all the parameter of Boost converter with untuned PID controller.

b. Waveforms when PID controller is tunned with kp= 0.18, ki = 2000 & kd = 0.000125

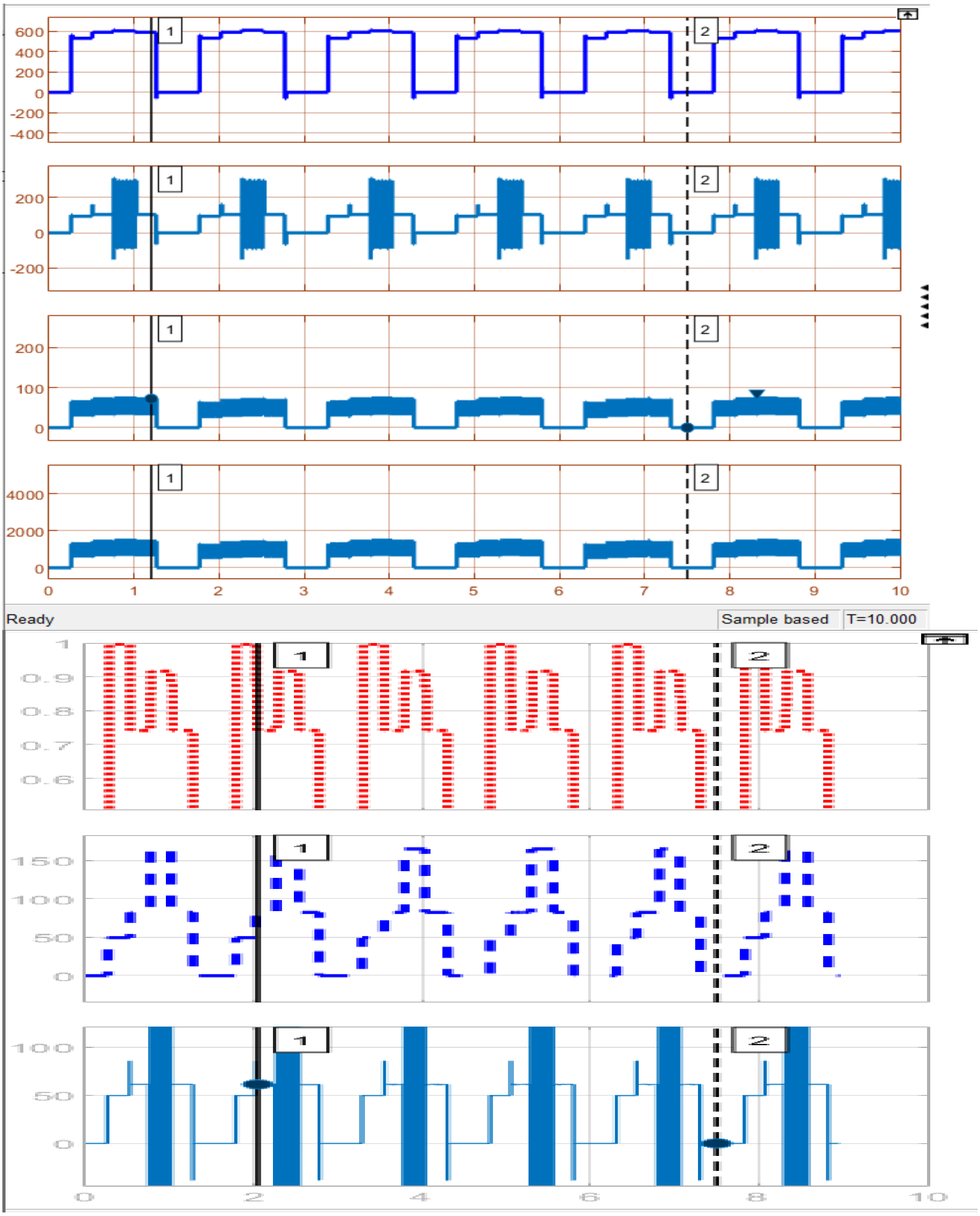


Figure 7.19 Waveform of all the parameter of Boost converter with tuned PID controller.

The both untuned and tuned waveforms looking similar and having approximately same values of parameter but in tuned waveform harmonics are less as compare to untuned PID controller.

II. PID controller at output side

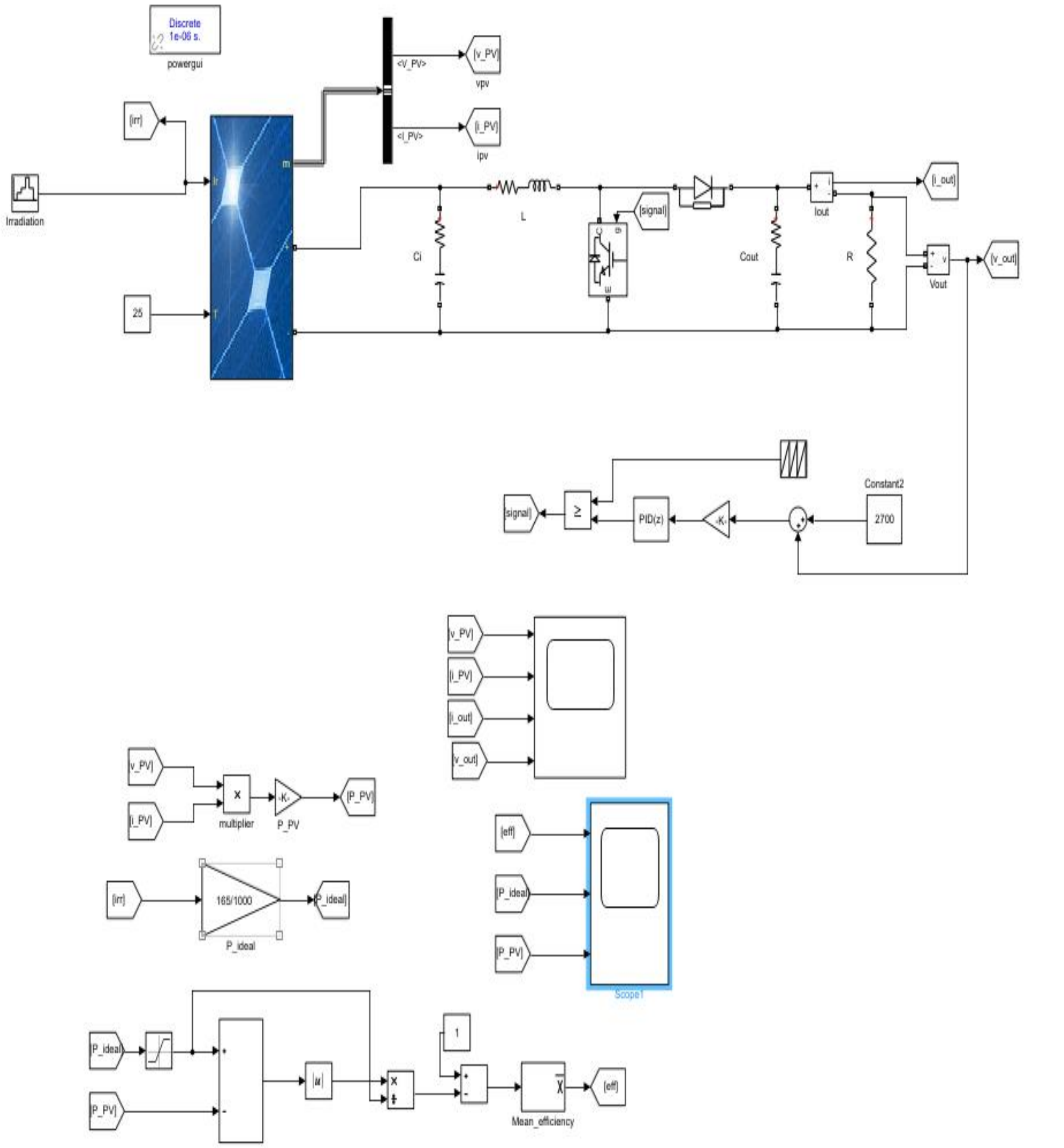


Figure 7.20 Circuit diagram of the Boost converter with PID controller at output side.

The figure 7.20 design for reducing the harmonics in output parameters like Vo and Io and increase the overall system efficiency.

a. Without tunning kp = 0.45 , ki = 0.01 , kd = 540

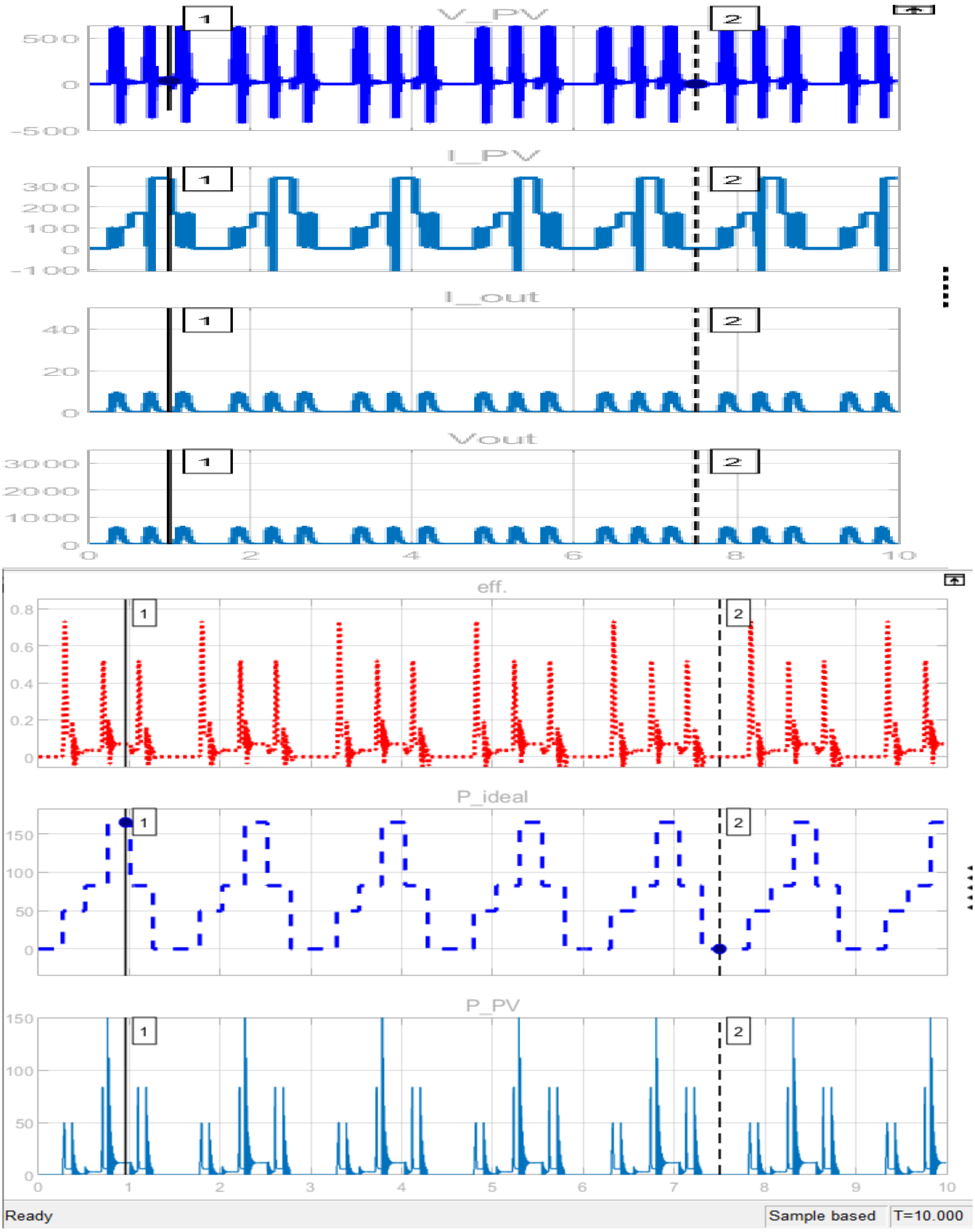


Figure 7.21 Waveforms of parameters of boost converter with untuned PID controller at output side.

b. With tunning kp = 0.3, ki = 600 , kd = 0.0000375

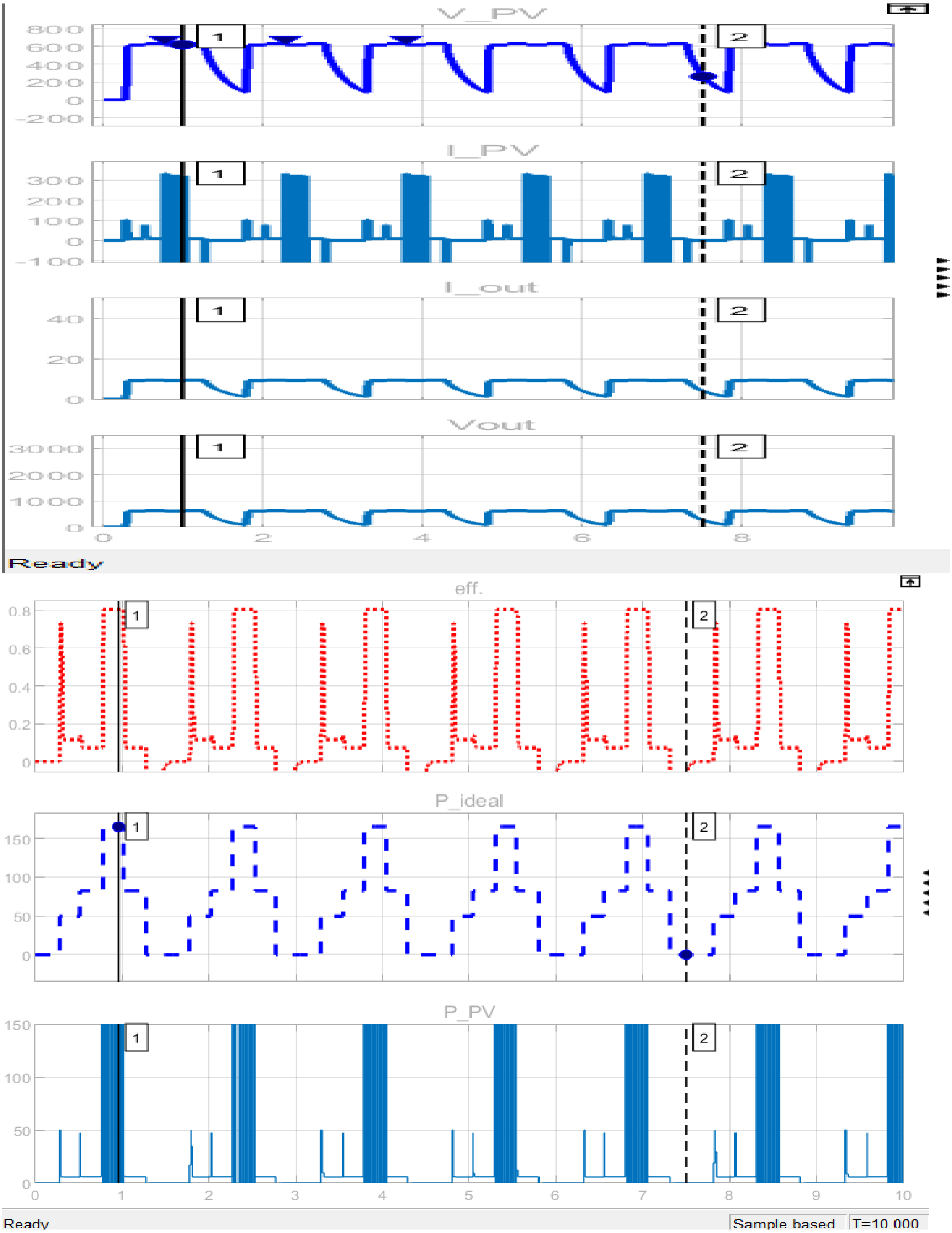


Figure 7.22 Waveforms of parameters of boost converter with tuned PID controller at output side.

By comparing the figure 7.21 and 7.22, it shows that untuned PID controller have less efficient than tuned one. And also output int terms of amplitude of different variables is less. Harmonics is more in untuned PID controller.

III. PID controller at input side and output side

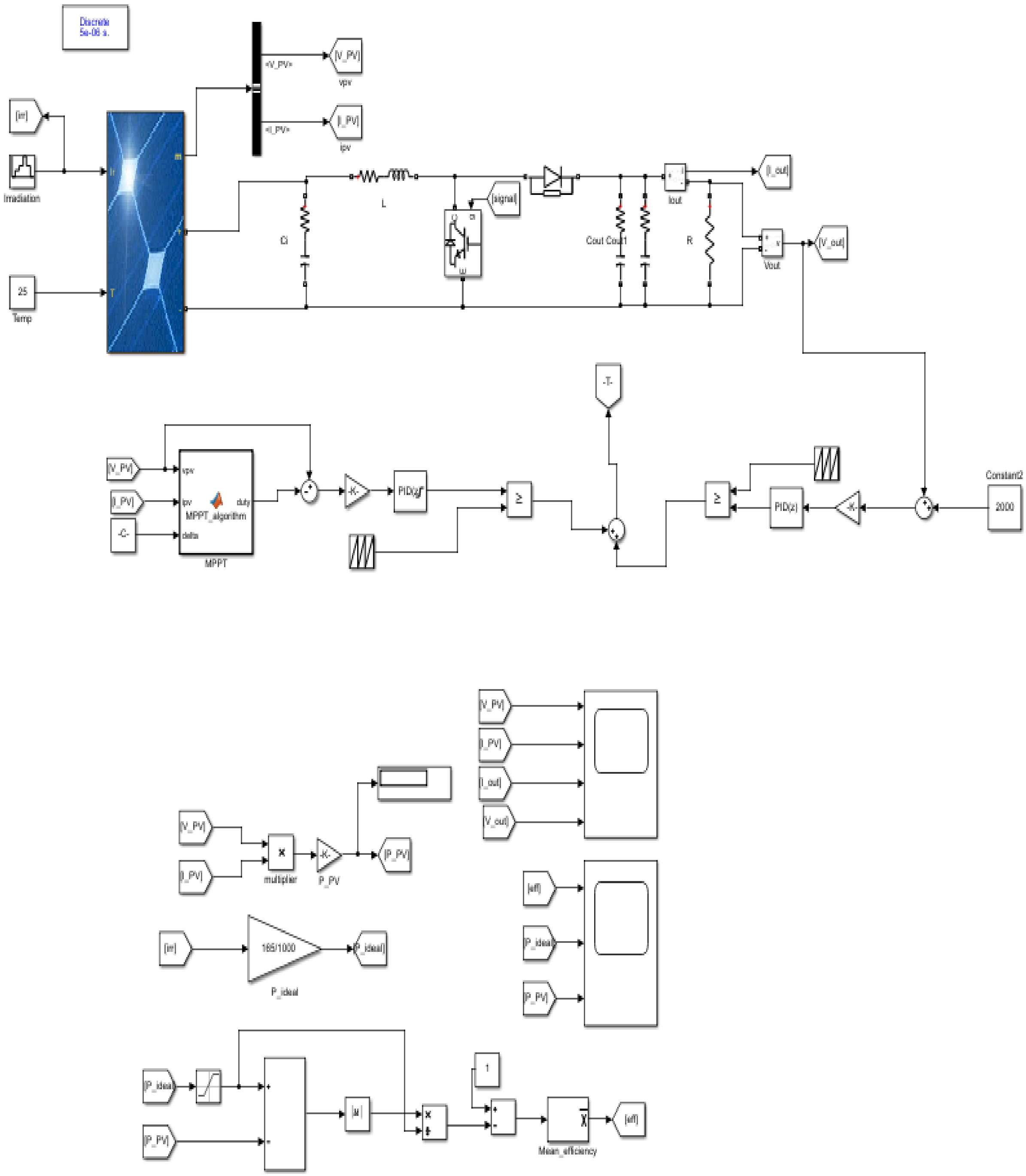


Figure 7.23 Circuit diagram of boost converter with untuned and tuned PID controller at both input and output side.

a. Without tunning kp = 0.45, ki = 0.01, kd= 54 (input side) and kp = 0.45 , ki = 0.01 , Kd = 540 (output side)

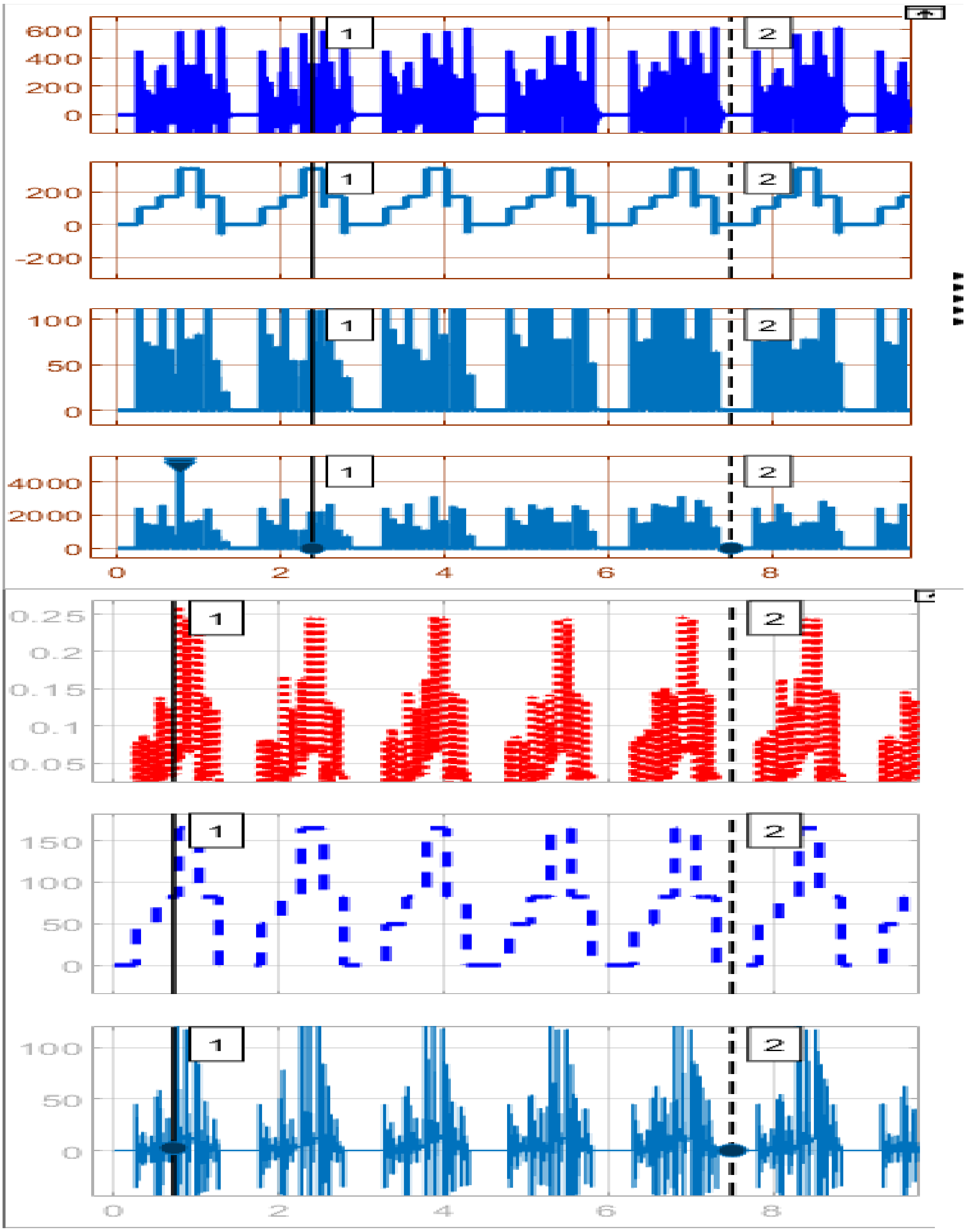


Figure 7.24 Waveforms of parameters of boost converter with untuned PID controller at both input and output side.

The untuned PID controller having less performance, more harmonics, less effective in power system in terms of power conversion.

b. With tunning kp = 0.54, ki = 1080, kd= 0.0000675 (input side) and kp = 0.48 , ki = 2000, kd= 0.000125 (output side)

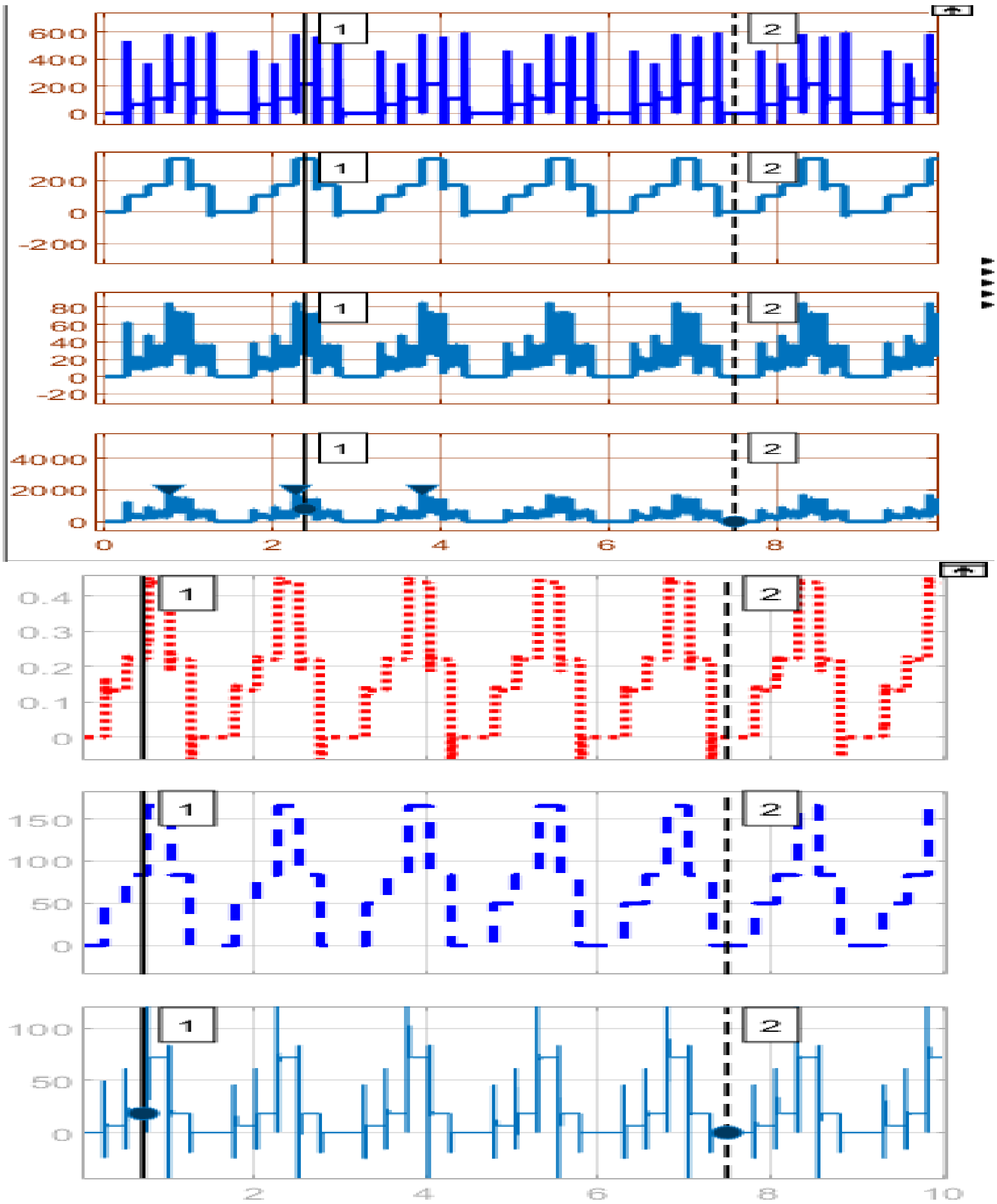
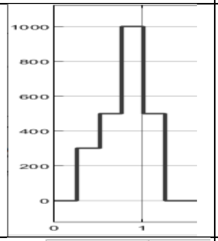
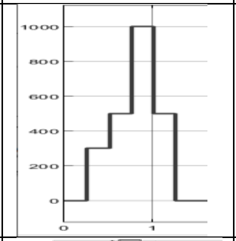
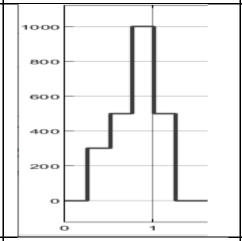
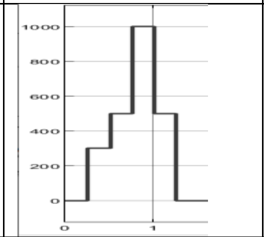
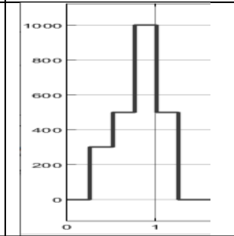
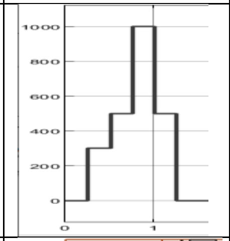
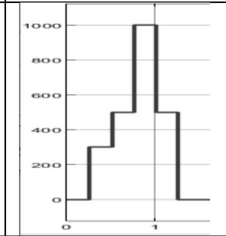
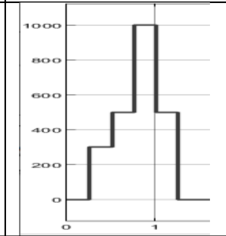
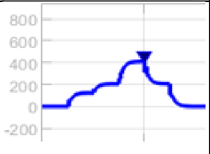
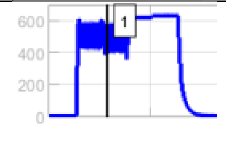
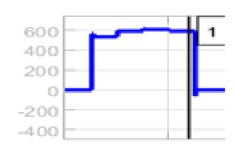
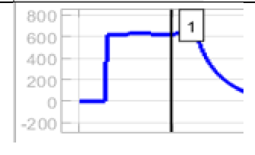
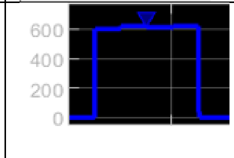
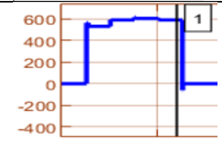
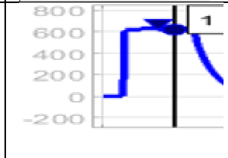
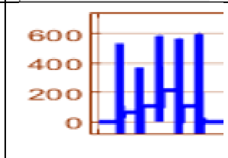
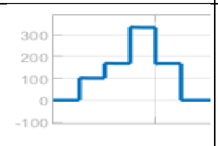
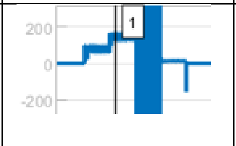
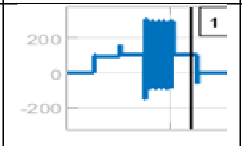
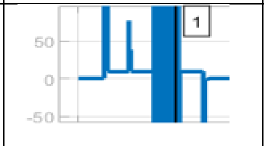
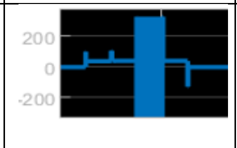
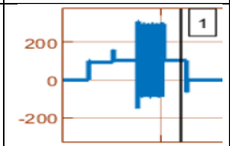
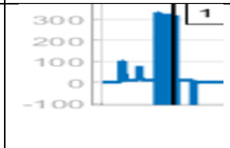
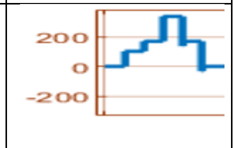
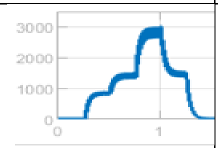
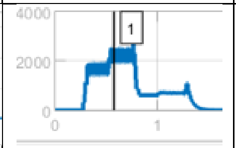
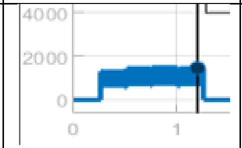
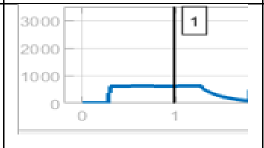
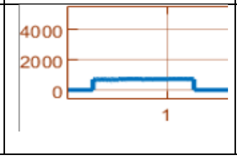
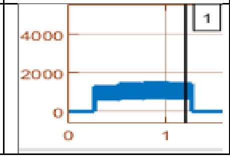
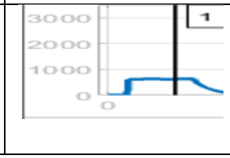
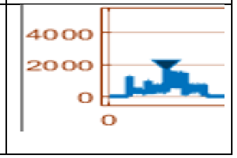


Figure 7.25 Waveforms of parameters of boost converter with tuned PID controller at both input and output side.

The tuned PID controller having high efficiency than untuned one. Harmonics are less, more power conversion. But the end of all type of controller's configuration for repetitive irradiance in specified time, the observations comes like the simulation time is more in all cases, overall efficiency less as compare to other type of irradiance.

7.3 Observation Table

Table 4: Comparative Study of tuned controllers for type 1 Irradiance (Repetitive) in terms of waveform.

Types of controller configuration / Parameters	Boost Converter without MPPT controller	Boost Chopper with MPPT Controller	Boost Chopper with MPPT with input side PI controller	Boost Chopper with output side PI controller	Boost Chopper with MPPT with input – output side PI controller	Boost Chopper with MPPT with input side PID controller	Boost Chopper with output side PID controller	Boost Chopper with MPPT with input – output side PID controller
Irradiance (watt/ m^2)								
V_PV (Volts)								
I_PV (A)								
Output Voltage (kV)								

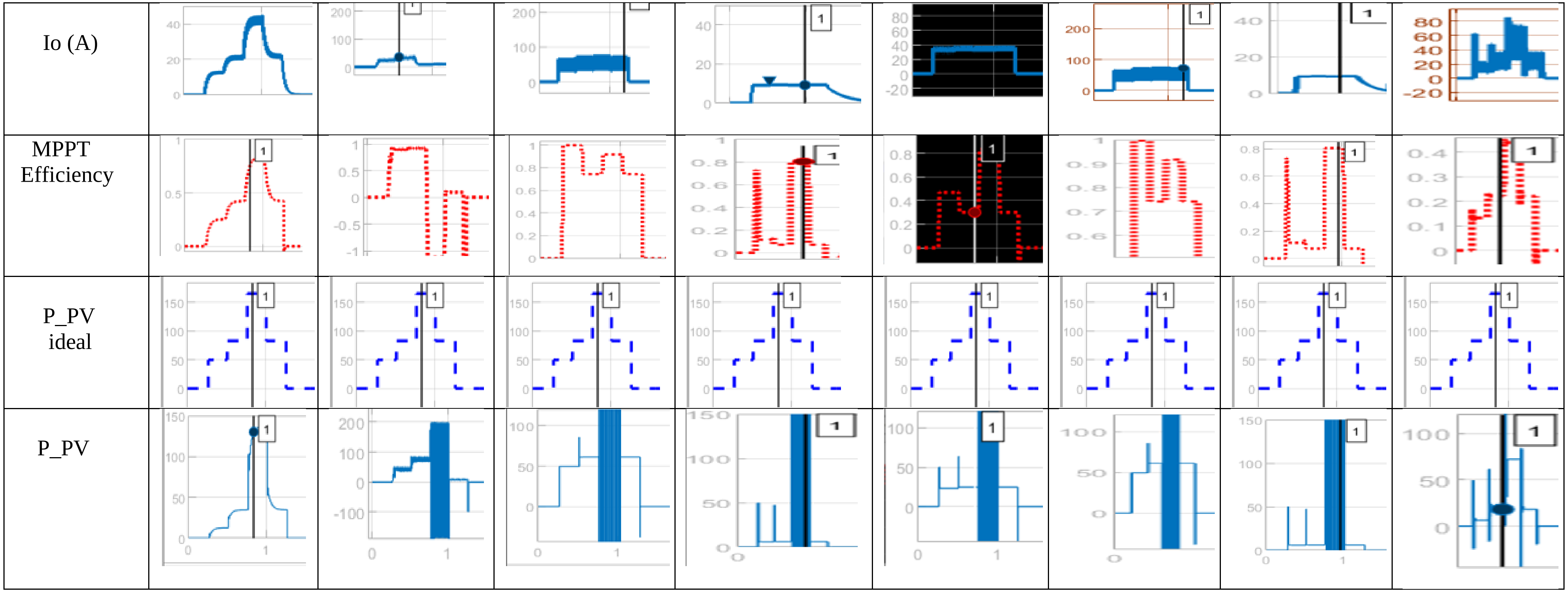

Io (A)
MPPT Efficiency
P_PV ideal
P_PV

Table 5: Comparative Study of untuned controllers for type 1 Irradiance in terms of numerical values of parameters.

Parameters / Types of controller configuration	V_PV (Volts)	I_PV (A)	Vo (kV)	Io (A)	P_pv or Pin (kW)	Po (kW)	System efficiency (%)
Boost Converter without MPPT controller	206.7	172.6	1.3730	20.73	35.68	28.46	79.80
Boost Chopper with MPPT Controller	467.8	146.1	1.1610	17.35	68.34	20.135	29.50
Boost Chopper with MPPT with input side PI controller	118.3	173.2	0.4472	22.36	20.50	10.00	48.78
Boost Chopper with output side PI controller	529.9	118	0.5284	7.90	62.53	4.20	6.716
Boost Chopper with MPPT with input – output side PI controller	118.8	174.0	0.4493	22.47	20.67	10.10	48.86
Boost Chopper with MPPT with input side PID controller	479.4	133	0.7583	37.92	63.80	28.755	45.10
Boost Chopper with output side PID controller	260.1	164.0	0.2766	4.136	42.66	1.144	2.68
Boost Chopper with MPPT with input – output side PID controller	89.0	173.0	0.1353	6.763	15.40	1.00	6.49

The comparison between controllers for untuned controller are as follows:

- The harmonics in untuned controller is high.
- The system efficiency is high for Boost converter without MPPT controller that is 79.80 %.
- The worst performing controller is Boost converter with output side PID controller.

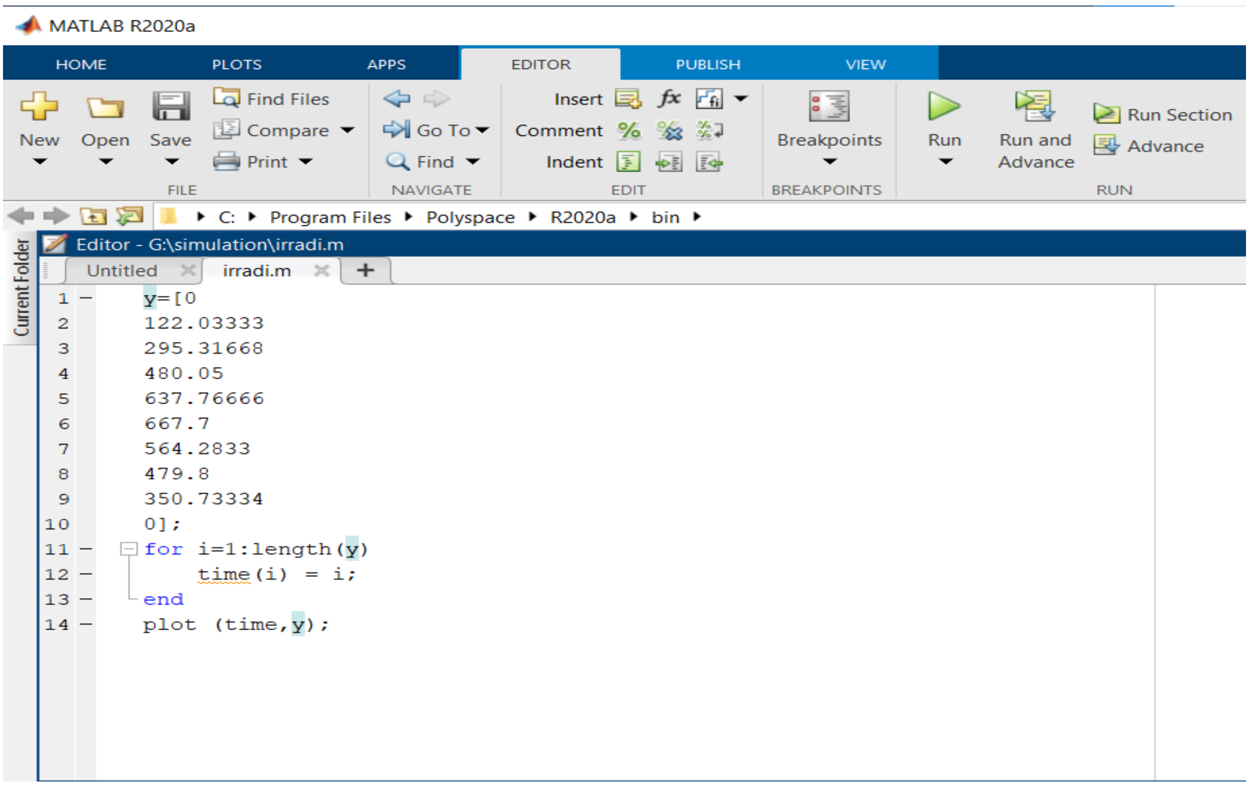
Table 6: Comparative Study of tuned controllers for type 1 Irradiance in terms of numerical values of parameters.

Parameters / Types of controller configuration	V_PV (Volts)	I_PV (A)	Vo (kV)	Io (A)	P_pv or Pin (kW)	Po (kW)	System efficiency (%)
Boost Converter without MPPT controller	206.7	172.6	1.3730	20.73	35.67	28.46	79.00
Boost Chopper with MPPT Controller	467.8	146.1	1.1610	17.35	68.345	20.14	29.50
Boost Chopper with MPPT with input side PI controller	475.0	113.30	0.8504	42.52	53.817	36.159	67.20
Boost Chopper with output side PI controller	529.9	114	0.5284	7.90	60.41	4.17	6.90
Boost Chopper with MPPT with input – output side PI controller	501.8	121.70	0.5628	28.14	61.01	15.84	25.96
Boost Chopper with MPPT with input side PID controller	475.0	113.30	0.8504	42.52	53.82	36.20	67.30
Boost Chopper with output side PID controller	527.0	112	0.5284	7.90	59.024	4.20	7.11
Boost Chopper with MPPT with input – output side PID controller	118.3	173.20	0.4472	22.36	20.45	10.00	48.90

The comparison between controllers of type 1 irradiance for tuned controllers and also with untuned controller:

- In tuned controller, for type 1 irradiance, system efficiency is high for Boost converter without MPPT, 79 % and lowest for Boost converter with output side PI controller, is 6.90 %.
- It is carefully observed that Boost converter with PI controller at input side, performance is significantly improved in terms of system efficiency, output power and also reduces the harmonics comparing to all untuned controllers and tuned controller other than input side PI controller.

Type 2 Irradiance: Sunny days Irradiance that is continuous.



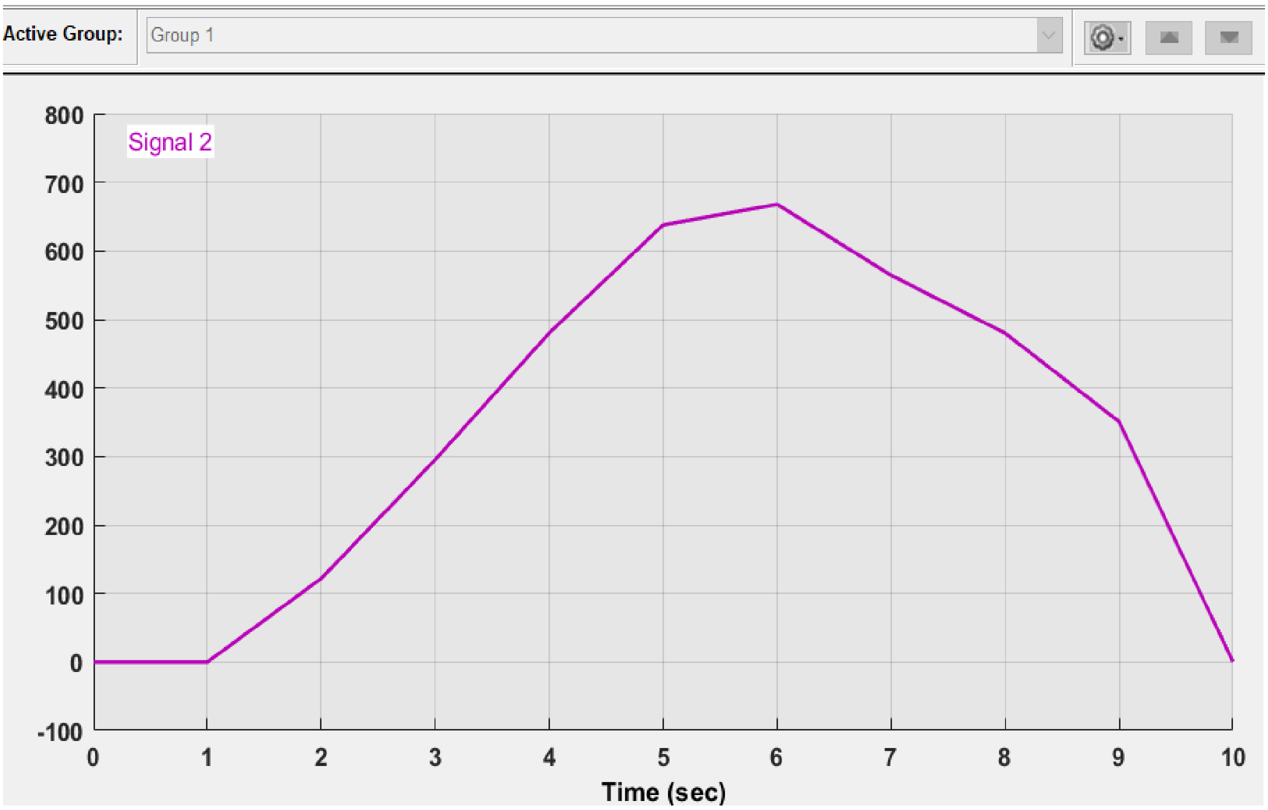
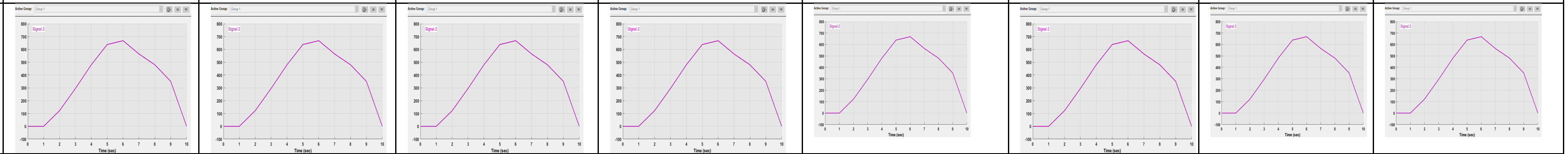
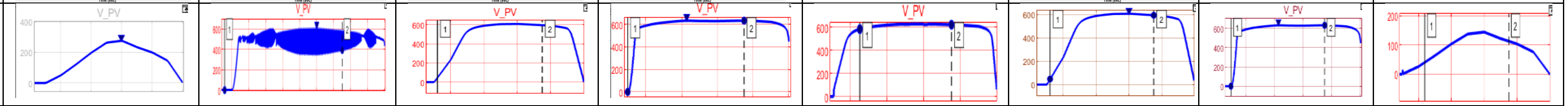
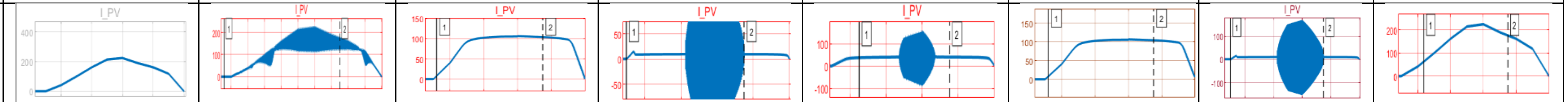
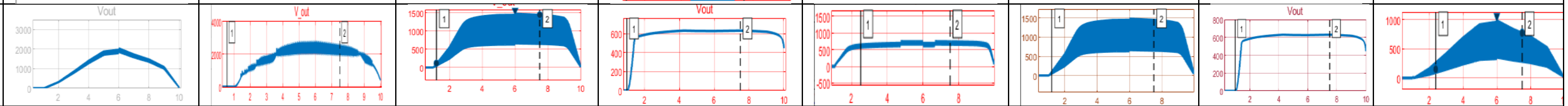
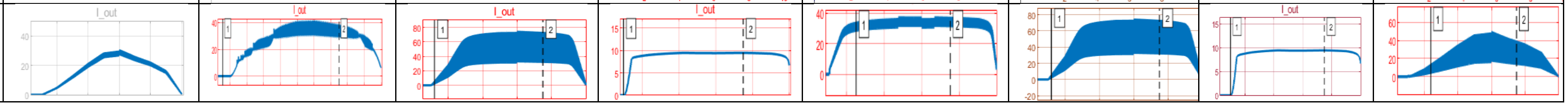


Figure 7.26 Waveform of type 2 irradiance (continuous).

Table 7: Comparative Study of tuned controllers for type 2 Irradiance (Continuous) in terms of waveform.

Types of controller configuration / Parameters	Boost Converter without MPPT controller	Boost Chopper with MPPT Controller	Boost Chopper with MPPT with input side PI controller	Boost Chopper with output side PI controller	Boost Chopper with MPPT with input – output side PI controller	Boost Chopper with MPPT with input side PID controller	Boost Chopper with output side PID controller	Boost Chopper with MPPT with input – output side PID controller
Irradiance (watt/ m^2)								
V_PV (Volts)								
I_PV (A)								
Output Voltage (kV)								
Io (A)								

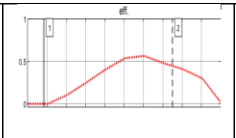
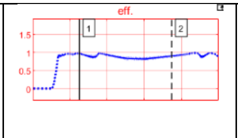
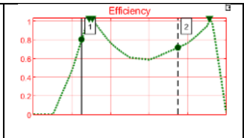
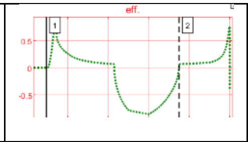
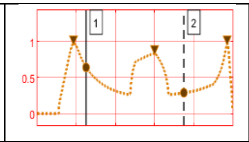
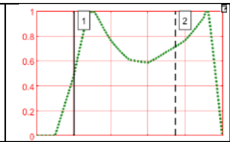
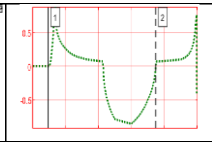
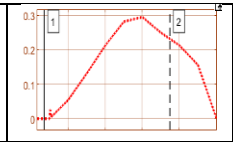
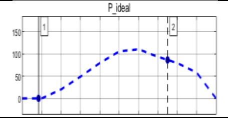
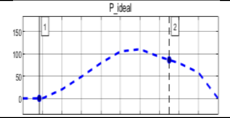
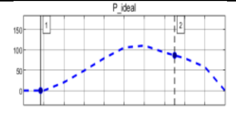
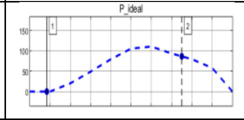
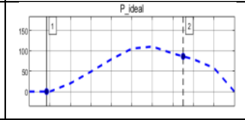
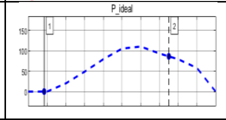
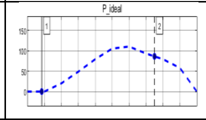
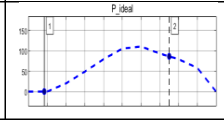
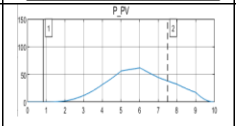
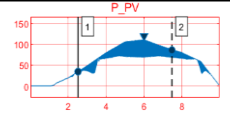
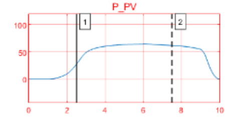
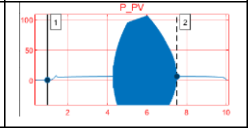
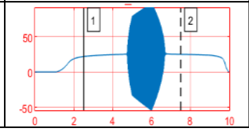
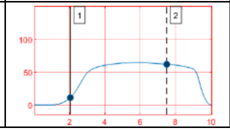
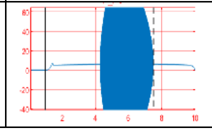
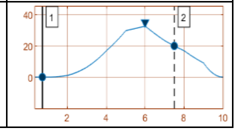
MPPT Efficiency								
P_PVideal								
P_PV								

Table 8: Comparative Study of tuned controllers for type 2 Irradiance in terms of numerical values of parameters.

Parameters / Types of controller configuration	V_PV (Volts)	I_PV (A)	Vo (kV)	Io (A)	P_pv or Pin (kW)	Po (kW)	System efficiency (%)
Boost Converter without MPPT controller	176.10	143.20	1.170	17.50	25.21	20.475	81.21
Boost Chopper with MPPT Controller	479.40	126.30	1.713	25.62	60.55	43.887	72.48
Boost Chopper with MPPT with input side PI controller	504.80	88.37	0.9035	45.18	44.61	40.82	91.50
Boost Chopper with output side PI controller	599.60	61.85	0.5979	8.939	37.10	5.344	14.40
Boost Chopper with MPPT with input – output side PI controller	578.50	50.99	0.6489	32.44	29.497	21.0503	71.36
Boost Chopper with MPPT with input side PID controller	491.00	85.97	0.8789	43.95	42.21	38.627	91.51
Boost Chopper with output side PID controller	592.50	73.2	0.5809	8.686	43.371	5.0456	11.61
Boost Chopper with MPPT with input – output side PID controller	96.32	150	0.3870	19.35	14.448	7.488	51.82

The comparison between tuned PI controller for Type 1 irradiance and tuned PI controller for Type 2 irradiance:

- Comparing to group of type 1 controllers' response, all type 2 controllers response is very high with less harmonics.

- The highest system efficiency from all the converters is 91.51 for Boost converter with input side PID controller and also approximately equal to efficiency of Boost converter with.
- And lowest efficiency for Continuous irradiance, is 14.61 % and 11.61 % for Boost converter with output side PI controller and boost converter with output side PID controller respectively.
- The input power that is P_PV is 60.55 kW high for Boost chopper with MPPT controller and lowest for input – output side PID controller that is 14.448 kW, for continuous irradiance.
- The output power is 43.887 kw, highest for Boost chopper with MPPT controller while lowest for Boost converter with output side PI controller is 5.344 kW.

CHAPTER 8

Result

1. For repetitive Irradiance or type 1 irradiance

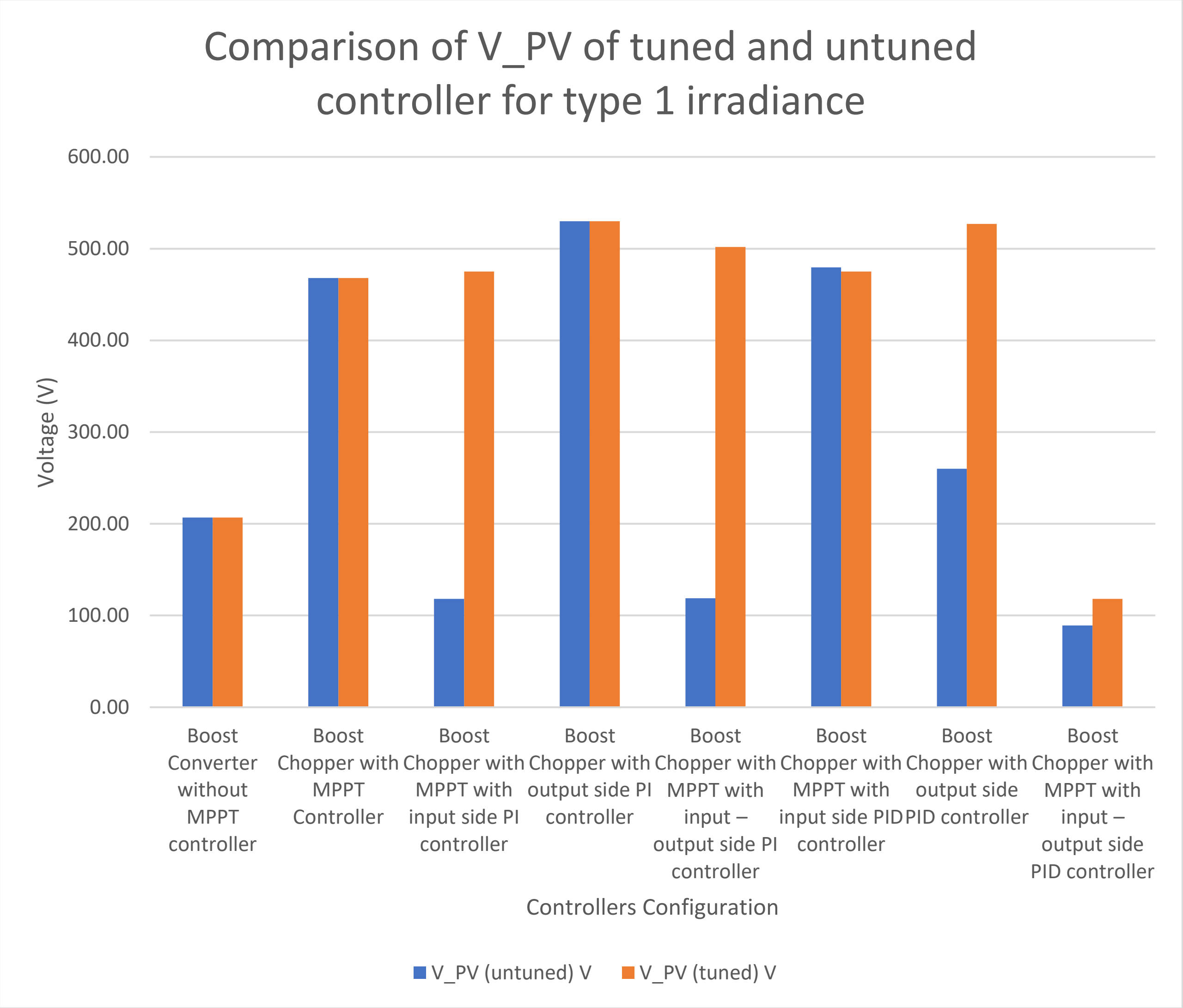
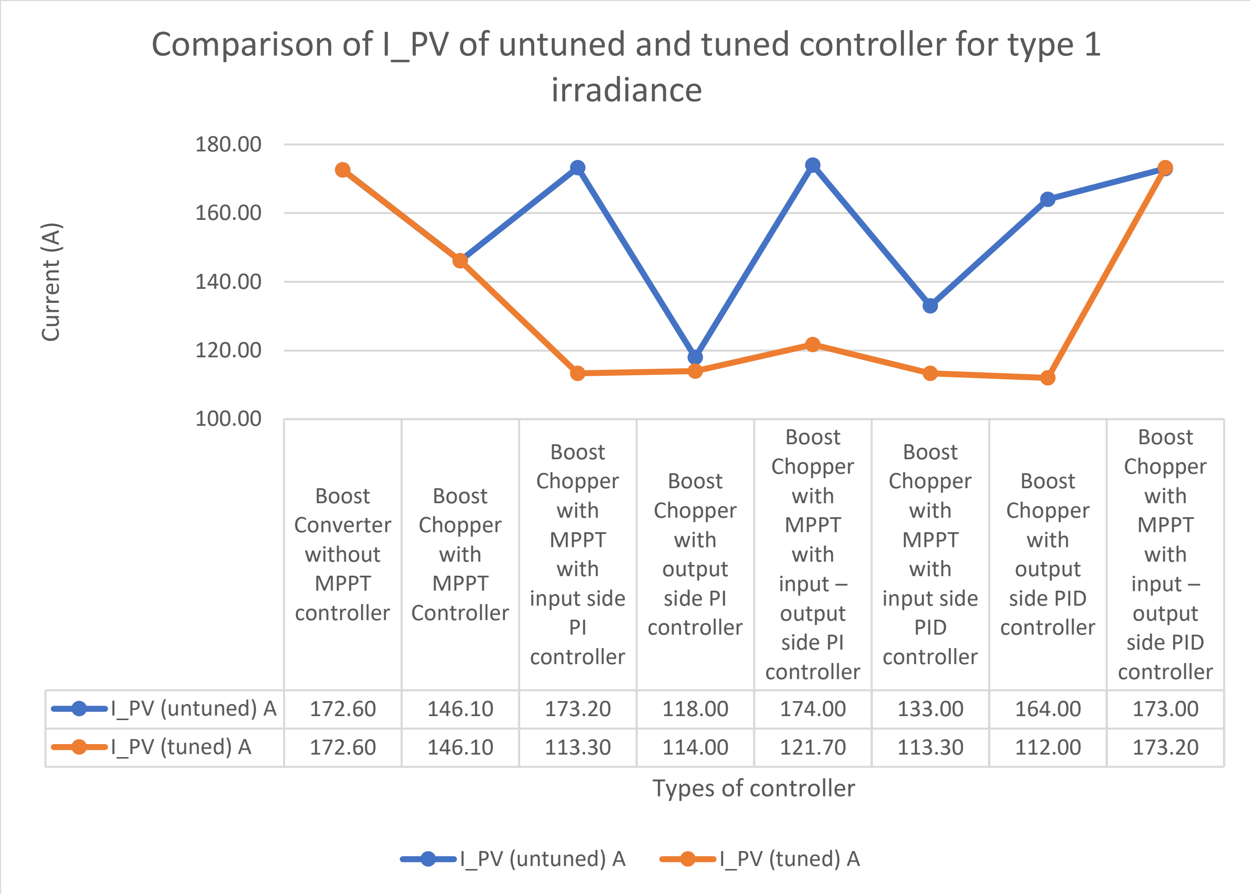


Figure 8.1 graph of comparative study V_PV of untuned and tuned controller for type 1 irradiance.

- From figure it is clearly shows that the V_PV amplitude for tuned controller is more as compare to untuned controllers.
- The harmonics in V_PV also removed in tuned controllers.



	Boost Converter without MPPT controller	Boost Chopper with MPPT Controller	Boost Chopper with MPPT with input side PI controller	Boost Chopper with output side PI controller	Boost Chopper with MPPT with input – output side PI controller	Boost Chopper with MPPT with input side PID controller	Boost Chopper with output side PID controller	Boost Chopper with MPPT with input – output side PID controller
I_PV (untuned) A	172.60	146.10	173.20	118.00	174.00	133.00	164.00	173.00
I_PV (tuned) A	172.60	146.10	113.30	114.00	121.70	113.30	112.00	173.20

Figure 8.2 graph of comparative study I_PV of untuned and tuned controller for type 1 irradiance.

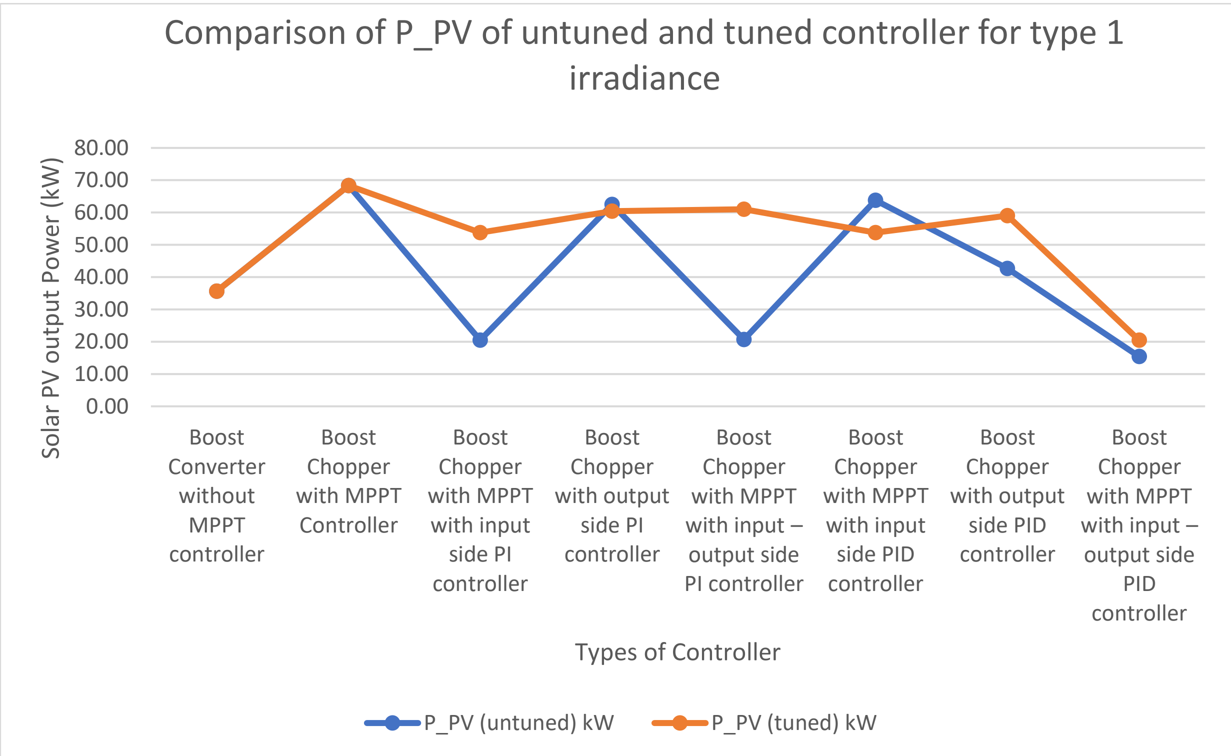


Figure 8.3 comparative graph of solar PV generating power (P_PV)

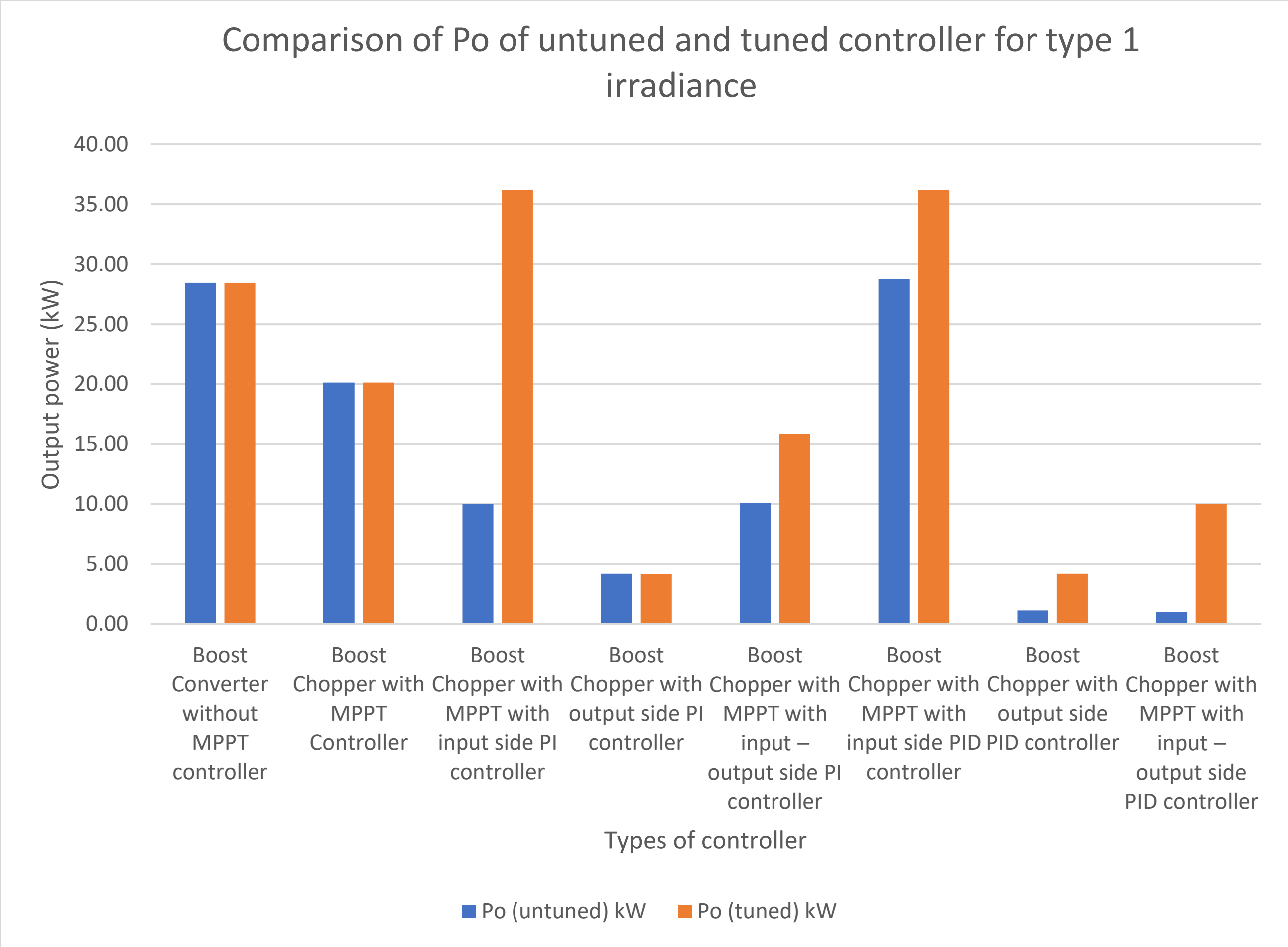
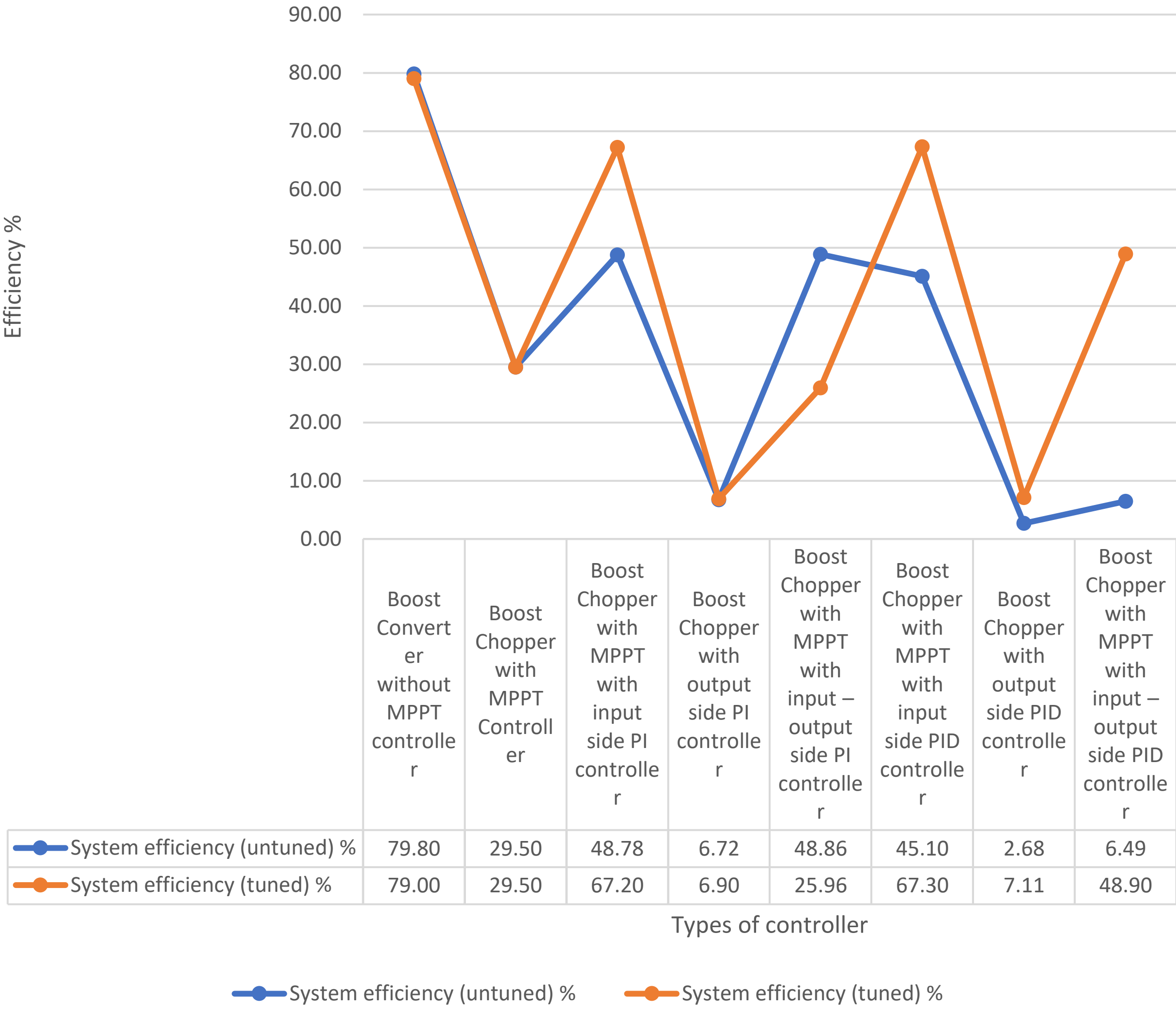


Figure 8.4 comparative graph of output power of type 1 irradiance tuned and untuned controller.

In figure 8.4 output power Po is maximum for Boost chopper with input side tuned PI controller. The harmonics in this configuration is very less and system improves its steady state stability by reducing its steady state error.

The Po for the tuned configuration of controllers having higher value than untuned controller. The minimum Po for tuned controller is Boost chopper with output side PID controller and with output side PI controller.

In untuned controller configuration the Po is maximum for Boost chopper with input side PID controller and lowest for both PID output side and input – output side.



	Boost Converter without MPPT controller	Boost Chopper with MPPT Controller	Boost Chopper with MPPT with input side PI controller	Boost Chopper with output side PI controller	Boost Chopper with MPPT with input – output side PI controller	Boost Chopper with MPPT with input side PID controller	Boost Chopper with output side PID controller	Boost Chopper with MPPT with input – output side PID controller
System efficiency (untuned) %	79.80	29.50	48.78	6.72	48.86	45.10	2.68	6.49
System efficiency (tuned) %	79.00	29.50	67.20	6.90	25.96	67.30	7.11	48.90

Figure 8.5 Graph of comparison of system efficiency of untuned and tuned controller for type 1 irradiance.

From figure 8.5 it is shown that the system efficiency of tuned controller for type 1 irradiance is maximum for Boost converter without MPPT controller. But the stability with controllers is more like with input side tuned PI controller and input side tuned PID controller.

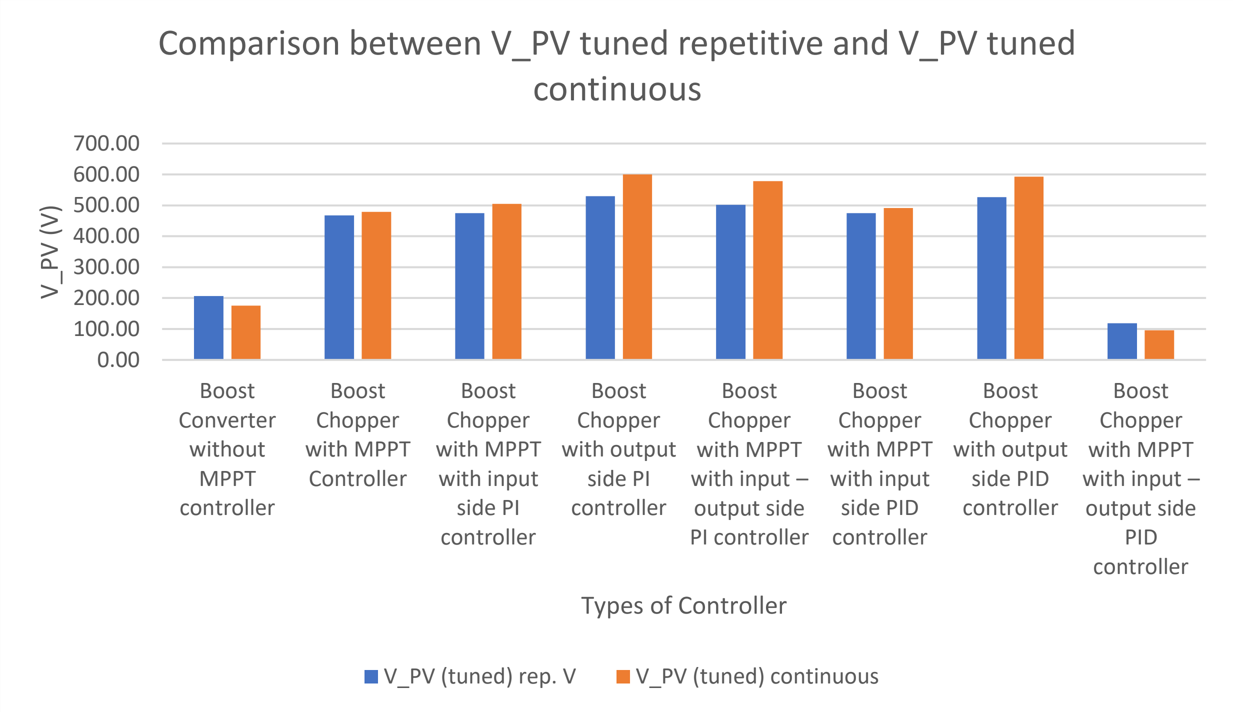


Figure 8.6 Graph for comparison between V_PV tuned for repetitive Irradiance and continuous Irradiance.

From figure 8.6 it is coming out that V_PV generated by controller for the type 2 irradiance is maximum as compare to voltage generated for type 1 irradiance except for tuned input – output PID controller and Boost converter without MPPT controller.

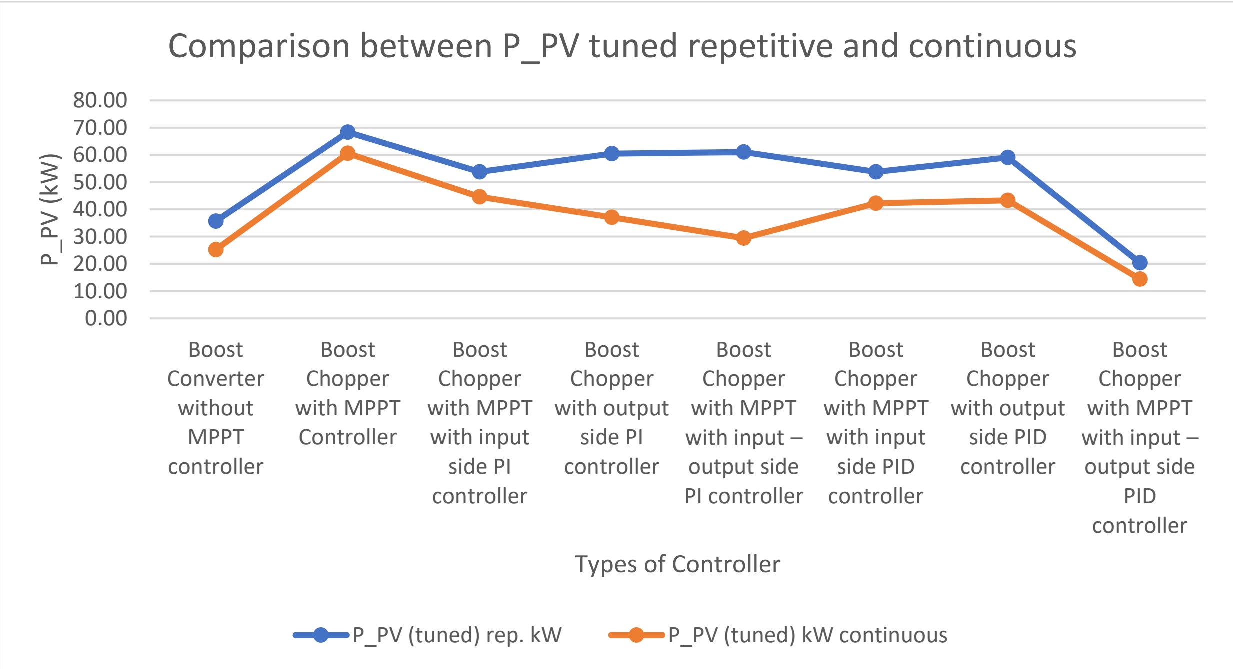


Figure 8.7 Graph for comparison between P_PV tuned for repetitive Irradiance and continuous Irradiance.

From figure 8.7 it is clear that P_PV for type 2 irradiance is always high as compare to type 1 irradiance for all type of controller configuration.

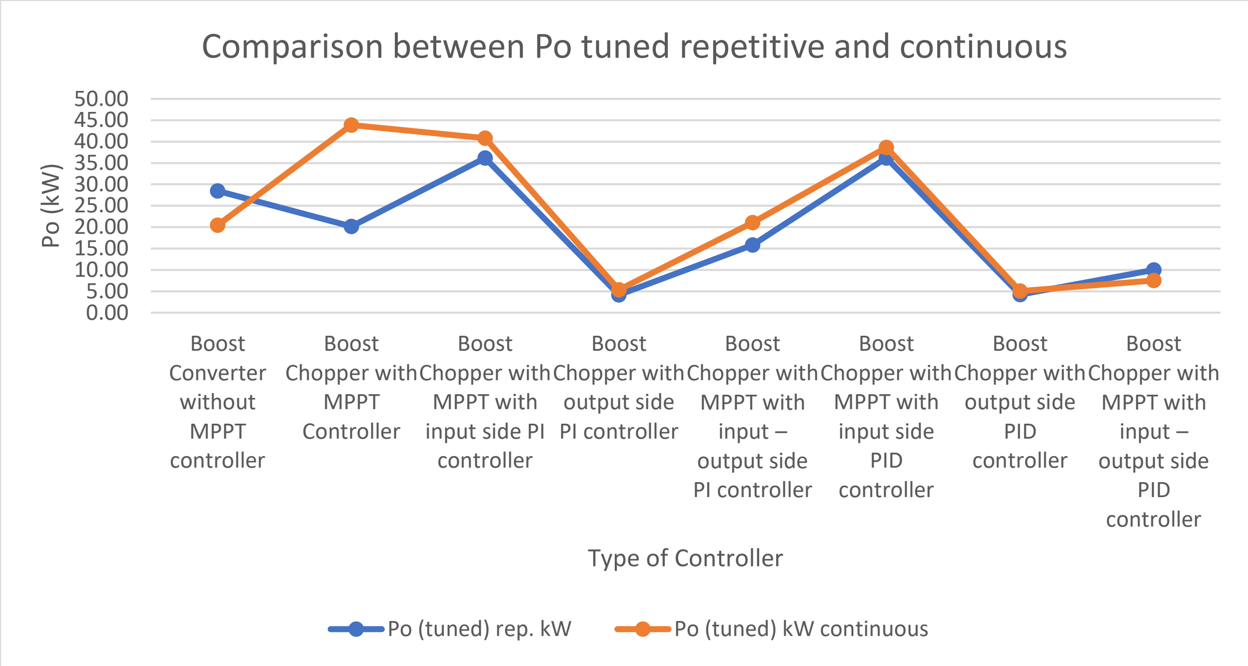


Figure 8.8 Graph for comparison between Po tuned for repetitive Irradiance and continuous Irradiance.

It is shown in figure 8.8 that Po, of tuned controller for type 2 irradiance, for converter with MPPT controller, with input side PI controller, with input – output side PI controller, with input side PID controller, with output side PID controller is higher as compare to Po for type 1 irradiance.

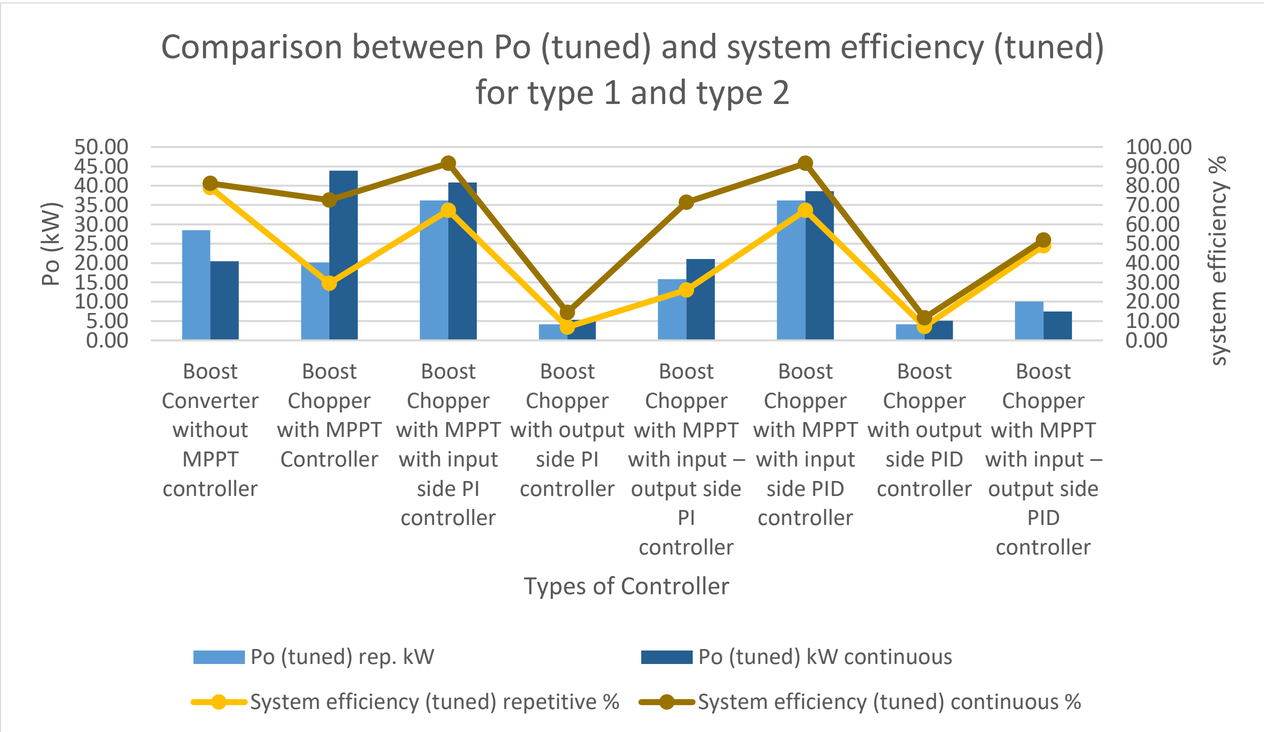


Figure 8.9 Graph of comparison between Po (tuned) and system efficiency for type 1 and type 2 irradiance.

In figure 8.9 author try to relate give good visual of Po and system efficiency in single plot. So, it comes out that efficiency of all the controllers for type 2 irradiance is better than the efficiency for type 1 irradiance.

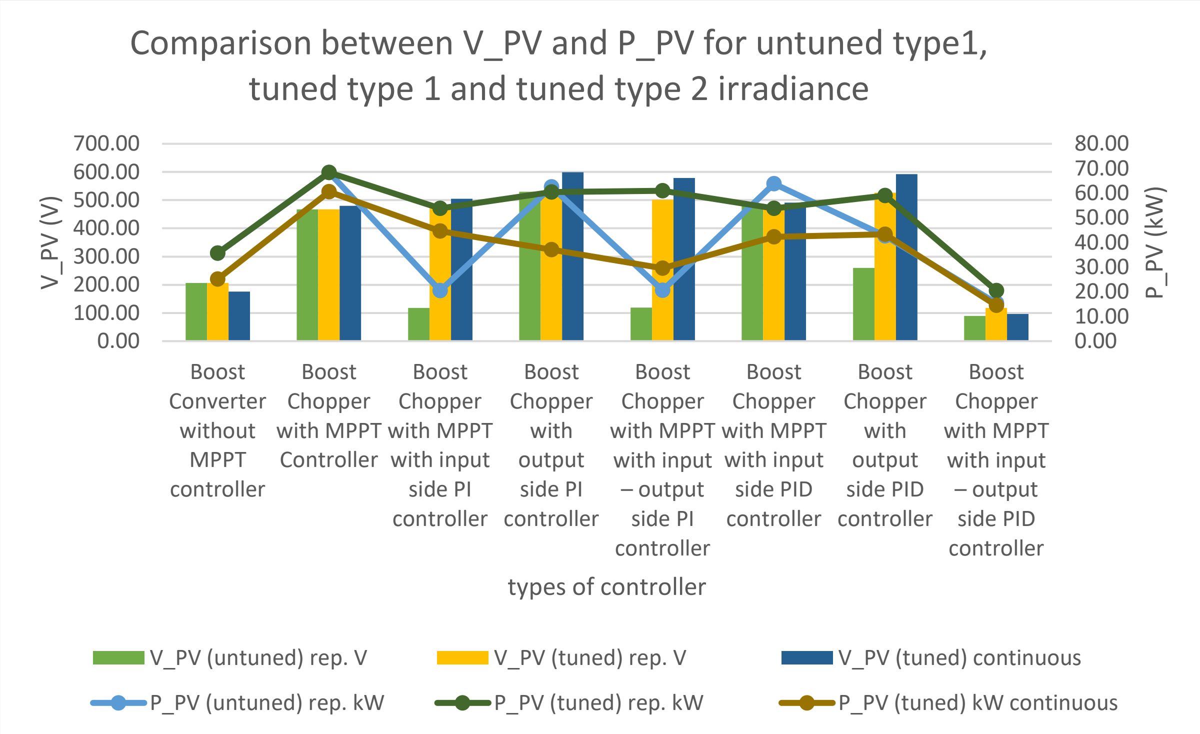


Figure 8.10 graph of Comparison between V_PV and P_PV for untuned type1, tuned type 1 and tuned type 2 irradiance.

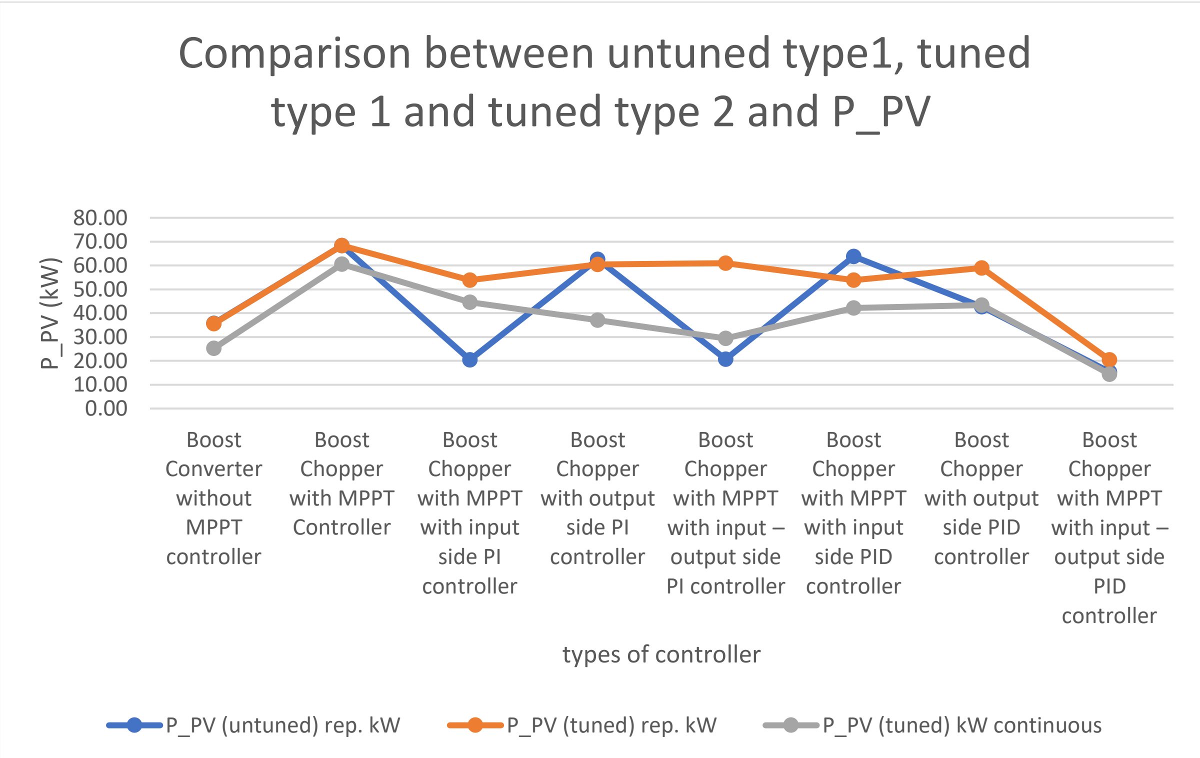


Figure 8.11 Graph of Comparison between untuned type1, tuned type 1 and tuned type 2 and P_PV.

Form fig.8.11 it is clearly showing that average P_PV of the tuned controller for type 2 irradiance having high power than the others.

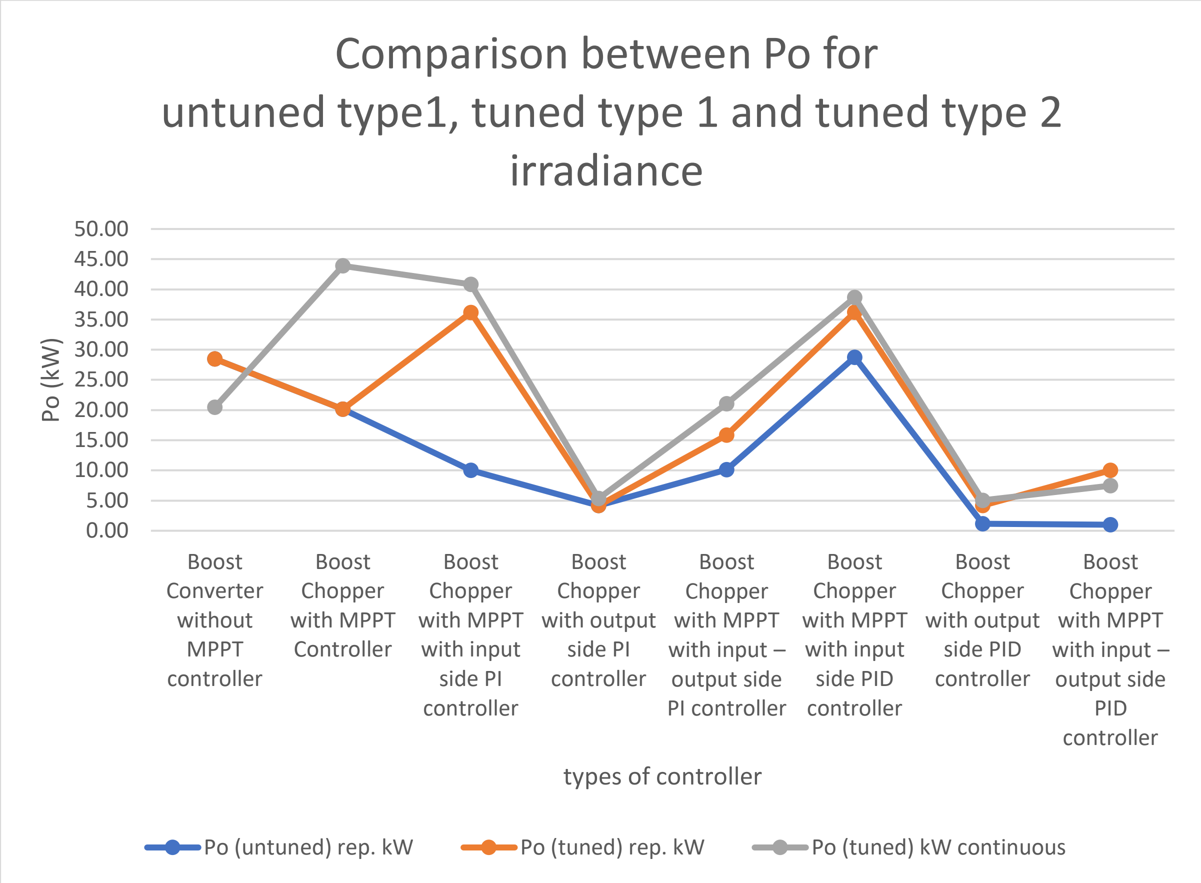


Figure 8.12 Graph of Comparison between Po of untuned type1, tuned type 1 and tuned type 2 Irradiance

Figure 8.12 give the exact picture of Po in which a output power approximately for all controller is more than for tuned controller of type 2 irradiance as input to solar PV module than after tuned controller for type 1 irradiance is best performing controller configuration.

From all over the configuration of controller, tuned with input side PI controller and input side PID controller is best performing in all aspects.

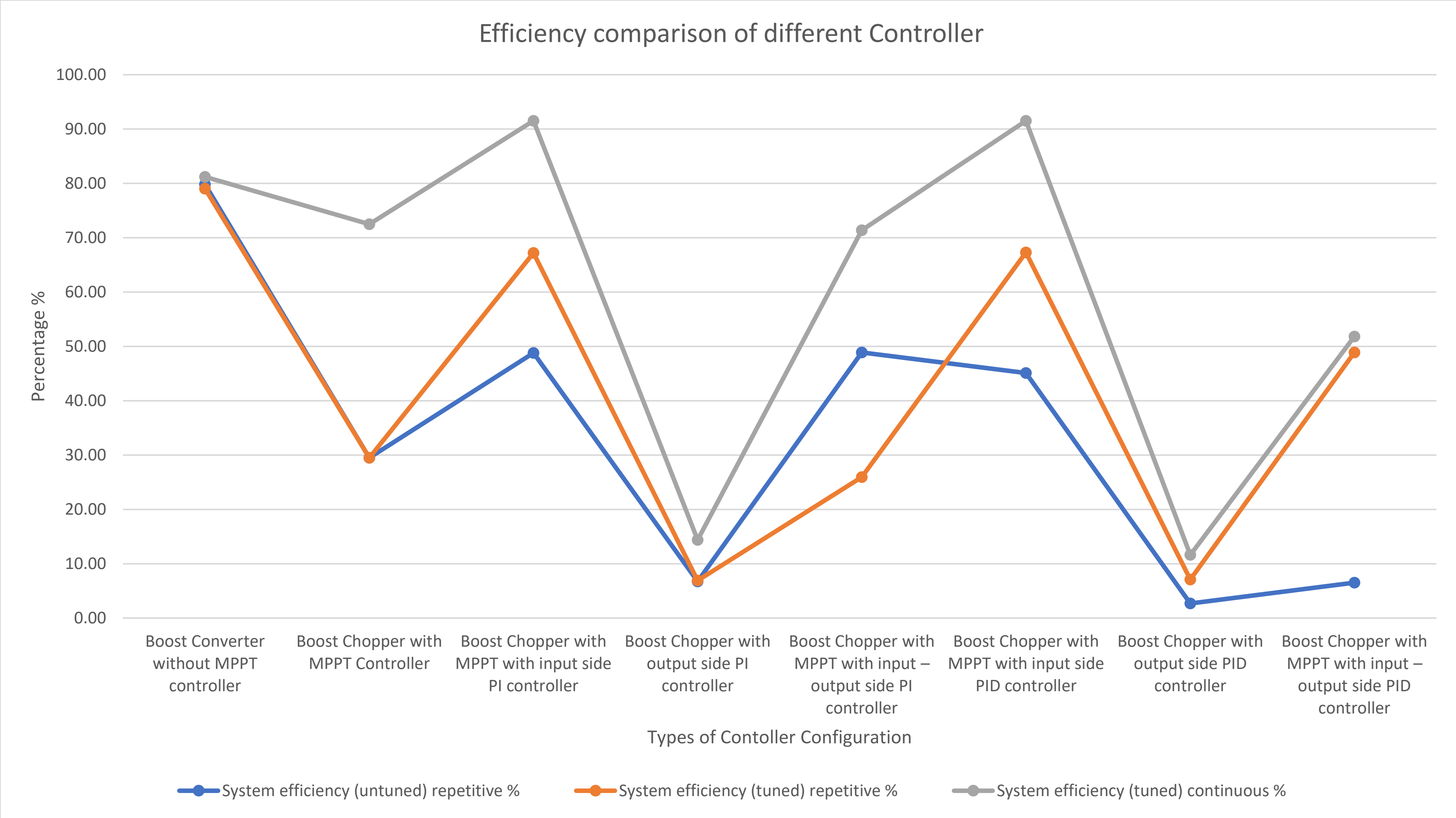


Figure 8.13 graph of Efficiency comparison of different Controller for different input to solar PV panel.

From figure 8.13 it is clear that efficiency is depends on the irradiance. Here, efficiency of all the controllers is maximum for type 2 irradiance.

CHAPTER 9

Conclusion and Future Scope

Conclusion

The proposed model under the project demonstrated and encouraging performance in two aspects, which were finding the effectiveness of different controllers. The finding of projects is the, one, tuned controller is highly effective than the untuned controller, second, the efficiency of different controllers' configuration is high for the continuous irradiance as compare to repetitive irradiance or equivalent to sunny days, third, the harmonics of the boost converter with tuned controller is less as compare to untuned, fourth, from all the controller's configuration PI and PID controller at input side is high recommended for the solar PV system. Fifth, the overall efficiency of the system is high for continuous irradiance. Finally, it is also found out that Ziegler Nichols algorithm is less effective for tunning and also lengthy process. So, from all the configuration of controller, input tuned PI controller is best for solar PV system.

Future Scope

There is lot of possibility to improve the efficiency of the controller to harness the maximum power from the solar PV using Generic algorithm (GA), Flower pollination algorithm (FPA), and many more. Also, author will concern about how to get optimized value of duty cycle of IGBT.

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