

Potential Equalizer Using Multi stacked Buck–Boost Converters for Partially Shaded Photovoltaic Module

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Abstract—

Photovoltaic (PV) systems have been developed into mature technology that has been used in specialized applications. Partially shaded condition of photovoltaic system will result in reduction of output power and produces multiple maximum power points (MMPP) in the panel. In this project Single-switch voltage equalizers using multi stacked buck–boost converters are proposed to settle the partial shading issues. The single-switch topology can reduce the number of switches which is proportional to number of PV strings. The proposed system can be derived by integrating CLD filters on buck–boost converters, like SEPIC, Zeta, and CUK etc., Operational analysis based on a simplified equivalent circuit is performed for a SEPIC-based topology. Experimental setup consists of three substrings in a PV panel. Local MPPs were eliminated and maximum power is increased by the equalizer.

Index Terms— **Index Terms—Buck–boost converter, partial shading, photovoltaic system, SEPIC, voltage equalizer.**

I. INTRODUCTION

The main purpose of this work is the optimal integration of photovoltaic energy resources in existing electrical distribution systems. In a conventional PV system many PV modules are connected in series to obtain a dc voltage suitable for ac utility line voltage. In series configuration, mismatch conditions could affect the PV system performance causing a lack of producible power. Usually in small-size applications the PV systems are affected by partial shading due to architectural and/or environmental issues. As a result, the total output power generated from the PV array decreases greatly, i.e. the efficiency of the generating electricity is lower. To extract as much energy as possible from photovoltaic (PV) modules, the energy utilization needs to be

improved, as well as power conversion efficiency of converters. Partial shading on a PV string comprising

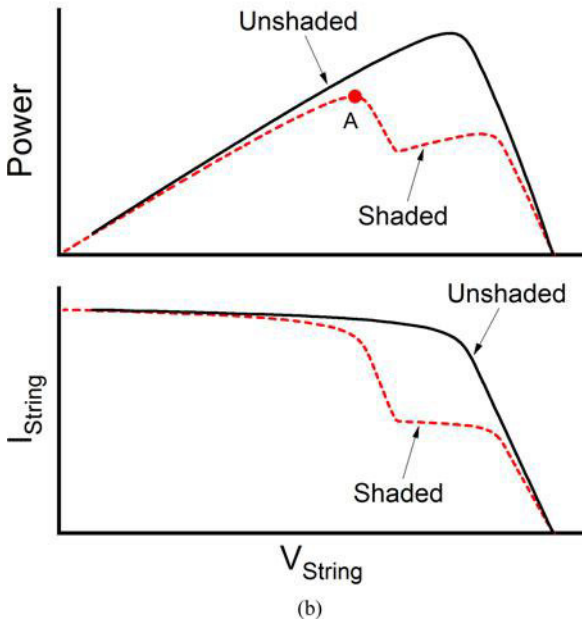
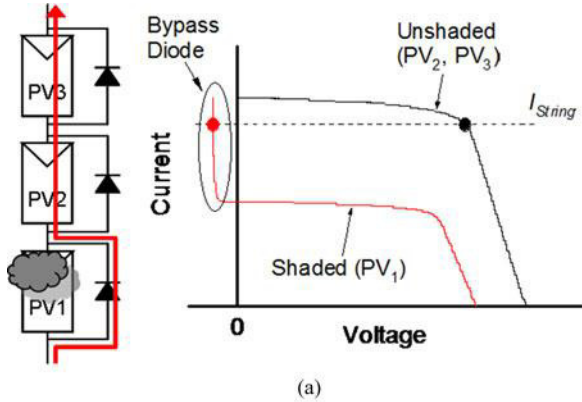
multiple modules/substrings (hereafter referred to as “substring” unless otherwise noted) is known as a serious cause that significantly decreases energy utilization. In general, substring currents are dependent on irradiance, and shaded substrings are less capable of generating current than unshaded ones. If shaded substrings are no longer capable of a string current, bypass diodes connected in parallel start conducting to bypass the shaded substrings resulting in a significant mismatch in operational

voltage. This mismatch triggers multiple maximum power points (MPPs), including a global and local MPPs, that encumber MPP tracking (MPPT) algorithms to track the global MPP in addition, even though the string as a whole is operated at a global MPP, some substrings in the string can never be fully utilized because of the operational voltage mismatch, significantly reducing the maximum extractable power. Decentralized PV systems employ Distributed Maximum Power Point Technique (DMPPT) to these partial-shading issues, and their energy yield benefit. All PV modules/substrings are basically able to operate at each MPP, even under partial-shading conditions, due to the individual control for each module unless micro converters operate outside a designed allowable range in terms of component rating and duty cycle. However, since the number of microinverters/converters is proportional to that of PV modules/substrings, systems tend to be complex and costly with increasing number of modules.

In this paper, single-switch potential equalizers using multistacked buck–boost converters are proposed. In this proposed system, equalizers are made up of multiple capacitor-inductor-diode (CLD) filters on Buck-Boost converters such as SEPIC, Cuk and Zeta Converters. Regardless of the number of substrings/modules, the required switch count is only one, considerably simplifying the circuitry compared

with conventional DPP converters and voltage equalizers.

II. EXISTING SYSTEM



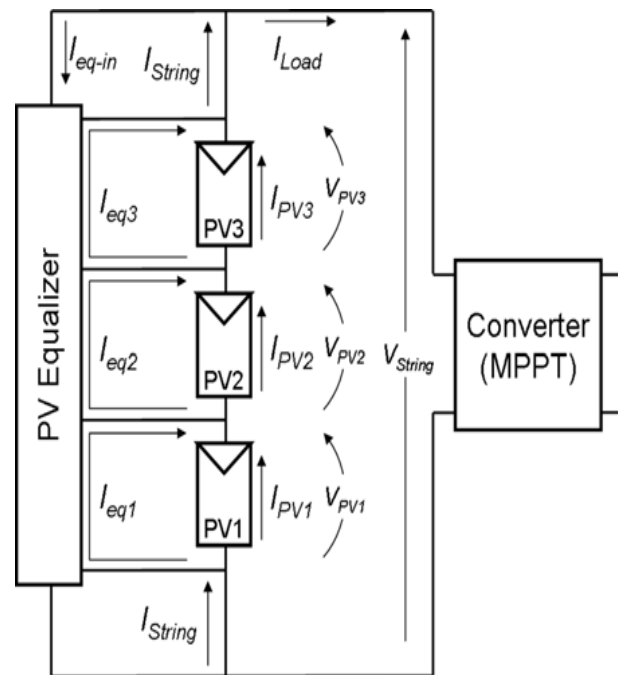
Partial shading on a PV string comprising multiple modules/substrings (hereafter referred to as “substring” unless otherwise noted) is known as a serious cause that significantly decreases energy utilization. In general, substring currents are dependent on irradiance, and shaded substrings are less capable of generating current than unshaded ones. If shaded substrings are no longer capable of a string current, bypass diodes connected in parallel start conducting to bypass the shaded substrings, as shown in Fig. 1(a), resulting in a significant mismatch in operational voltage. This mismatch triggers multiple maximum power points (MPPs), including a global and local MPPs, as

shown in Fig. 1(b), that encumber MPP tracking (MPPT) algorithms to track the global MPP [point A in Fig. 1(b)].

Drawbacks of Existing System

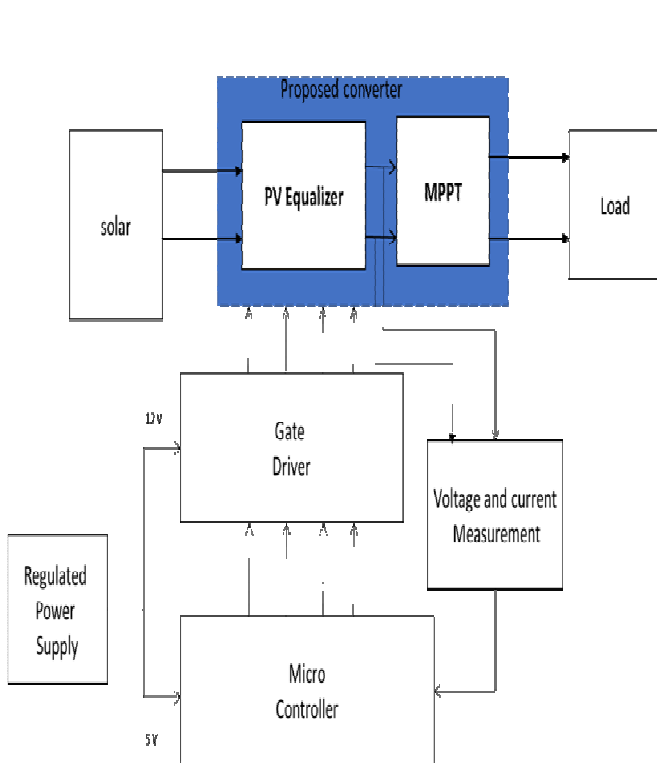
- Partially shaded PV array results in reduction in power generation.
- Conventional circuit introduction of bypass diode causes multiple peaks in the characteristics.
- Switching losses is high.
- There is poor voltage regulation.
- Variation of voltage in the system reduces the efficiency
- High voltage gain could not be achieved.

III. PROPOSED SYSTEM



The proposed system uses voltage equalizer circuit to boost the output power against the shading losses. Voltage equalizer is made up capacitor, inductor, diode [CLD] filters stack in traditional SEPIC converter. The converter can also be any type of buck-boost such as CUK, ZETA etc. CLD filters have different voltage levels. SEPIC based converter is chosen because it does not require floating-gate driver and transformer compared to ZETA and CUK. Any number of substrings can

be used but according to that number of CLD filters have to be increased. Thus, component rating will be increased. Single switch used in this equalizer reduces the circuit complexity greatly. The equalizer will boost the current at its output to match the current flowing through the unshaded modules. This allows the shaded module to produce the same amount of electrical power without impeding the output of other modules. Hence voltage equalizer eliminates the multiple power points and voltage imbalance problem, consequently power output is increased.



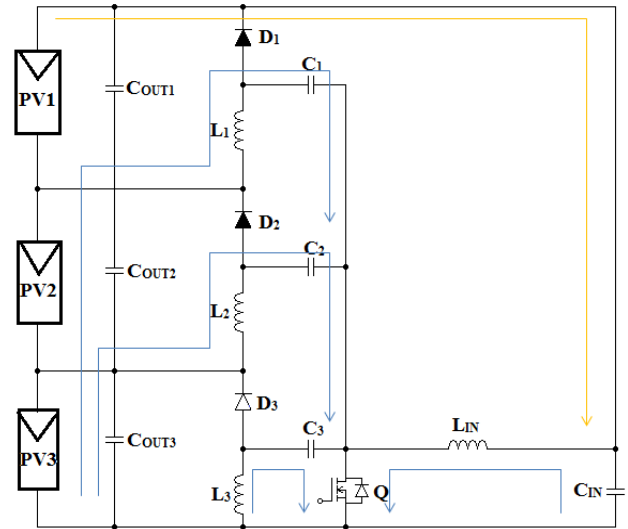
Advantages of Proposed System

- Implemented with renewable energy.
- Improved voltage gain due to boost converter.
- Better voltage regulation.
- The single-switch topology can considerably simplify the circuit compared with conventional equalizers.
- Voltage equalizer eliminates the multiple peaks and voltage imbalance problem.
- Usage of single switch, simple and easy to control
- Power output is increased.

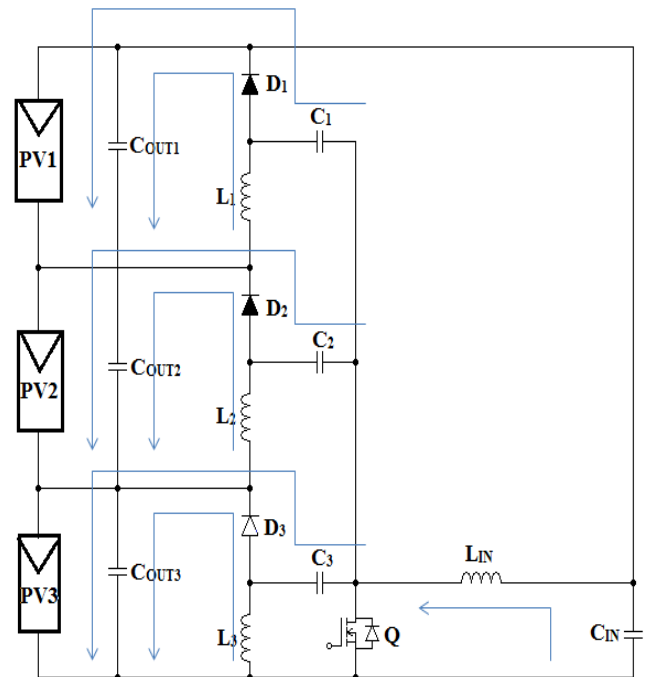
MODES OF OPERATION

MODE 1

During mode-1, the switch (Q) is in ON position; the output of series connected PV panels supply the power to the voltage equalization circuit. During this period, currents of all inductors (L_1 , L_2 and L_3) in equalization circuit increases and the inductors store the corresponding energies. The current flowing through L_{IN} and C_{IN} also flows towards the switch (Q).

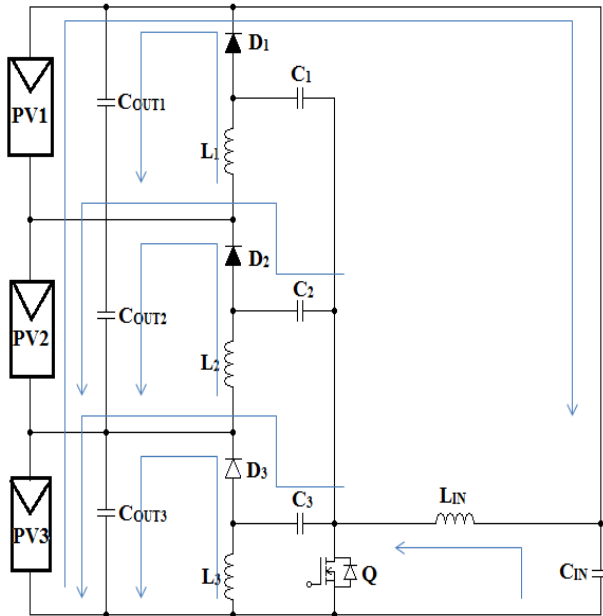


MODE 2



MODE-2(TOFF -a): During mode-2, the switch (Q) is OFF. During this period, the diode corresponding to lowest voltage PV panel-3 will get forward biased. Hence, the stored energies in the inductors (L1, L2 and L3) transferred to that PV module.

MODE 3



MODE-3(TOFF -b): During mode-3, switch (Q) and diodes (D1, D2 and D3) are in OFF position. During this period, inductor currents are constant and equal to zero and therefore the inductor voltage must be zero. After the current of diode (D3) falls to zero, the currents in the equalizer inductors become constant or zero. In multi-stage SEPIC circuit, the average currents of D1, D2 and D3 are equal to average currents of IL1, IL2 and IL3 respectively. Therefore, the average currents of L1, L2 and L3 are zero and only ripple current will flow through these inductors. As the large power generated by unshaded panels is transferred to the low illuminated panel through multi-stage SEPIC equalizing circuit, slowly imbalance of PV panel voltages vanishes.

IV. SOFTWARE IMPLEMENTATION AND SIMULATION RESULTS

4.1 Mat lab

4.1.1 Introduction

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include

- Math and computation
- Algorithm development
- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non-interactive language such as C or Fortran. The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation. MATLAB is a high-level language and interactive environment that enables to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and Fortran. MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis. MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, aerospace, bioinformatics, image processing and many others. Areas in which block sets are available include aerospace, communications, RF, signal processing, video and image processing.

4.1.2 Key Features

- High-level language for technical computing
- Development environment for managing code, files, and data
- Interactive tools for iterative exploration, design, and problem solving

- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, and numerical integration
- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces
- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java, COM, and Microsoft Excel

4.1.3 Simulink

4.1.3.1 Introduction

Simulink is an environment for multidomain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing. Add-on products extend Simulink software to multiple modelling domains, as well as provide tools for design, implementation, and verification and validation tasks. Simulink is integrated with MATLAB, providing immediate access to an extensive range of tools that let you develop algorithms, analyse and visualize simulations, create batch processing scripts, customize the modelling environment, and define signal, parameter, and test data.

4.1.3.2 Key Features

1. Extensive and expandable libraries of predefined blocks
2. Interactive graphical editor for assembling and managing intuitive block diagrams
3. Ability to manage complex designs by segmenting models into hierarchies of design components
4. Model Explorer to navigate, create, configure, and search all signals, parameters, properties, and generated code associated with your model

Application programming interfaces (APIs) that connect with other simulation programs and incorporate hand-written code. Embedded MATLAB Function blocks for bringing MATLAB algorithms into Simulink and embedded system implementations. Simulation modes (Normal, Accelerator, and Rapid Accelerator) for running simulations interpretively or at compiled C-code speeds using fixed- or variable-step solvers. Graphical debugger and profiler to examine simulation results and then diagnose performance and unexpected behaviour in your design. Full access to MATLAB for analysing and visualizing results, customizing the modelling environment, and defining signal, parameter, and test data. Model analysis and diagnostics tools to ensure model consistency and identify modelling errors.

4.1.3.3 Creating and Working with Models

With Simulink, we can quickly create, model, and maintain a detailed block diagram of your system using a comprehensive set of predefined blocks. Simulink provides tools for hierarchical modeling, data management, and subsystem customization, making it easy to create concise, accurate representations, regardless of your system's complexity.

4.1.3.4 Selecting and Customizing Blocks

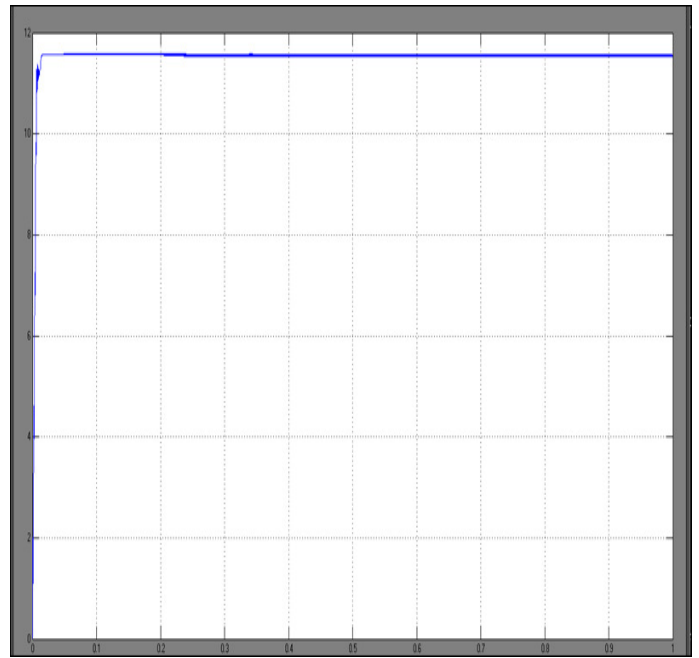
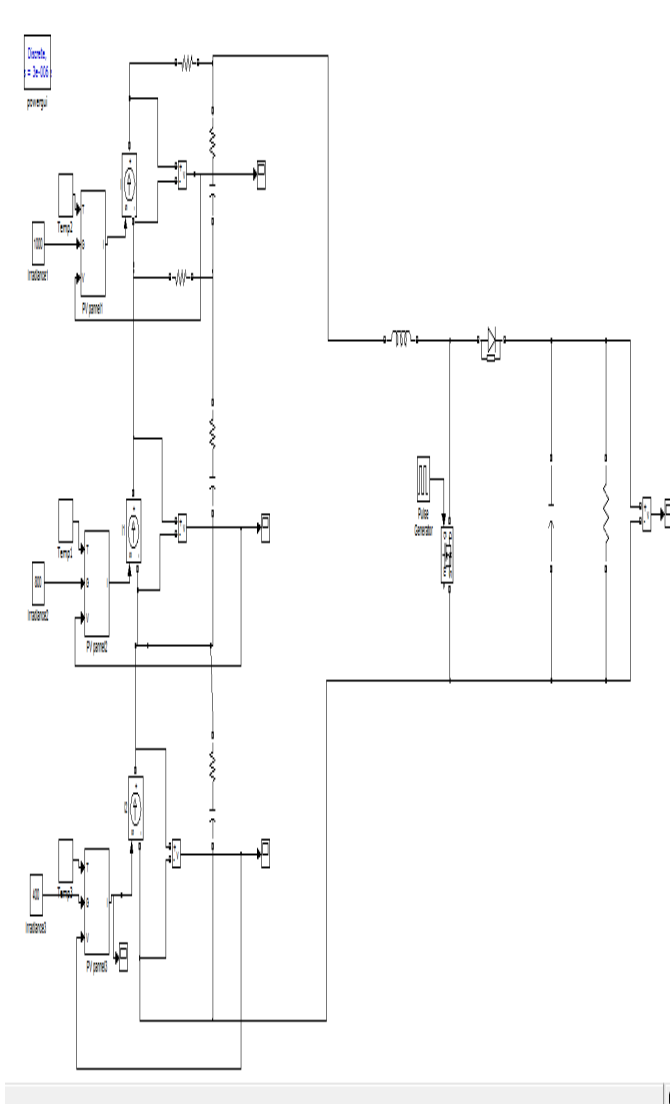
Simulink software includes an extensive library of functions commonly used in modeling a system. These include:

1. Continuous and discrete dynamics blocks, such as Integration and Unit Delay
2. Algorithmic blocks, such as Sum, Product, and Lookup Table
3. Structural blocks, such as Mux, Switch, and Bus Selector

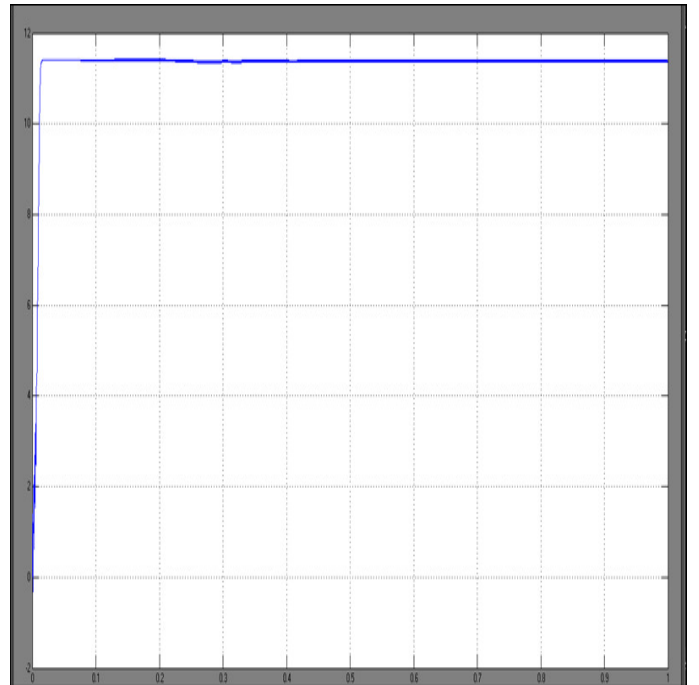
We can customize these built-in blocks or create new ones directly in Simulink and place them into your own libraries. Additional block sets (available separately) extend Simulink with specific functionality for aerospace, communications, radio frequency, signal processing, video and image processing, and other applications. We can model Physical system in Simulink. Simscape, SimDriveline, SimHydraulics, Sim Mechanics and SimPower System (all available separately) provide expanded capabilities for modeling physical systems, such as those with mechanical, electrical, and hydraulic components.

SIMULATION RESULTS

EXISTING SYSTEM



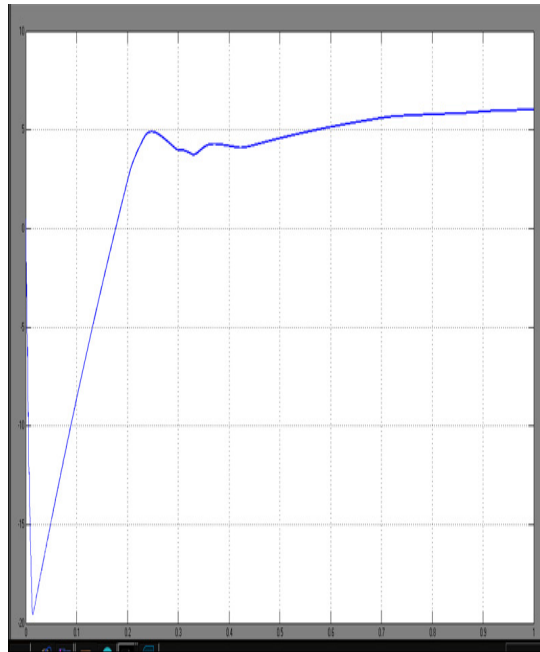
PV 2 VOLTAGE



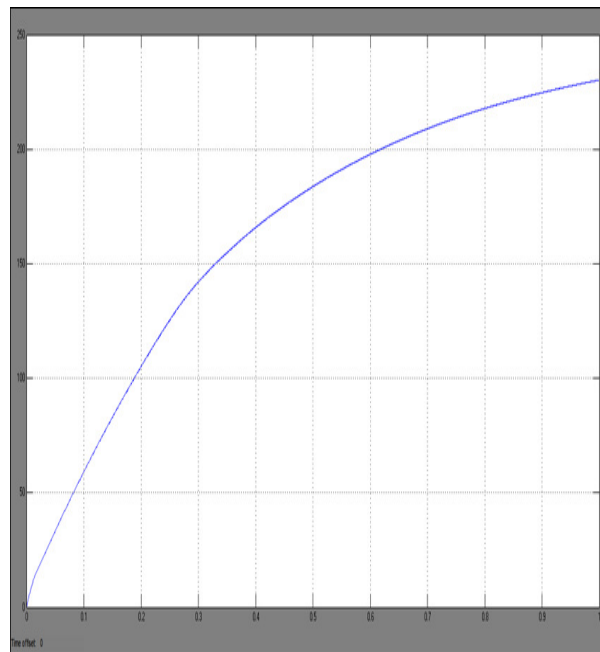
OUTPUT CURVES OF EXISTING SYSTEM:

PV 1 VOLTAGE

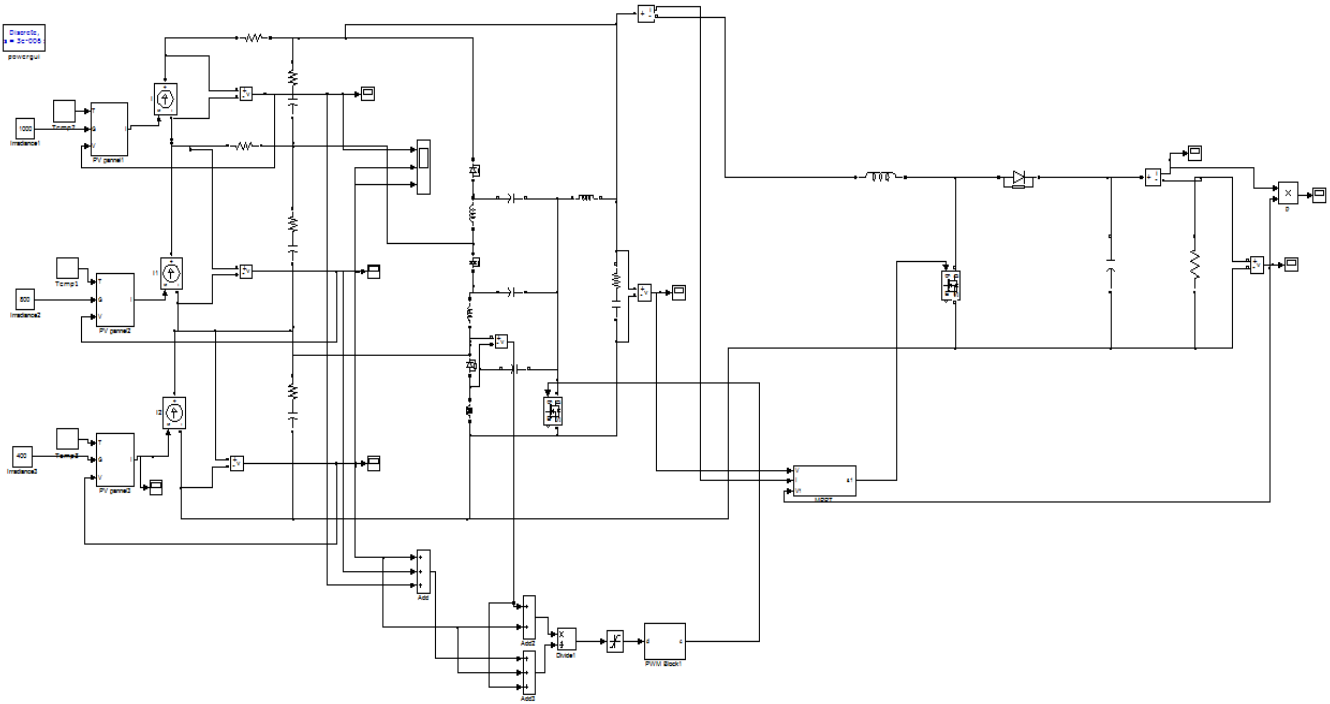
PV 3 VOLTAGE



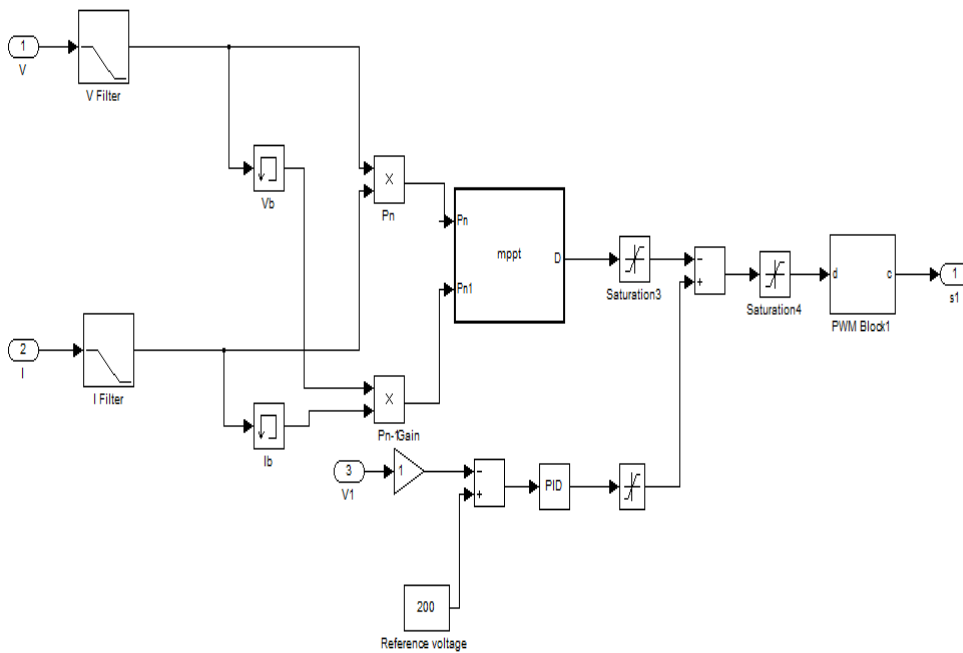
BOOST VOLTAGE



PROPOSED SYSTEM:



MPPT algorithm (Incremental conductance)



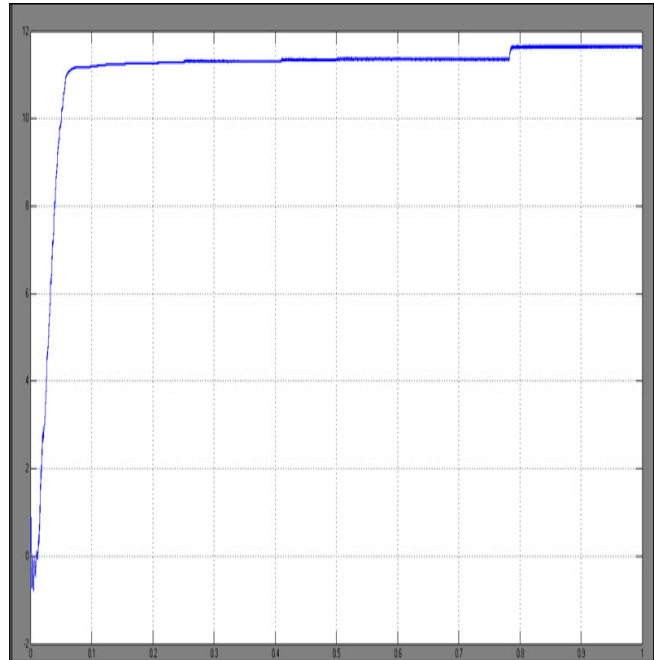
MPPT condition

```
function D = mppt(Pn, Pn1)
Do = .5;
D = Do;
dd = .001; %
dataType = 'double';

    if Pn < Pn1
        D = Do - dd;
    end
    if Pn > Pn1
        D = Do + dd;
    end

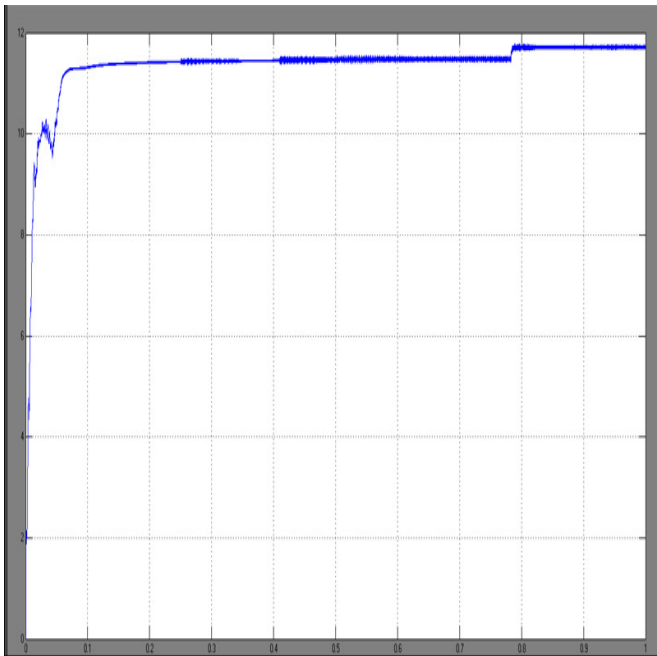
Do=D;
```

PV 3 VOLTAGE

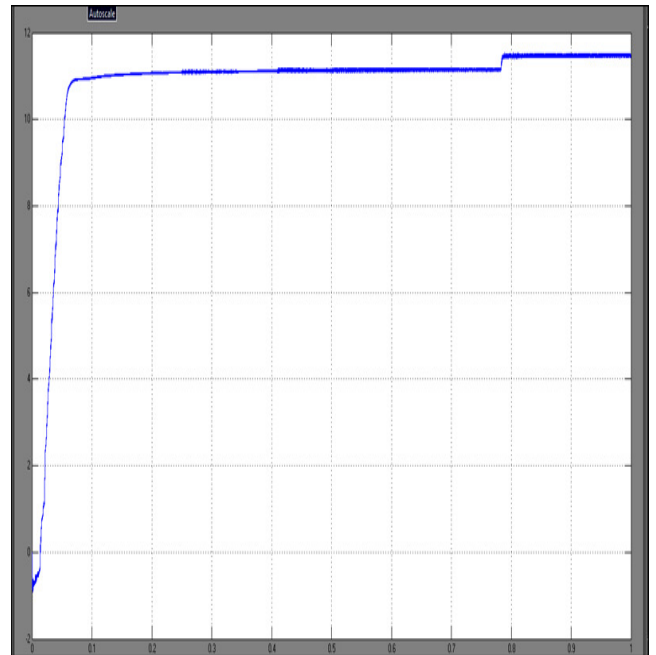


OUTPUT CURVES OF PROPOSED SYSTEM:

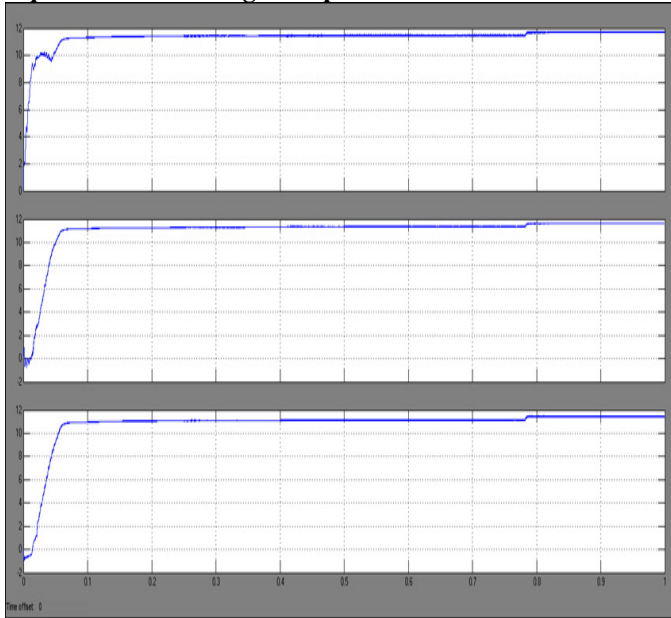
PV 1 VOLTAGE



PV 3 VOLTAGE



Equalization of voltage in 3 panels



V. POWER SUPPLY UNIT

Any new invention cannot be activated without the source of power. So, in this fast-moving world we deliberately need a proper power source which will be apt for a particular requirement. All the electronic components starting from diode to Intel IC's only work with a DC supply ranging from +5v to +12, we are utilizing for the same, the commonly available and cheapest energy source of 230volts and 50Hz frequency. The supply side involves rectifying, stepping down, regulating and filtering the voltage. This will be dealt briefly in the upcoming sections.

$10 \llcorner f/25v$: for maintaining the stability of the voltage at the load side.

$O,1 \llcorner f$: for bypassing the high frequency disturbances

Voltage Regulators:

A voltage regulator is an electronic circuit that provides a stable DC voltage independent of temperature, load current. The primary purpose of a regulator is to aid the filter and rectifier circuit in providing a constant DC voltage to the device. The regulator ensures the output voltage will always stay at permissible limits. A regulated power supply with

multiple regulators can offer multiple output voltages for operating multiple devices. IC7812 and 7912 is used in this project for providing +12v and -12v DC supply.

+5V Regulated Power Supply:

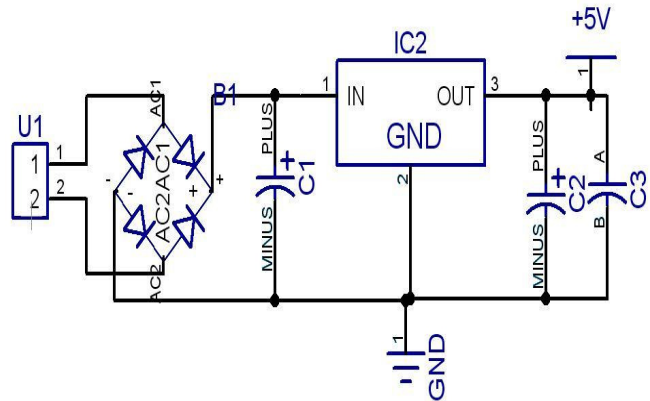


Fig 3.2 Circuit diagram Of Regulated Power Supply

Input from transformer and gives a rectified output of 5 V which is been to my microcontroller. here we using the fixed voltage regulator 7805.

Opto Isolation Circuit

Introduction:

Since the MOSFET's used to switch the capacitor voltage into the supply line there will be switching transients produced by them. These switching transients in turn will affect the pulses developed by the dsPIC30F2010 and by time the micro controller itself. So, in order to protect the microcontroller and the control circuit from power circuit we are providing isolation circuit.

Description:

Once the logical gate signals G1-G4 are available for four MOSFET switches, these have to be isolated before giving to the gate terminals of the switches. An opto-coupler (IC 6N136) is used to provide isolation of logic gate pulse from power circuit. Since there are four switches in VSI, therefore four units of opto-couplers are used. However, only three isolated regulated DC voltage supplies are required. Two isolated DC power supplies for upper two switches of the inverter and one isolated power supply for lower two switches as emitter is common for these switches.

The response of opto-coupler depends on the value of output resistance, this is designed based on the value of supply voltage and current withstand capability of photo transistor in opto-coupler IC.

$$H = \frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}$$

In general this transfer function is a complex, rational function of frequency.

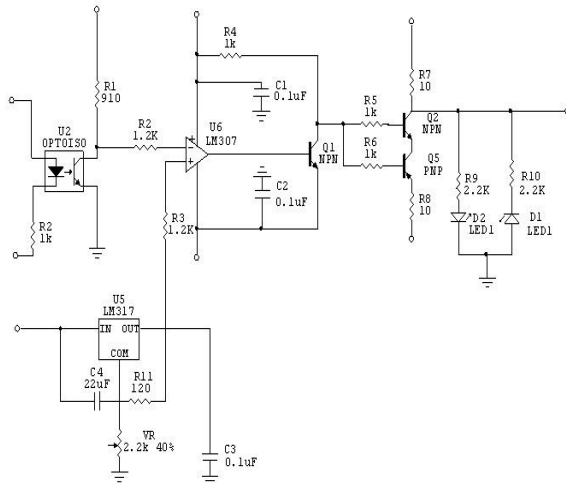


Fig 3.4 Circuit Diagram of Opto Isolation Circuit

Voltage Divider Rule

In electronics or EET, a voltage divider (also known as a potential divider) is a linear circuit that produces an output voltage (V_{out}) that is a fraction of its input voltage (V_{in}). Voltage division refers to the partitioning of a voltage among the components of the divider.

Calculation

A voltage divider referenced to ground is created by connecting two electrical impedances in series, as shown in Figure 1. The input voltage is applied across the series impedances Z_1 and Z_2 and the output is the voltage across Z_2 . Z_1 and Z_2 may be composed of any combination of elements such as resistors, inductors and capacitors.

Applying Ohm's Law, the relationship between the input voltage, V_{in} , and the output voltage, V_{out} , can be found:

$$V_{out} = \frac{Z_2}{Z_1 + Z_2} \cdot V_{in}$$

Proof:

$$V_{in} = I \cdot (Z_1 + Z_2)$$

$$V_{out} = I \cdot Z_2$$

$$I = \frac{V_{in}}{Z_1 + Z_2}$$

$$V_{out} = V_{in} \cdot \frac{Z_2}{Z_1 + Z_2}$$

The transfer function (also known as the divider's **voltage ratio**) of this circuit is simply:

VI. CONCLUSION

Depending on the equalization strategies, the proposed voltage equalizers might supply excessive equalization currents for unshaded substrings, needlessly increasing power conversion loss. The optimum equalization strategy, with which equalization currents for unshaded substrings are minimized, was proposed and discussed for the equalizers to work efficiently. Operational analyses based on the simplified equivalent circuit were also performed for the SEPIC-based equalizer, and a control circuit that substantiates the optimum equalization strategy was also introduced. Experimental equalization tests emulating partial-shading conditions for a PV panel consisting of three substrings were performed using the prototype, and measured string characteristics with and without equalization were compared. Local MPPs found in the case without equalization were successfully eliminated by the support of the equalizer. The extractable maximum powers with equalization were considerably increased compared with those without equalization, demonstrating the efficacy of the proposed voltage equalizer

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