Sun Tracking Solar Power System

Project report submitted in partial fulfillment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted By:

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Submitted To:

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SECTOR-62

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Candidates’ Declaration

This is to certify that the work which is being presented in B.Tech Minor Project Report entitled “**Sun Tracking Solar Power System**”, submitted by “Shree Kumar Singh & Mohammed Fayez Khan”, in partial fulfillment of the requirements for the award of degree of **Bachelor of Technology** in **Electronics & Communication Engineering** and submitted to the Department of Electronics & Communication Engineering of Jaypee Institute of Information Technology, Noida is an authentic record of our own work carried out during a period from January 2023 to May 2023 under the supervision of **“Mrs K. Nisha”**, ECE Department. The matter presented in this report has not been submitted by us for the award of any other degree elsewhere.

Shree Kumar Singh(20102113) **Mohammed Fayez Khan(20102148)**

This is to certify that the above statement made by the candidates is correct to the best of my knowledge.

(Signature of Supervisor)

Mrs K. Nisha
Assistant Professor

Date:

Acknowledgement

It is my great fortune that I have got opportunity to carry out this project work under the supervision of **Mrs. K. Nisha** in the Department of Electronics and Communication Engineering , Jaypee Institute of Information Technology (JIIT), Noida Sector-62. I express my sincere thanks and deepest sense of gratitude to my guide for her constant support, unparalleled guidance and limitless encouragement.

I wish to convey my gratitude to Prof. Shweta Srivastava, HOD/Dean, Department of Electronics and Communication Engineering, JIIT and to the authority of JIIT for providing all kinds of infrastructural facility towards the research work.

I would also like to convey my gratitude to all the faculty members and staffs of the Department of Electronics and Communications Engineering, JIIT for their whole-hearted cooperation to make this work turn into reality.

Name and Signature of the StudentsPlace:

Date:

List of Acronyms and Abbreviation

AC	Alternate Current
LDR	Light Dependent Resistor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PV	Photovoltaic Cell
DC	Direct Current
ADC	Analog-to-Digital Converter
MPPT	Maximum Power Point Tracking
PWM	Pulse Width Modulation
ICSP	In-Circuit Serial Programming
USB	Universal Serial Bus
CMOS	Complementary Metal-Oxide-Semiconductor
RISC	Reduced Instruction Set Computer
IC	Integrated Circuit
EEPROM	Electrically Erasable programmable Read-Only Memory
SRAM	Static Random Access Memory
I/O	Input/ Output
GND	Ground
VCC	Supply Voltage
RAM	Random Access Memory
CCM	Continuous Conduction Mode
DCM	Discontinuous Conduction Mode

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CHAPTER 1

Introduction

1 Objective

The goal of this thesis was to develop a laboratory prototype of a solar tracking system, whichis able to enhance the performance of the photovoltaic modules in a solar energy system and make it **a Stand Alone PV Systems or Microgrid**. The operating principle of the device is to keep the photovoltaic modules constantly aligned with the sunbeams, which maximises the exposure of solar panel to the Sun's radiation. As a result,more output power can be produced by the solar panel.

The work of the project included hardware design and implementation, together with software programming for the microcontroller unit of the solar tracker. The system utilised an ATmega328P microcontroller to control motion of two servo motors, which rotate solar panelin two axes. The amount of rotation was determined by the microcontroller, based on inputs retrieved from four photo sensors located next to solar panel.

At the end of the project, a functional solar tracking system was designed and implemented. Itwas able to keep the solar panel aligned with the sun, or any light source repetitively. Design of the solar tracker from this project is also a reference and a starting point for the developmentof more advanced systems in the future.

2 Approach Overview

With the unavoidable shortage of fossil fuel sources in the future, renewable types of energy have become a topic of interest for researchers, technicians, investors and decision makers allaround the world. New types of energy that are getting attention include hydroelectricity, bioenergy, solar, wind and geothermal energy, tidal power and wave power. Because of theirrenewability, they are considered as favorable replacements for fossil fuel sources. Among those types of energy, solar photovoltaic (PV) energy is one of the most available resources. This technology has been adopted more widely for residential use nowadays, thanks to research and development activities to improve solar cells' performance and lower the cost. According to International Energy Agency (IEA), worldwide PV capacity has grown at 49% per year on average since early 2000s. Solar PV energy is highly expected to become a major source of power in the future.

However, despite the advantages, solar PV energy is still far from replacing traditional sources on the market. It is still a challenge to maximize power output of PV systems in areasthat don't receive a large amount of solar radiation. We still need more advanced technologies from manufacturers to improve the capability of PV materials, but improvementof system design and module construction is a feasible approach to make solar PV power more efficient, thus being a reliable choice for customers. Aiming for that purpose, this project had been carried out to support the development of such promising technology.

One of the main methods of increasing efficiency is to maximize the duration of exposure to the Sun. Tracking systems help achieve this by keeping PV solar panels aligned at the appropriate angle with the sun rays at any time. The goal of this project is to build a prototypeof light tracking system at smaller scale, but the design can be applied for any solar energy system in practice. It is also expected from this project a quantitative measurement of how well tracking system performs compared to system with fixed mounting method.

CHAPTER-2 RELATED WORK

ARDUINO UNO

The **Arduino Uno** is a microcontroller board based on the ATmega328. Arduino is an open-source, prototyping platform and its simplicity makes it ideal for hobbyists to use as well as professionals. The Arduino Uno has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Arduino Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 microcontroller chip programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Arduino Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform.

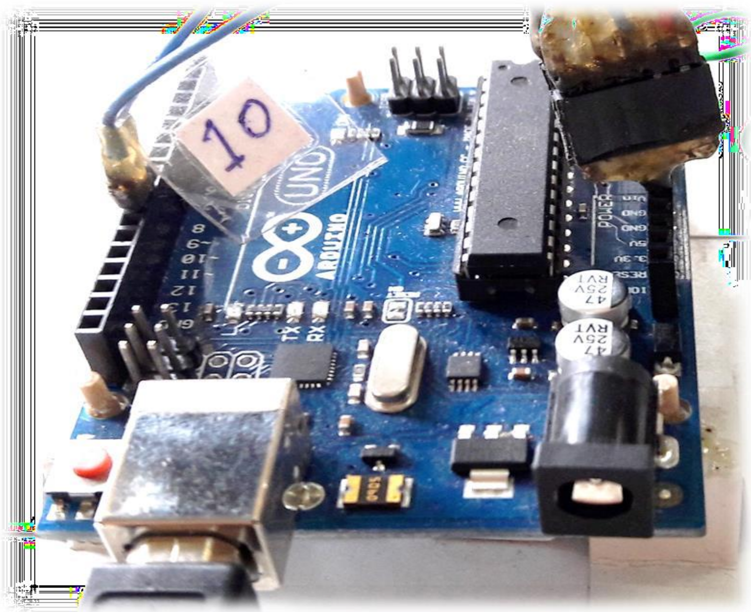

Fig 1

- **THE ATMEGA328P-PU ATMEL 8 BIT 32K AVR MICROCONTROLLER**

The Atmel®picoPower®ATmega328/P is a low-power CMOS 8-bit microcontroller based onthe AVR® enhanced RISC architecture.

PIN DIAGRAM:

Pin layout of ATmega328p is showed below:

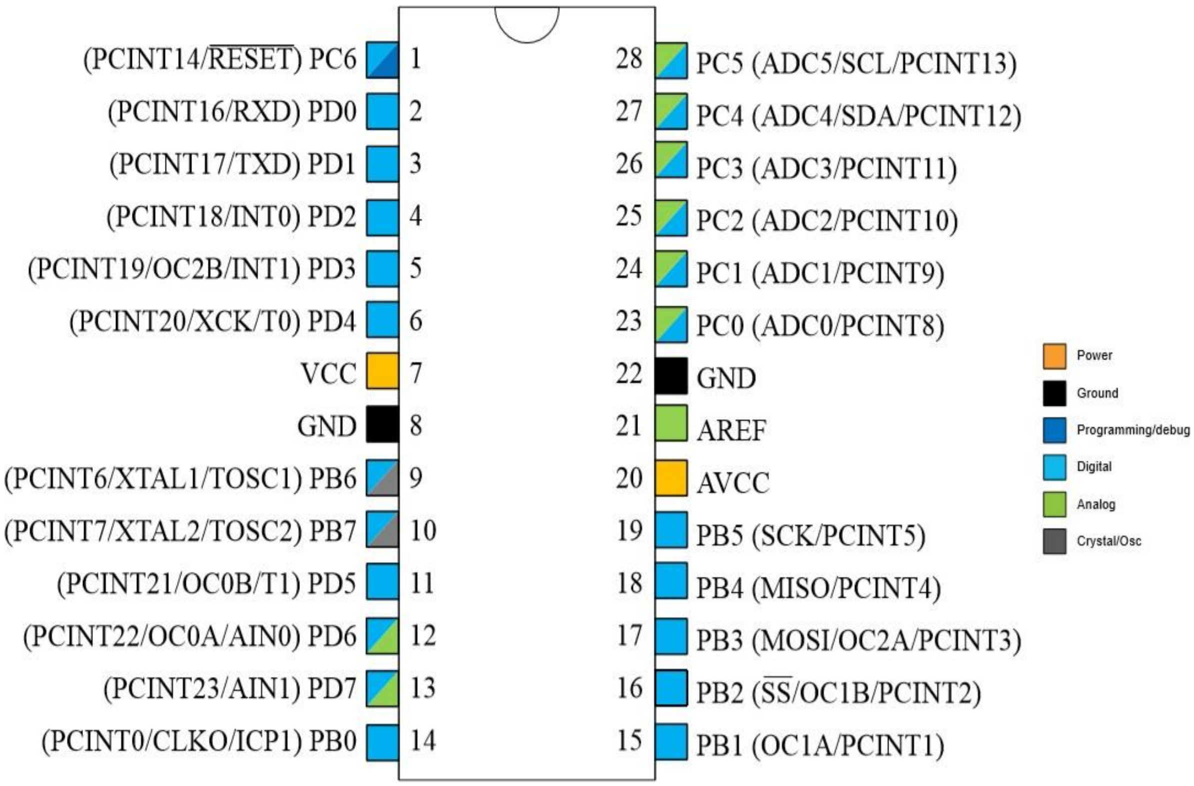

Fig 2

CPU

The CPU of the AVR microcontroller is same but so simple like the one in a computer. The main purpose of the CPU is to confirm correct program performance. Therefore, the CPU must be able to access perform calculations, memories, control peripherals & handle interrupts. The CPUs of Atmel's 8-bit and 32-bit AVR are based on an innovative "Harvard architecture" thus every IC has two buses namely one instruction bus and data bus. The CPU reads executable instructions in instruction bus, wherein the data bus, is to read or write the corresponding data. The CPU core of the AVR consists of the ALU, General Purpose Registers, Program Counter, Instruction Register, Instruction Decoder, Status Register and Stack Pointer

Flash Program Memory

The program of the AVR microcontroller is stored in non-volatile programmable Flash program memory which is just similar to the flash storage in your SD Card or Mp3 Player. The Flash program memory is separated into two units. The first unit is the Application Flash section. It is where the program of the AVR is stored. The second section is named as the Boot Flash section and can be fixed to perform directly when the device is powered up. One significant fact to note is that the microcontrollers Flash program memory has a resolution of at least 10,000 writes/erase cycles.

SRAM

The SRAM (Static Random Access Memory) of the AVR microcontroller is just like computer RAM. While the registers are used to execute calculations, the SRAM is used to supply data through the runtime. This volatile memory is prearranged in 8-bit registers.

EEPROM

The term EEPROM stands for Electrically Erasable Read-Only Memory is like a nonvolatile memory, but you can't run a program from it, but it is used as long time storage. The EEPROM doesn't get removed when the IC loses power. It's a great place for storing data like device parameters and configuration of the system at runtime so that it can continue between resets of the application processor. One significant fact to note is that the EEPROM

Memory of the AVR has a limited lifetime of 100,000 writes/ EEPROM page- reads are limitless.

Mind in your application and try to keep writing to a minimum, so that you only write the small amount of info required for your application every time you update the EEPROM.

Digital I/O Modules

The digital I/O modules let digital communication or logic communication with the AVR microcontroller and the exterior world. Communication signals are that of TTL/CMOS logic.

Analog I/O Modules

Analog I/O modules are used to input or output analog information from or to the exterior world. These modules comprise analog comparators and analog-to-digital converters (ADC).

Interrupt Unit

Interrupts have enabled the microcontroller to monitor particular events in the background while performing and application program & respond to the occurrence if required pausing the unique program. This is all synchronized by the interrupt Unit.

Timer

Most AVR microcontrollers have at least one Timer or Counter module which is used to achieve timing or counting operations in the microcontroller. These comprise time stamping, counting events, measuring intervals, etc.

SERVO MOTOR

A DC servo motor consists of a small DC motor, feedback potentiometer, gearbox, motor drive electronic circuit and electronic feedback control loop. It is more or less similar to the normal DC motor.

The stator of the motor consists of a cylindrical frame and the magnet is attached to the insideof the frame.

A brush is built with an armature coil that supplies the current to the commutator. At the backof the shaft, a detector is built into the rotor in order to detect the rotation speed.

With this construction, it is simple to design a controller using simple circuitry because the torque is proportional to the amount of current flow through the armature.

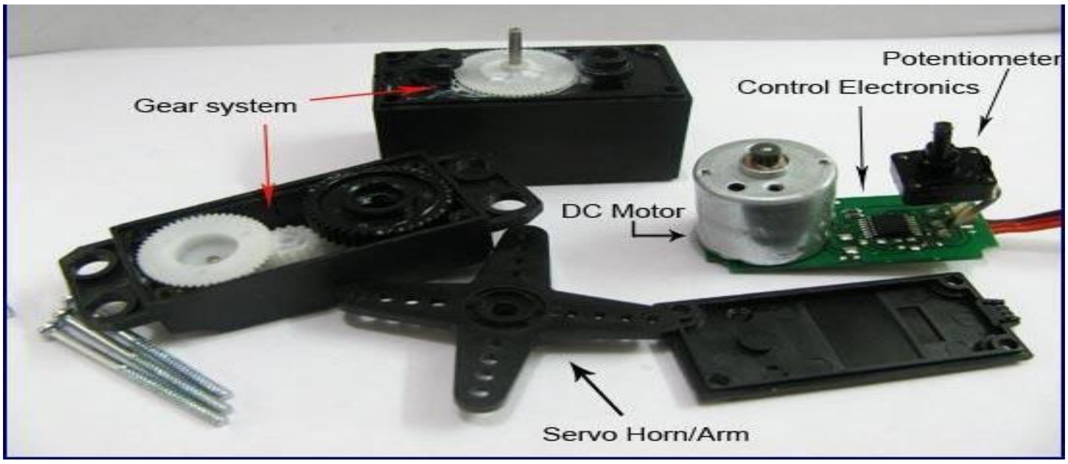

Fig 3

LDR

It is a photo-resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices. They are also called as photo conductors, photo conductive cells or simply photocells.

They are made up of semiconductor materials having high resistance.

LDR works on the principle of photo conductivity.

Photo conductivity is an optical phenomenon in which the material's conductivity is increased when light is absorbed by the material.

The most common type of LDR has a resistance that falls with an increase in the light intensity falling upon the device (as shown in the image above). The resistance of an LDR may typically have the following resistances:

*Daylight = 5000*Ω

*Dark = 20000000*Ω

Therefore, it is seen that there is a large variation between these figures. If this variation is plotted on a graph, something similar to the figure given below can be seen.

Fig 4

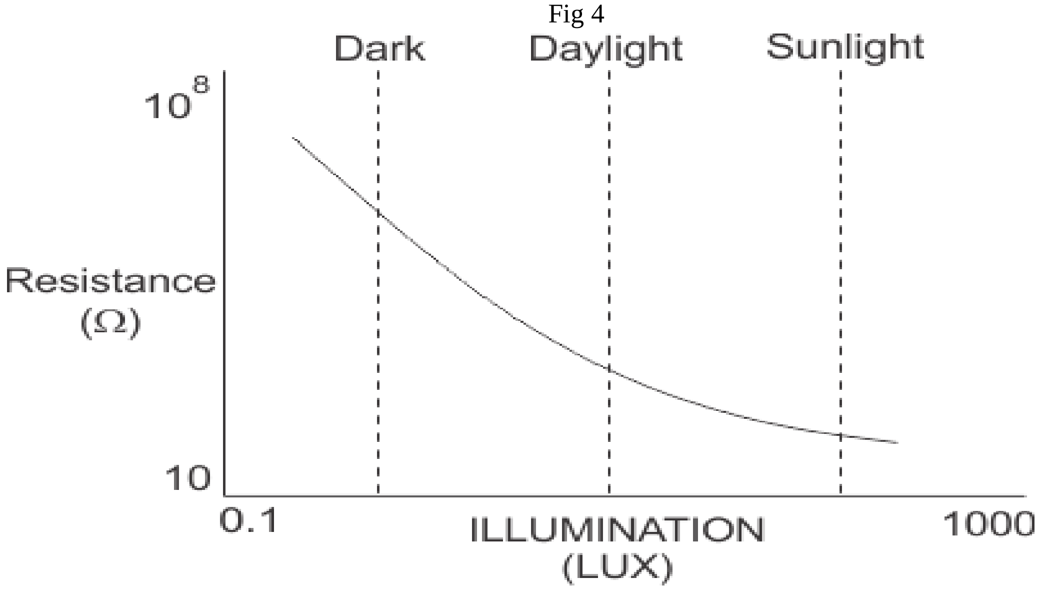

Fig 4

DC to DC Boost Converter

DC/DC converters are used in several appliances used in our everyday lives. The main goal of these converters is to step up or step down the DC voltage based on the application at hand while providing voltage regulation.

A step-up or boost converter is one of the simplest switch-mode converter types, increasing or boosting the input voltage based on the requirements. There are ample scenarios where there is a need for a slightly higher voltage. Read on to learn more about the basics of step-up converters and how they work.

The CN6009 is a type of DC to DC voltage booster module that is commonly used to increase the voltage of a DC power source. Here are some typical specifications for the CN6009 module:

Input voltage range: 2V to 35V
Output voltage range: 5V to 35V (adjustable via a potentiometer)
Maximum output current: 2A (with proper heat dissipation)
Conversion efficiency: up to 94%
Switching frequency: 400kHz
Operating temperature range: -40°C to +85°C
Over-temperature protection: Yes
Short-circuit protection: Yes
Reverse polarity protection: No
Dimensions: 43mm x 21mm x 14mm
The CN6009 module typically includes a voltage regulating chip, an inductor, and a MOSFET switch to provide high-efficiency voltage conversion. It also includes a potentiometer for adjusting the output voltage, and input and output terminals for connecting to a DC power source and load, respectively.

Note that the actual specifications may vary depending on the specific manufacturer and model of the CN6009 module. It's important to review the datasheet and user manual for the specific module being used to ensure proper operation and safety.

CHAPTER 3

ADC CONCEPT IN ARDUINO UNO

ADC INPUT CHANNELS

Fig 5

Arduino uno board has 6 ADC input ports. Among those any one or all of them can be used as inputs for analog voltage. The **Arduino Uno ADC** is of 10 bit resolution (so the integer values from (0-(2^10) 1023)). This means that it will map input voltages between 0 and 5 voltsinto integer values between 0 and 1023. So, for every (5/1024= 4.9mV) per unit.

The UNO ADC channels have a default reference value of 5V. This means we can give a maximum input voltage of 5V for ADC conversion at any input channel. Since some sensors provide voltages from 0-2.5V, with a 5V reference we get lesser accuracy, so we have a instruction that enables us to change this reference value. So for changing the reference value we have (“**analogReference()**;”).

As default we get the maximum board ADC resolution which is 10bits, this resolution can be changed by using instruction (“**analogReadResolution(bits)**;”).

ABOUT SOLAR PANEL AND CONNECTED LOAD

- Solar panel is placed at the top and connected to a load directly. The load may a led ora voltmeter which could be connected to get the exact voltage which depends on the intensity of light falling on the panel and the position of the tracker.
- Concentrated solar photovoltaics' and have optics that directly accept sunlight, so solar trackers must be angled correctly to collect energy. All concentrated solar systems have trackers because the systems do not produce energy unless directed correctly toward the sun.
- The solar panel is just a mere device to accept the light radiation which is purely controlled by LDR sensors and the load connected depends upon the rating of the panelused.

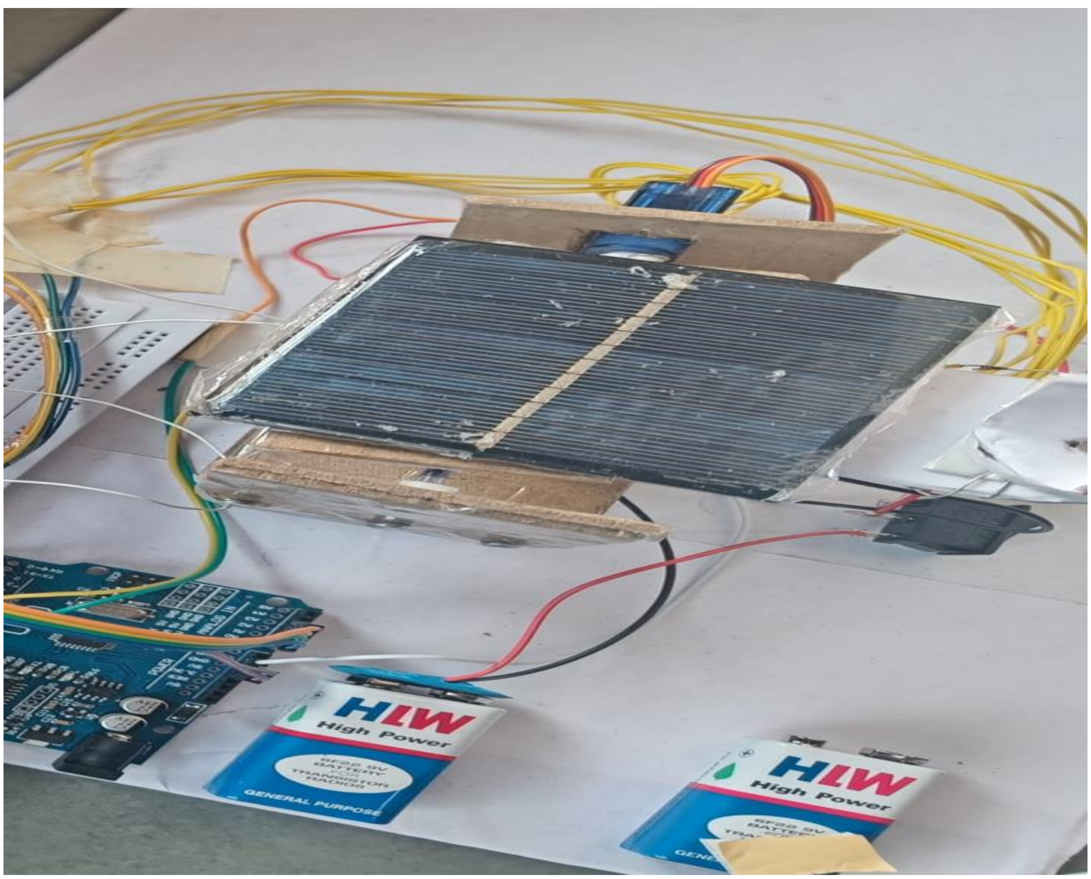

Fig 6

DUAL AXIS MOVEMENT OF SOLAR TRACKER

- The dual axis solar tracker is device which senses the light and positions towards the maximum intensity of light. It is made in such a way to track the light coming from any direction.
- To simulate the general scenario of the Sun's movement, the total coverage of the movement of the tracker is considered as 120˚ in both the directions.
- The initial position of both the servo motors are chosen at 90˚i.e, for east-west servo motor as well as for north-south servo motor.
- The position of the tracker ascends or descends only when the threshold value is abovethe tolerance limit.

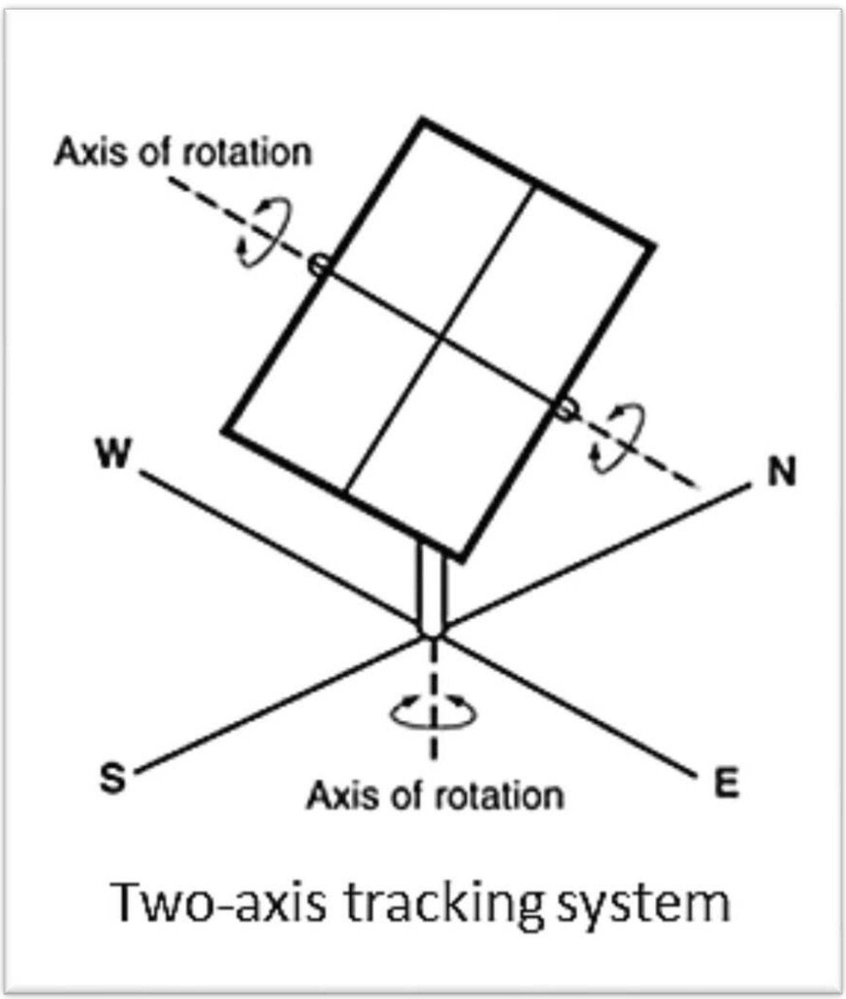

Fig 7

Functional Block Diagram

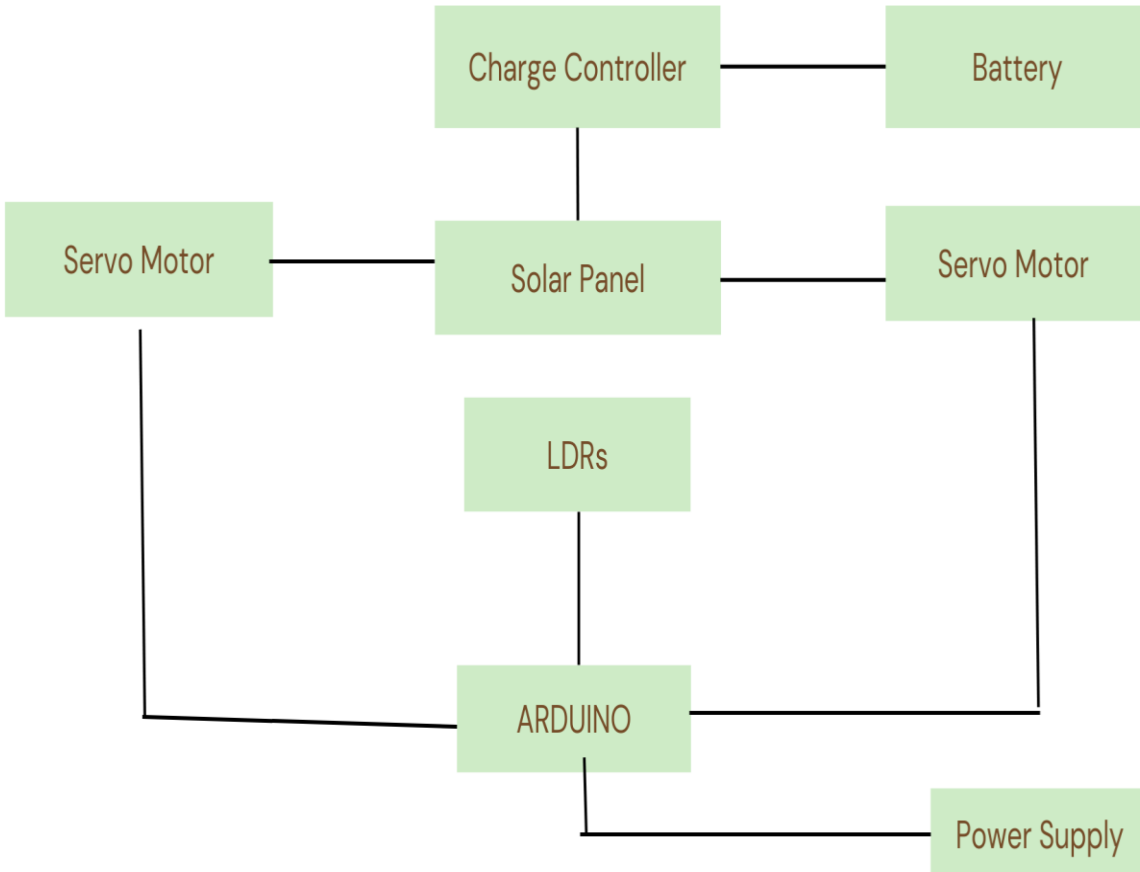

Fig 8

CHAPTER 4

DC/DC CONVERTER TOPOLOGIES

4.1 Introduction

DC/DC converters at a module level can convert each module from a current source into a power source thus allowing each module to deliver its maximum power to the load despite any mismatches in the system. There are several topologies and algorithms available to achieve this. For the sake of this paper, the most common topologies available will be analyzed to understand each advantage and disadvantage and how it applies to the system. The three most common topologies are buck (step down), boost (step up) and buck-boost (step down/step up).

4.1 Converter Topologies

4.1.1 Buck Converter

In a buck converter, the output voltage must always be lower than the input voltage [18]. A simple buck converter circuit is shown in Figure 13 consisting of a MOSFET, diode, inductor, capacitor and a load. While the MOSFET is on, current is flowing through the load via the inductor. The action of any inductor opposes changes in current flow and also acts as a store of energy. In this case, the MOSFET output is prevented from increasing immediately to its peak value as the inductor stores energy taken from the increasing output. This stored energy is later released back into the circuit as a back-electromotive force (back-EMF) as current from the switching MOSFET is rapidly turned off [18].

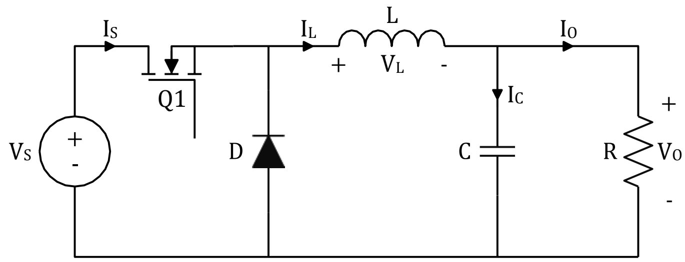

Figure : Conventional Buck Converter

There are two modes in which this converter can operate. The first mode is when the MOSFET is in position 1 (on state) and the second mode is when the switch is in position 2 (off state).

In the on state, shown in the circuit in Figure 14, the MOSFET is supplying the load with current. Initially, current flow to the load is restricted as energy is also being stored in the inductor. Therefore, the current in the load and the charge on the capacitor builds up gradually. During this on state, there is a large positive voltage on the diode so the diode will be reverse biased and play no role in the circuit. The voltage across the inductor and current through the capacitor is represented by the following equations:

$$V_L = V_s - V_o$$

$$I_c = I_L - \frac{V_o}{R}$$

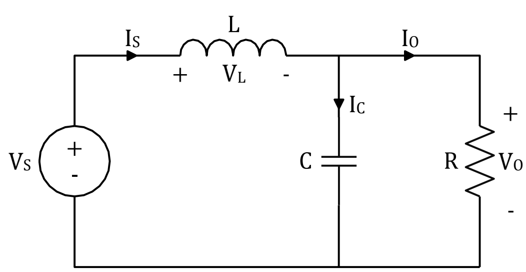

Figure 10: Buck Converter (On State)

During the on state, the current through the inductor rises linearly given by:

$$V_L = L\,(\frac{dI_L}{dt})$$

$$(\frac{dI_L}{dt}) = \frac{V_L}{L} \Rightarrow (\frac{V_s - V_o}{L})$$

$$\Delta I_{L(on)} = \int_0^{t_{on}} \frac{V_L}{L}\,dt \Rightarrow (\frac{V_s - V_o}{L})\,t_{on}\ where\ t_{on} = DT$$

$$\Delta I_{L(on)} = (\frac{V_s - V_o}{L})\,DT$$

The voltage across the capacitor is given by:

$$I_c = C\,(\frac{dV_o}{dt})$$

$$(\frac{dV_o}{dt}) = \frac{I_c}{C} \Rightarrow (\frac{I_L - \frac{V_o}{R}}{C})$$

$$\Delta V_{c(on)} = \int_0^{t_{on}} \frac{I_c}{C}\,dt \Rightarrow (\frac{I_L - \frac{V_o}{R}}{C})\,t_{on}\quad where\ t_{on} = DT$$

$$\Delta V_{c(on)} = (\frac{I_L - I_o}{C})\,DT$$

During the off state, shown in Figure 15, the energy stored in the magnetic field around the inductor is released back into the circuit. The voltage across the inductor is not in reverse polarity to the voltage across the inductor during the on period, and sufficient stored energy is available in the collapsing magnetic field to keep current flowing for at least part of the time the transistor switch is open. The back-EMF from the inductor now causes the current to flow around the circuit via the load and the diode, which is now forward biased. Once the inductor has returned a large part of its stored energy to the circuit and the load voltage begins to fall, the charge stored in the capacitor becomes the main source of current, keeping current flowing through the load until the next on period begins. The current across the inductor and current through the capacitor is represented by the equations:

$$V_L = -V_o$$

$$I_c = I_L - \frac{V_o}{R}$$

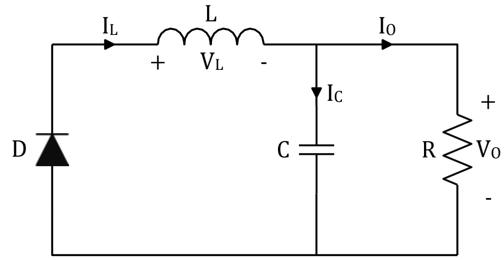

Figure 13: Buck Converter (Off State)

During the off state, the current through the inductor is given by:

$$V_L = L\,(\frac{dI_L}{dt})$$

$$(\frac{dI_L}{dt}) = \frac{V_L}{L} \Rightarrow (\frac{-V_o}{L})$$

$$\Delta I_{L(off)} = \int_{t_{on}}^{T=t_{on}+t_{off}} \frac{V_L}{L}\,dt \Rightarrow (\frac{-V_o}{L})\, t_{off} \ where\ t_{off} = (1-D)T$$

$$\Delta I_{L(off)} = (\frac{-V_o}{L})\,(1-D)T$$

The voltage across the capacitor is given by:

$$I_c = C\,(\frac{dV_o}{dt})$$

$$(\frac{dV_o}{dt}) = \frac{I_c}{C} \Rightarrow (\frac{I_L - \frac{V_o}{R}}{C})$$

$$\int^{T=t_{on}+t_{off}} I \qquad I - \frac{V_o}{}$$

$$\Delta V_{c(off)} = \left(\frac{I_L - I_o}{C}\right)(1-D)T$$

From the steady state perspective, magnitude of the inductor current increment during switch on is equal to the inductor current decrement during switch off. In other words, the net change in inductor current or the total area (or volt-seconds) under the inductor voltage waveform is zero whenever the converter operates in steady state. Therefore, the output voltage is directly dependent on the duty cycle and the input voltage.

$$\Delta I_{L(on)} + \Delta I_{L(off)} = 0$$

$$\left(\frac{V_s - V_o}{L}\right) DT - \left(\frac{-V_o}{L}\right)(1-D)T = 0$$

$$(V_s - V_o)DT - (-V_o)(1-D)T = 0$$

$$V_o - DV_s = 0$$

$$V_o = DV_s$$

Likewise, from the steady state perspective, magnitude of the capacitor voltage increment during switch on is equal to the capacitor voltage decrement during switch off. In other words, the net change in capacitor voltage or the total area (or charge balance) under the capacitor current waveform is zero whenever the converter operates in steady state. Therefore, the output current is directly dependent on the input current.

$$\Delta V_{c(on)} + \Delta V_{c(off)} = 0$$

$$\left(\frac{I_L - I_o}{C}\right) DT - \left(\frac{I_L - I_o}{C}\right)(1-D)T = 0$$

$$(I_L - I_o)DT - (I_L - I_o)(1-D)T = 0$$

$$I_L - I_o = 0$$

$$I_L = I_o$$

The output waveforms of the voltage and current during one cycle period are shown below

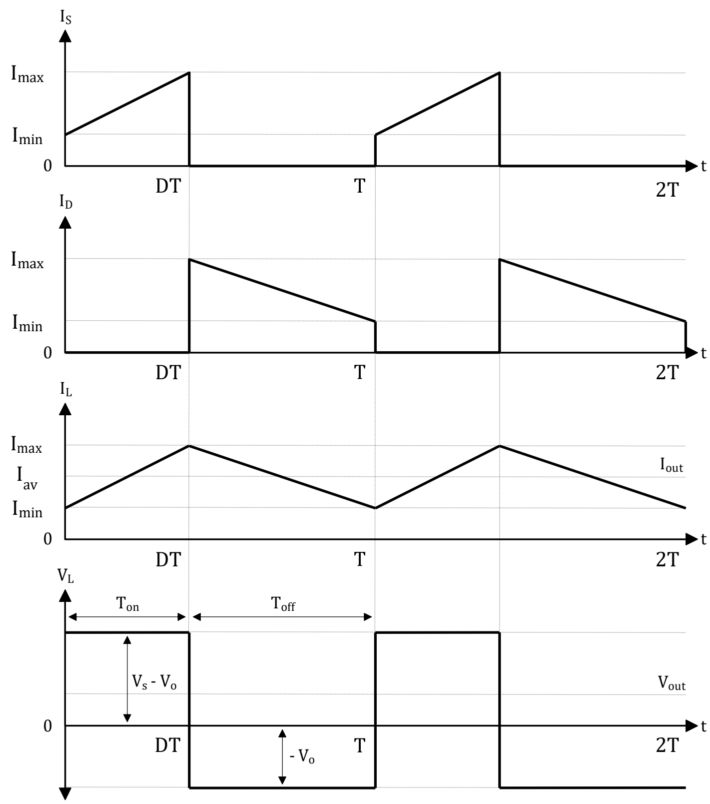

Figure 11: Buck Converter Voltage and Current Waveforms

4.1.1 Boost Converter

In a boost converter, the output voltage is always higher than the input voltage [18]. Much like the buck converter, the boost converter consists of a MOSFET, diode, inductor, capacitor and a load but in a lightly different configuration. Figure 12 shows a basic boost converter with ideal components.

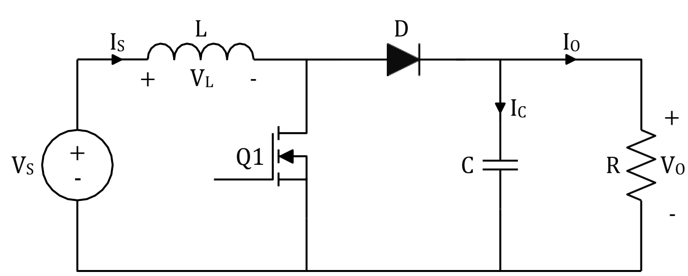

Figure 12: Conventional Boost Converter

In this circuit, there are two modes in which it can operate. The first mode is when the switch is in position 1 (on state) and the second mode is when the switch is in position 2 (off state).

When the boost converter is initially in the on state as shown Figure 18, a short is created from the right-hand side of the inductor to the negative input of the supply terminal. Current flows between the positive and negative supply terminal through the inductor, which stores energy in its magnetic field. There is virtually no current flowing in the remainder of the circuit as the combination of the diode and capacitor represent a much higher impedance that the path directly through the MOSFET.

After the initial startup on state, every other time the circuit is in the on state the cathode of the diode is more positive than its anode, to the charge on the capacitor. The diode is therefore turned off so the output of the circuit is isolated form the input. However, the load continues to be supplied with $(V_{in} + V_L)$ from the charge of the capacitor. Although the charge of the capacitor drains away through the load during this period, the capacitor is recharged each time the MOSFET switches off, so maintaining an almost steady output voltage across the load. The voltage across the inductor and current through the capacitor is simply:

$$V_L = V_s$$

$$I_c = \frac{-V_o}{R}$$

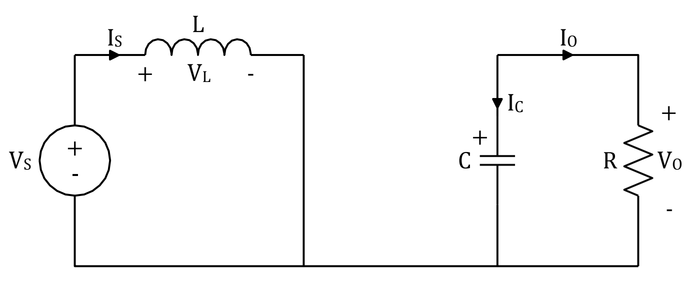

Figure 13: Boost Converter (On State)

During the on state the current through the inductor rises linearly given by:

$$V_L = L\left(\frac{dI_L}{dt}\right)$$

$$\left(\frac{dI_L}{dt}\right) = \frac{V_L}{L} \Rightarrow \left(\frac{V_s}{L}\right)$$

$$\Delta I_{L(on)} = \int_0^{t_{on}} \frac{V_L}{L}\, dt \Rightarrow \left(\frac{V_s}{L}\right) t_{on} \; where \; t_{on} = DT$$

$$\Delta I_{L(on)} = \left(\frac{V_s}{L}\right) DT$$

The voltage across the capacitor is given by:

$$I_c = C\left(\frac{dV_o}{dt}\right)$$

$$\left(\frac{dV_o}{dt}\right) = \frac{I_c}{C} \Rightarrow \left(\frac{-V_o}{R * C}\right)$$

$$\Delta V_{c(on)} = \int_0^{t_{on}} \frac{I_c}{C}\, dt \Rightarrow \left(\frac{-V_o}{R * C}\right) t_{on} \; where \; t_{on} = DT$$

$$\Delta V_{c(on)} = \left(\frac{I_o}{C}\right) DT$$

During the off state when the MOSFET is rapidly turned off, as shown in Figure 19, there is a sudden drop in current causing the inductor to produce a back-EMF in the opposite polarity to the voltage across the inductor during the on period, to keep current flowing. This results in two voltages, the supply voltage V_{in} and the back-EMF voltage across the inductor in series with each other. This higher voltage forward biases the diode $(V_{in} + V_L)$, now that there is no current path through the MOSFET. The resulting current through the diode charges up the capacitor to $(V_{in} + V_L)$ minus the small forward voltage drop across the diode, and also supplies the load. The voltage across the inductor and current through the capacitor is:

$$V_L = V_s - V_o$$

$$I_c = I_L - \frac{V_o}{R}$$

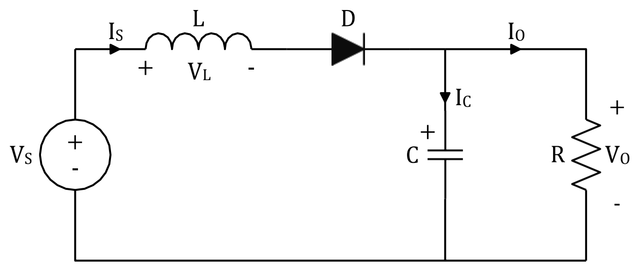

Figure 14: Boost Converter (Off State)

During the off state, the current through the inductor is given by:

$$V_L = L\,(\frac{dI_L}{dt})$$

$$(\frac{dI_L}{dt}) = \frac{V_L}{L} \Rightarrow (\frac{V_s - V_o}{L})$$

$$\Delta I_{L(off)} = \int_{t_{on}}^{T=t_{on}+t_{off}} \frac{V_L}{L}\,dt \Rightarrow (\frac{V_s - V_o}{L})\,t_{off}\ where\ t_{off} = (1-D)T$$

$$\Delta I_{L(off)} = (\frac{V_s - V_o}{L})\,(1-D)T$$

The voltage across the capacitor is given by:

$$I_c = C\,(\frac{dV_o}{dt})$$

$$(\frac{dV_o}{dt}) = \frac{I_c}{C} \Rightarrow (\frac{I_L - \frac{V_o}{R}}{C})$$

$$\Delta V_{c(off)} = \int_{t_{on}}^{T=t_{on}+t_{off}} \frac{I_c}{C}\,dt \Rightarrow (\frac{I_L - \frac{V_o}{R}}{C})\,t_{off}\quad where\quad t_{off} = (1-D)T$$

$$\Delta V_{c(off)} = \left(\frac{I_L - I_o}{C}\right)(1 - D)T$$

Like the buck converter, the net change in inductor current or the total area (or volt-seconds) under the inductor voltage waveform is zero whenever the converter operates in steady state. By applying the inductor volt-second balance equation for a boost converter and breaking it down, the output voltage equation for a boost converter can be obtained in terms of the output voltage, input voltage and duty cycle:

$$\Delta I_{L(on)} + \Delta I_{L(off)} = 0$$

$$\left(\frac{V_s}{L}\right)DT + \left(\frac{V_s - V_o}{L}\right)(1 - D)T = 0$$

$$(V_s)DT + (V_s - V_o)(1 - D)T = 0$$

$$V_o = \left(\frac{V_s}{1 - D}\right)$$

Also, the net change in capacitor voltage or the total area (or charge balance) under the capacitor current waveform is zero whenever the converter operates in steady state. By applying the capacitor charge balance equation, the output current can be obtained in terms of the output current, input current and duty cycle:

$$\Delta V_{c(on)} + \Delta V_{c(off)} = 0$$

$$\left(\frac{I_o}{C}\right)DT + \left(\frac{I_L - I_o}{C}\right)(1 - D)T = 0$$

$$(I_o)DT + (I_L - I_o)(1 - D)T = 0$$

$$I_L = \left(\frac{I_o}{1 - D}\right)$$

The output waveforms of the voltage and current during one cycle period are shown in Figure 15.

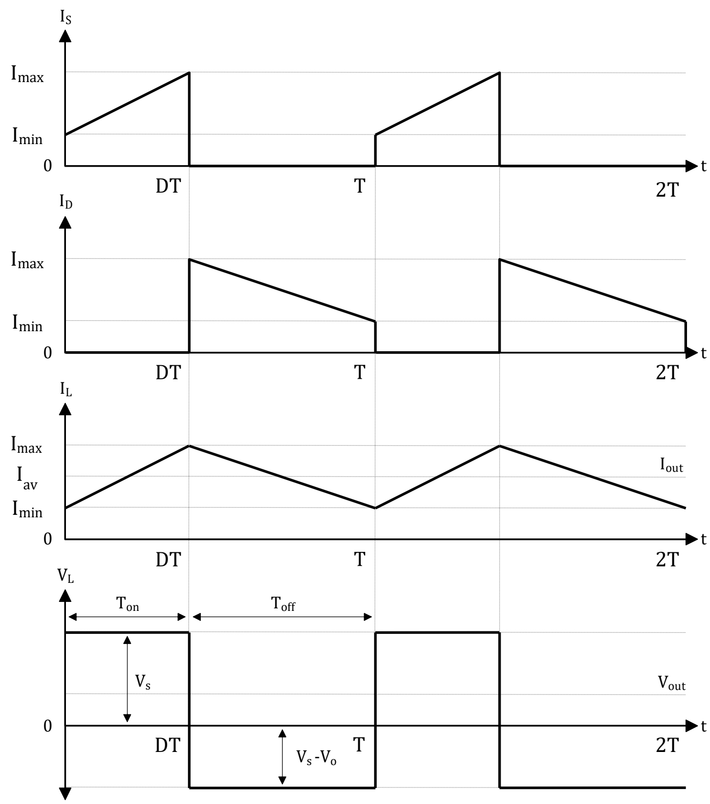

Figure 15: Boost Converter Voltage and Current Waveforms

4.1.2 Buck-Boost Converter

In a buck-boost converter, the output voltage magnitude is either greater than or less than the input voltage magnitude [18]. It is a type of switch mode power supply that combines the principles of the buck converter and the boost converter in a single circuit. With this topology, there are essentially two modes in which it can operate, inverting and non-inverting.

3.2.3.1 Inverting Buck-Boost Converter

A basic inverting buck-boost converter has a negative output voltage with respect to ground [19]. In addition to input and output capacitors, the power stage consists of a MOSFET, a diode and an inductor as shown in Figure 21.

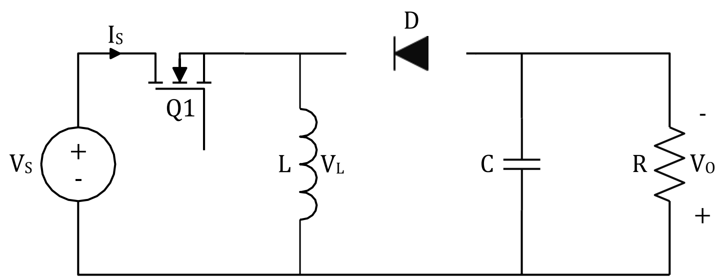

Figure 16: Conventional Inverting Buck-Boost Converter

In the on state, shown in Figure 22, the input voltage source is directly connected to the inductor causing the inductor current to ramp up at a rate that is proportional to the input voltage. This results in accumulating energy in the inductor. At this state, the output capacitor supplies the entire load current. The voltage across the inductor is simply:

$$V_s = V_L$$

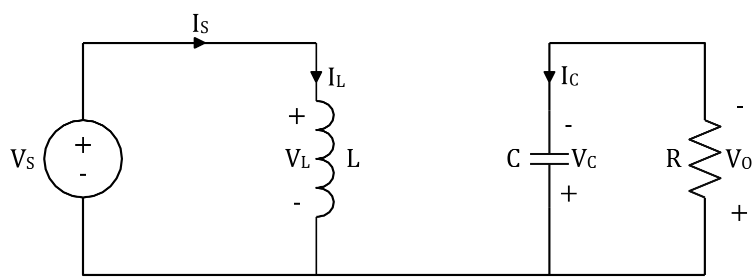

Figure 17: Inverting Buck-Boost Converter (On State)

During the on state the current through the inductor is given by:

$$V_L = L\,(\frac{dI_L}{dt})$$

$$(\frac{dI_L}{dt}) = \frac{V_L}{L} \Rightarrow (\frac{V_s}{L})$$

$$\Delta I_{L(on)} = \int_0^{DT} \frac{V_L}{L}\,dt \Rightarrow (\frac{V_s}{L})\,t_{on} \ where \ t_{on} = DT$$

$$\Delta I_{L(on)} = (\frac{V_s}{L})\,DT$$

During the off state, shown in Figure 23, the diode becomes forward-biased and the inductor current ramps down at a rate proportional to V_{out}. While in this state, energy is transferred from the inductor to the output load and capacitor. If zero voltage drop in the diode is assumed, and a capacitor large enough for its voltage to remain constant then he voltage across the inductor is:

$$V_o = V_L$$

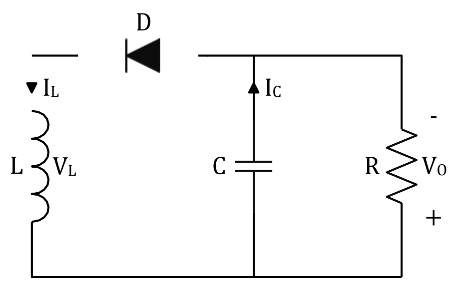

Figure 18: Inverting Buck-Boost Converter (Off State)

During the off state, the current through the inductor is given by:

$$V_L = L\,(\frac{dI_L}{dt})$$

$$(\frac{dI_L}{dt}) = \frac{V_L}{L} \Rightarrow (\frac{V_o}{L})$$

$$\Delta I_{L(off)} = \int_0^{(1-D)T} \frac{V_L}{L}\,dt \Rightarrow (\frac{V_o}{L})\,t_{off}\ where\ t_{off} = (1-D)T$$

$$\Delta I_{L(off)} = (\frac{V_o}{L})(1-D)T$$

By applying the inductor volt-second balance equation for a buck-boost converter and breaking it down, the output voltage equation can be obtained for a boost converter in terms of the output voltage, input voltage and duty cycle [19].

$$\Delta I_{Lon} + \Delta I_{Loff} = 0$$

$$\left(\frac{V_s}{L}\right) DT + \left(\frac{V_o}{L}\right)(1-D)T = 0$$

$$(V_s)DT + (V_o)(1-D)T = 0$$

$$V_o = -\left(\frac{D}{1-D}\right) V_s$$

This equation indicates that the magnitude of the output voltage could be either higher when $D > 0.5$ or lower when $D < 0.5$ than the input voltage. However, the output voltage always has an inverse polarity relative to the input. The output waveforms of the voltage and current during one cycle period are shown in Figure 19.

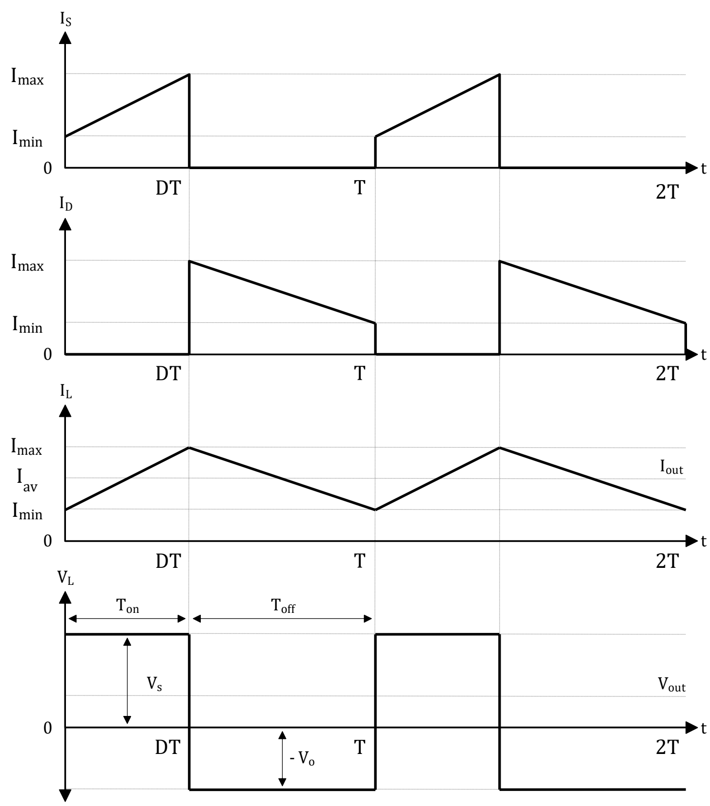

Figure 19: Buck-Boost Converter Voltage and Current Waveforms

Non-Inverting Buck-Boost Converter

The inverting buck-boost converter does not serve the needs of applications where a positive output voltage is required. To solve this issue, the SEPIC, Zeta and two-switch buck- boost converter are three popular non-inverting buck-boost topologies with a positive output. Each topology has its advantages and disadvantages however in the scope of this paper the two-switch buck-boost converter will be discussed.

The two-switch buck-boost converter is a cascaded combination of a buck converter followed by a boost converter seen in Figure 25. By combining these two converter designs, it is possible to have a circuit that can cope with a wide range of input voltages both higher or lower than that needed by the load. Since both buck and boost converters use very similar components; they just need to be re-arranged depending on the level of the input voltage. A conventional two- switch buck-boost converter uses a single inductor. However, it has an additional MOSFET and diode compared to an inverting buck-boost converter. By switching the MOSFETs $Q1$ and $Q2$ onand off simultaneously, the converter operates in buck-boost mode with a non-inverting conversion.

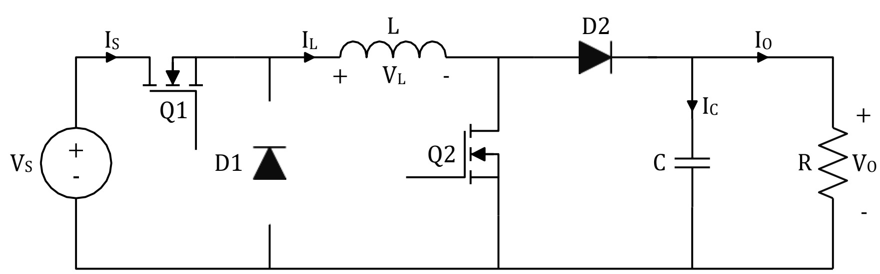

Figure 20: Conventional Non-Inverting Buck-Boost Converter

In buck mode, $Q2$ is controlled to be always off and the output voltage is regulated by controlling $Q1$ as in a typical buck converter. The circuit with $Q2$ off is shown in Figure 26.

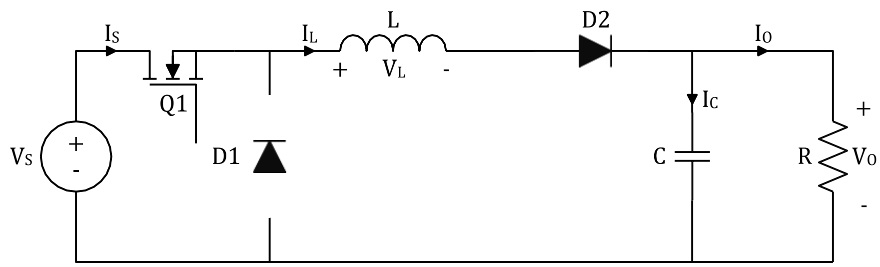

Figure 21: Non-Inverting Buck-Boost Converter (Buck Mode)

The voltage conversion ratio in this mode of operation is the same as that of a typical buck converter given by:

$$V_o = DV_s$$

Where D is the duty cycle of $Q1$. In buck mode, the output voltage is always lower than the input voltage since D is always less than one. In boost mode, $Q1$ is controlled to always be on, $D1$ is reverse biased disconnecting it from the circuit and the output voltage is regulated by controlling $Q2$ as in a typical boost converter as shown in Figure 27.

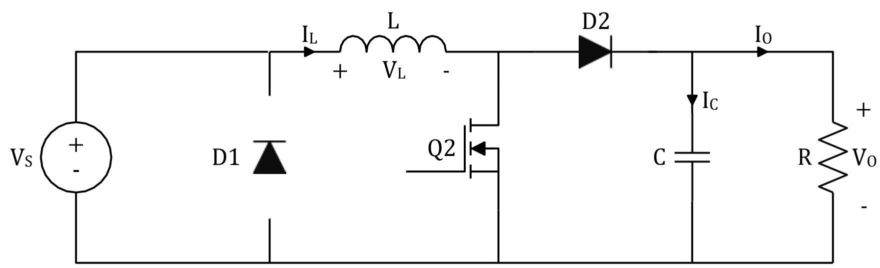

Figure 22: Non-Inverting Buck-Boost Converter (Boost Mode)

The voltage conversion ratio in this mode of operation is the same as that of a typical buck converter given by:

$$V_o = (\frac{V_s}{1-D})$$

In this equation, D is the duty cycle of $Q2$. In boost mode, the output voltage is always greater than the input voltage because D is always greater than zero [19].

4.3 Modes of Operation

Discontinuous vs. Continuous Conduction Mode

One of the most important parts of a converter is the inductor [20]. Sizing the inductor and setting its operation mode makes the converter function correctly. The shape and magnitude of current of the inductor are dictated by the inductance of the inductor itself. Therefore, choosing the right inductor value is very important. The inductor current of a converter can be classified in three types; continuous, discontinuous or boundary. A continuous current means that the minimum level of the inductor current waveform is never touching zero in any switching period [20]. A discontinuous current is the other way around. The minimum level of the inductor current is touching zero before the next PWM high or on state occurs. In boundary, current, the inductor current waveform minimum level is always at zero every switching cycle [20].

Discontinuous conduction mode (DCM) (Figure 28) is characterized by the inductor current being zero for a portion of the switching cycle. It starts at zero, reaches a peak value, and returns to zero during each switching cycle as shown in the figure below. As the DC load current is reduced to a value that causes the average inductor current to be less than half the inductor ripple current. When the inductor current becomes zero, the power to the load is supplied by the capacitance alone. The output voltage depends on the circuit component values and the duty ratio of the MOSFET.

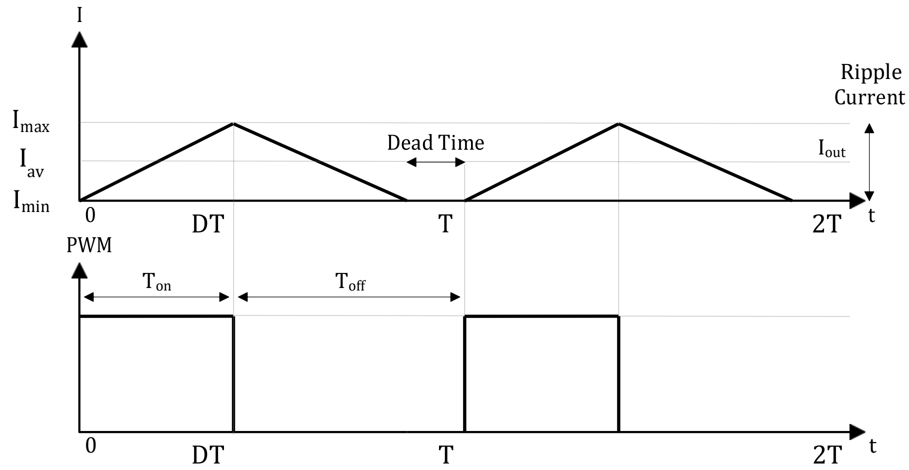

Figure 23: Discontinuous Conduction Mode (DCM)

Letting the current on the inductor become discontinuous yields very high peak value and the root mean square (RMS) currents of the inductor as well as the active devices are high. These correspond to high power losses that jeopardize efficiency and needs more rugged and expensive devices [20]. The inductor ripple current is high as well. Converters with high power ratings are not deliberately set to operate at DCM. As illustrated there is a dead time on the inductor current meaning that the energy on the inductor is already consumed before the next charging period occurs.

Continuous conduction mode (CCM) (Figure 29) is characterized by current flowing continuously in the inductor during the entire switching cycle in steady state operation.

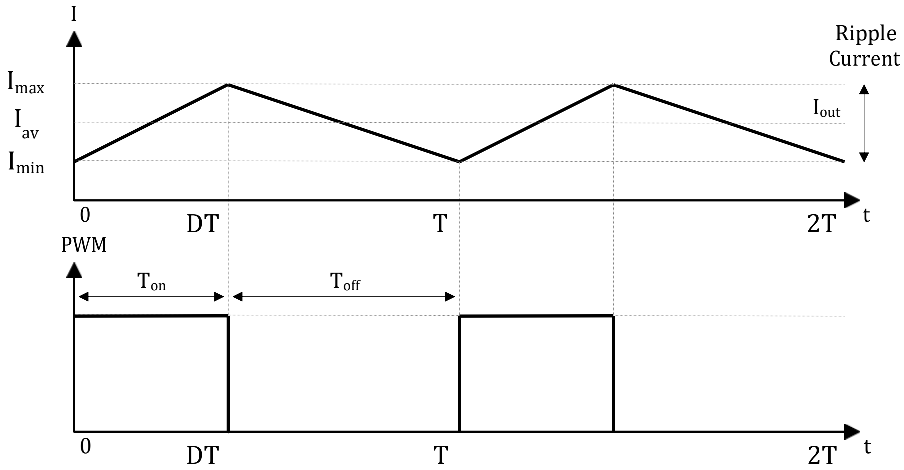

Figure 24: Continuous Conduction Mode (CCM)

To ensure the operation of the converter in the CCM region, the inductor must be big enough such that its energy will not be depleted until the next charging cycle occurs [20]. Provided the load current is higher than half the ripple current of the output inductor, the converter will operate in this mode. When the inductor current is continuous, it will not go to zero at any switching cycle. Because of this, the ripple current is small. A smaller ripple current corresponds to lower losses on the inductor as well as on the active power devices. Thus, this is more preferred for higher efficiency requirement. The drawback on setting the inductor current of for example a buck converter to CCM is that it needs a larger inductance. A larger inductance means a bulky physical size and there is a price increase.

The advantages of CCM over DCM include the DC conversion ratio is independent of the load, which makes DC analysis of converters operating in CCM easier. While operating in DCM, the output voltage depends on the load and the duty ratio of the switch, which makes DC analysis of converters operating n DCM more complicated. Also, to deliver the same power in DCM as in CCM, the peak currents are higher, resulting in greater losses in the conduction paths leading to reduced efficiency and higher peak current can also cause switch stress and greater input andoutput current ripple that adversely affect the noise issue

4.1.2 Non-Synchronous vs. Synchronous

Power converters are becoming increasingly commonplace in the electrical industry. Product manufacturers and suppliers of electrical equipment are demanding ever increasing functionality (lower input and output voltages, higher currents, faster transient response) from their power supply systems. While earlier DC/DC power converters relied on the use of diodes for current rectification (which is necessary for the converters operation) increased performances have been achieved by adopting synchronous rectification in the design of the power supply instead. Synchronous rectification means that the functionality once provided by the diode -i.e. current rectification – is now undertaken by a rectifying transistor (MOSFET). Such rectification improves efficiency, thermal performance, power densities, manufacturability, reliability as well as having typically faster switching transients and decreases the overall system cost for power supplies [21].

Conventional converters like those mentioned above consisted of a MOSFET, diode, capacitor, inductor and load. This configuration, where a diode is used instead of a MOSFET, is considered to be nonsynchronous meaning only the MOSFET is being switched while the diode (typically Schottky) only acts as a switch. The Schottky diode in this circuit is selected by its forward voltage drop and reverse leakage current characteristics alone. However, physical limitations prevent he forward voltage drop of diodes from being reduce below approximately 0.3 V so as the output voltage drops the diodes forward voltage becomes more significant which reduces the converters efficiency [21].

1 In a synchronous converter, the diode is replaced with a power MOSFET and controlled to be either on or off mimicking what the diode would be doing. Figure 30 shows a buck converter in the non-synchronous and synchronous configuration to illustrate the difference between the two converters.

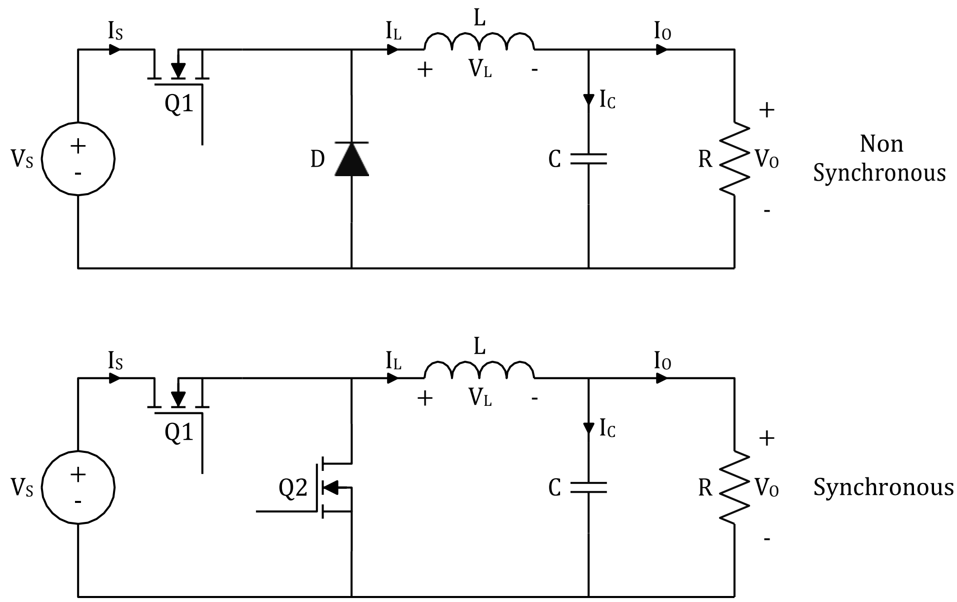

Figure 25: Non-Synchronous and Synchronous Buck Converter

The main advantage of a synchronous rectifier is that the voltage drop across the MOSFET can be lower than the voltage drop across the diode of the nonsynchronous converter. If there is no change in power level, a lower voltage drop translates into less power dissipation and higher efficiency [22]. This can be seen in the Figure 31 below. The plot shows the efficiency comparison between the non-synchronous and synchronous buck converters shown in Figure 30 if the power level remains the same. When the converter is not bucking, there is very little difference between the two converters. However, as the converter begins to buck its voltage and current begins to rise, the difference in efficiency between the two becomes present.

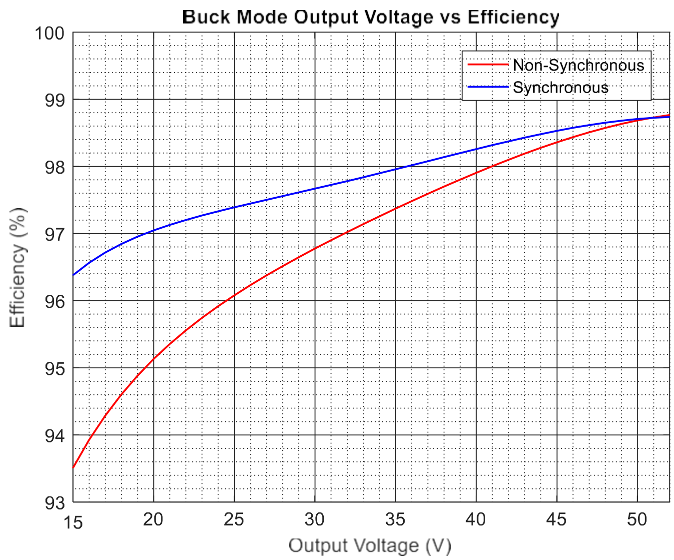

Figure 26: Buck Converter Synchronous vs. Non-Synchronous Efficiency

There are many advantages for using a synchronous topology vs. non-synchronous such as higher efficiency, lower power dissipation, better thermal performance, lower profile, increased quality and optimal current sharing when MOSFETs are paralleled. Yet, with all these benefits they have their disadvantages. The MOSFETs must be driven in a complimentary manner with a small dead time between their conduction intervals to avoid shoot-through which essentially shorts the power supply to ground through the MOSFET. This current introduces a large switching loss, and in the worst case, the MOSFET or the power supply can be damaged [23]. In addition to switching losses, conduction losses play a big role in the overall efficiency of the converter. Using MOSFETs in place of the diode reduces the conduction loss significantly, however, it does not eliminate it entirely. Therefore, MOSFETs must be chosen with a low R_{dson} to reduce conduction losses as much as possible. In addition, MOSFETs can be paralleled to handle higher output currents and because the effective R_{dson} is inversely proportional to the number of paralleled devices, conduction losses can be reduced. Since R_{dson} has a positive temperature coefficient, the MOSFETs will automatically share current equally making this an attractive solution to reduce the R_{dson}.

Another drawback is that by using MOSFETs in place of the diode, it prohibits the converter from entering the discontinuous conduction mode and thus degrades the efficiency at light loads. Here the CCM operation at light load (implies low output power) in synchronous converters is a drawback if standby efficiency is a major concern. In short, the MOSFETs conduction loss comes into play and the total power dissipation will be relatively large. In DCM operation, there is no conduction loss when the inductor current is zero. In addition, zero current switching operation helps reduce switching loss. To summarize, a synchronous converter yields high efficiency at high output current but low efficiency at low output power

CHAPTER-5
BENEFITS AND DEMERITS OF SOLAR ENERGY

There are several benefits that solar energy has and which make it favourable for many uses.

Benefits:

- Solar energy is a clean and renewable energy source.
- Once a solar panel is installed, the energy is produced at reduced costs.
- Whereas the reserves of oil of the world are estimated to be depleted in future, solar energy will last forever.
- It is pollution free.
- Solar cells are free of any noise. On the other hand, various machines used for pumping oil or for power generation are noisy.
- Once solar cells have been installed and running, minimal maintenance is required. Some solar panels have no moving parts, making them to last even longer with no maintenance.
- On average, it is possible to have a high return on investment because of the free energy solar panels produce.
- Solar energy can be used in very remote areas where extension of the electricity power grid is costly.

Demerits:

- Solar panels can be costly to install resulting in a time lag of many years for savings on energy bills to match initial investments.
- Generation of electricity from solar is dependent on the country's exposure to sunlight. That means some countries are slightly disadvantaged.
- Solar power stations do not match the power output of conventional power stations of similar size. Furthermore, they may be expensive to build.
- Solar power is used for charging large batteries so that solar powered devices can be used in the night. The batteries used can be large and heavy, taking up plenty of space and needing frequent replacement.

FINALLY,

As the merits are more than the demerits, the use of solar power is considered as a clean and viable source of energy. The various limitations can be reduced through various ways.

CHAPTER-6
OBSERVATIONS AND RESULT

Observation Table

Table1 :Voltage and Current for different times

S. No.	Time	Current	Voltage	Power
1.	3:30 pm	5.85 mA	5.202 V	30.4317 W
2.	4:00 pm	5.02 mA	4.962 V	24.90924 W
3.	4:30 pm	4.72 mA	4.452 V	21.01344 W
4.	5:00 pm	3.98 mA	4.03 V	16.0394 W

Table2: Voltage and Current for different Duty cycles

Duty Cycle	Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Input Power (W)	Output Power (W)	V0/Vin	1/(1-d)	% error
0.1	5.3	0.34	5.1	0.57	1.8	2.9	0.96	1.11	0.25
0.2	5.3	0.44	5.8	0.65	2.33	4.01	1.09	1.25	0.37
0.3	5.3	0.56	7.2	0.61	2.97	4.4	1.36	1.43	0.48
0.4	5.3	0.66	8.22	0.71	3.5	5.84	1.55	1.67	0.74
0.5	5.3	0.76	9.25	0.83	4.03	7.68	1.75	2.00	1.13
0.6	5.3	0.87	10.28	0.91	4.61	9.35	1.94	2.50	1.72
0.7	5.3	0.97	10.1	0.53	5.14	5.35	1.91	3.33	2.76
0.8	5.3	1.08	9.2	0.42	5.72	3.87	1.74	5.00	4.65
0.9	5.3	1.19	5.3	0.41	6.3	2.17	1.00	10.00	9.90

From the given table, the following conclusions (after addition of CN6009 voltage booster) can be drawn:

- As the duty cycle increases, the input current also increases, while the input voltage remains constant.
- The output voltage increases with an increase in duty cycle, while the output current first increases, then reaches a maximum at a certain duty cycle (around 0.6), and then decreases with further increases in duty cycle.
- The output power increases with an increase in duty cycle until it reaches a maximum value at a certain duty cycle (around 0.6) and then decreases with further increases in duty cycle.
- The voltage gain increases with an increase in duty cycle until it reaches a maximum value at a certain duty cycle (around 0.8) and then decreases with further increases in duty cycle.
- The V0/Vin ratio also increases with an increase in duty cycle until it reaches a maximum value at a certain duty cycle (around 0.9) and then decreases suddenly.
- The efficiency of the converter increases with an increase in duty cycle until it reaches a maximum value at a certain duty cycle (around 0.6) and then decreases with further increases in duty cycle.
- There is a sudden decrease in the output voltage and V0/Vin ratio at a duty cycle of 0.9, which could be due to the saturation of the inductor or the switch.

Here are some Characterstics graph showing the trends of CN6009 dc to dc voltage booster getting input from two serially connected 70mm*70mm*1mm 6V 100mAh solar panels giving output 5.3 volts under some conditions.

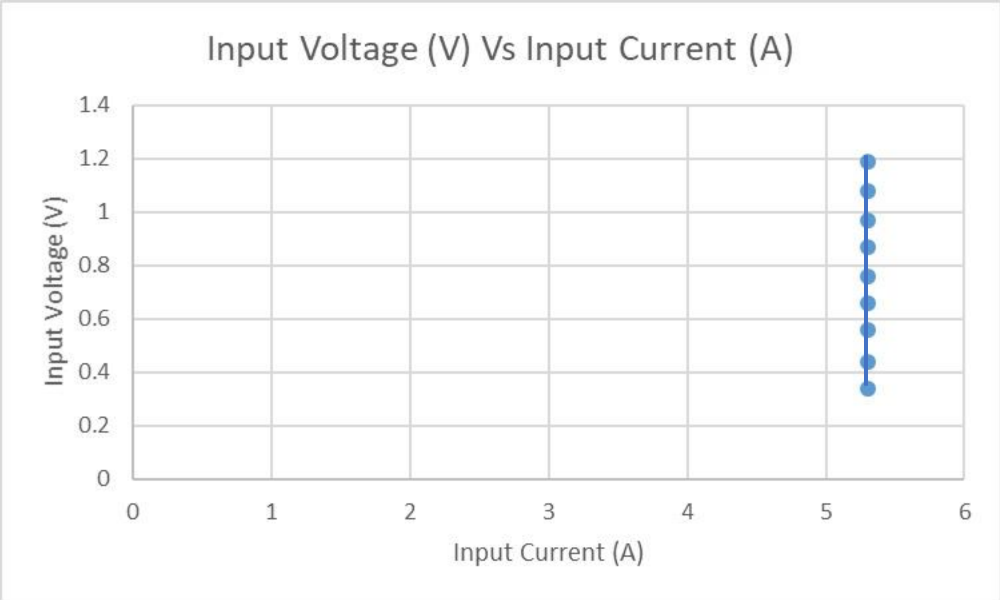

Figure 27 Input Voltage vs Input Current graph

Input current vs Input voltage graph:
From the graph, we can observe that the input current increases with an increase in input voltage. This behavior is expected as the input power is directly proportional to the input voltage.

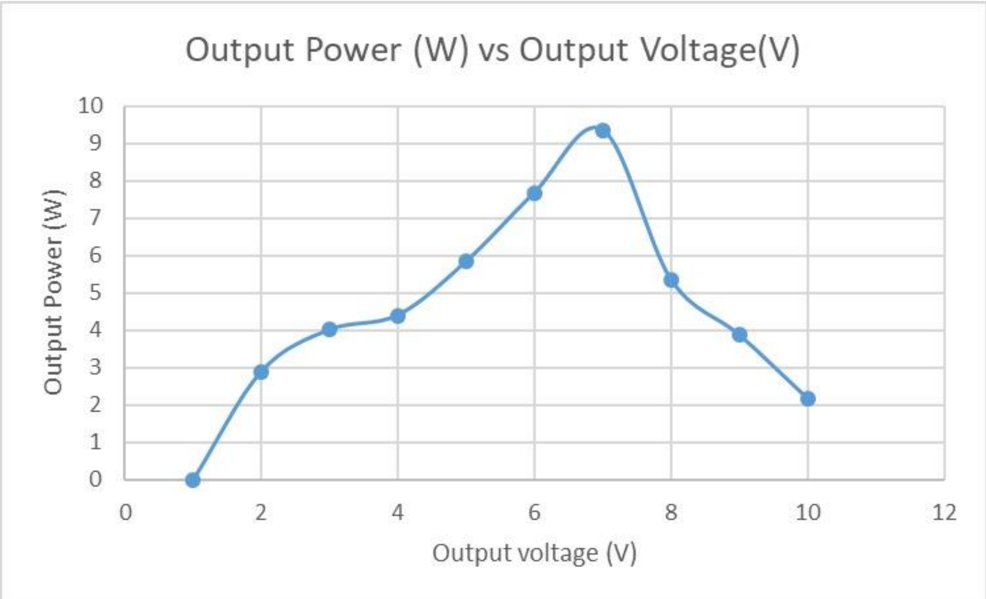

Figure 28 Output current vs Output voltage graph

Output current vs Output voltage graph:
From the graph, we can observe that the output current decreases with an increase in output voltage. This behavior is expected as the output power is constant, and an increase in output voltage leads to a decrease in output current.

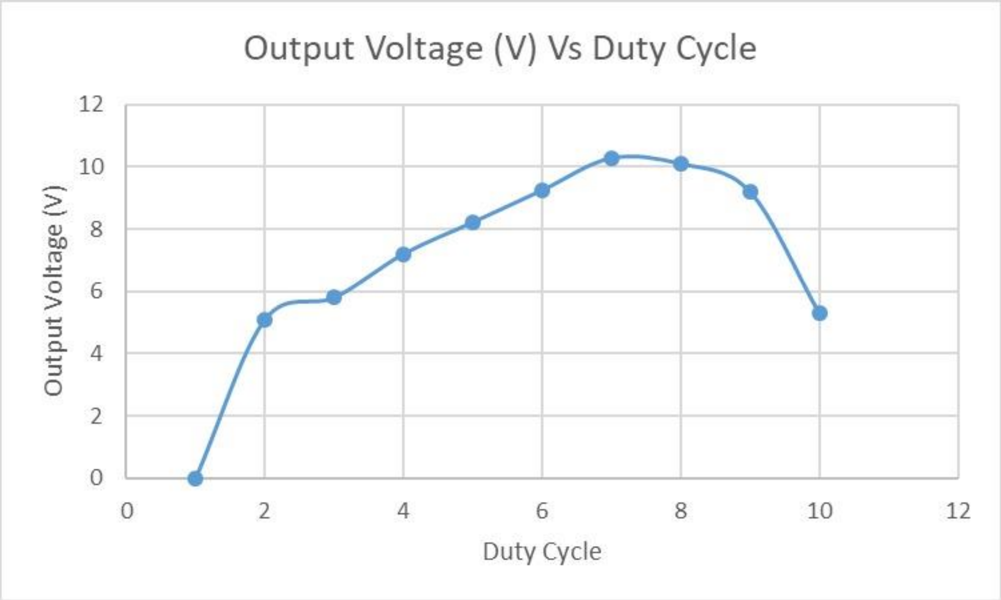

Figure 29 Output voltage vs Duty cycle graph

Output voltage vs Duty cycle graph:
From the graph, we can observe that the output voltage increases with an increase in duty cycle until a certain point. After that point, there is a sudden decrease in the output voltage. This behavior is due to the fact that the CN6009 is a boost converter, and the output voltage is directly proportional to the duty cycle until a certain point. Beyond that point, the output voltage starts to decrease due to the inductor's saturation.

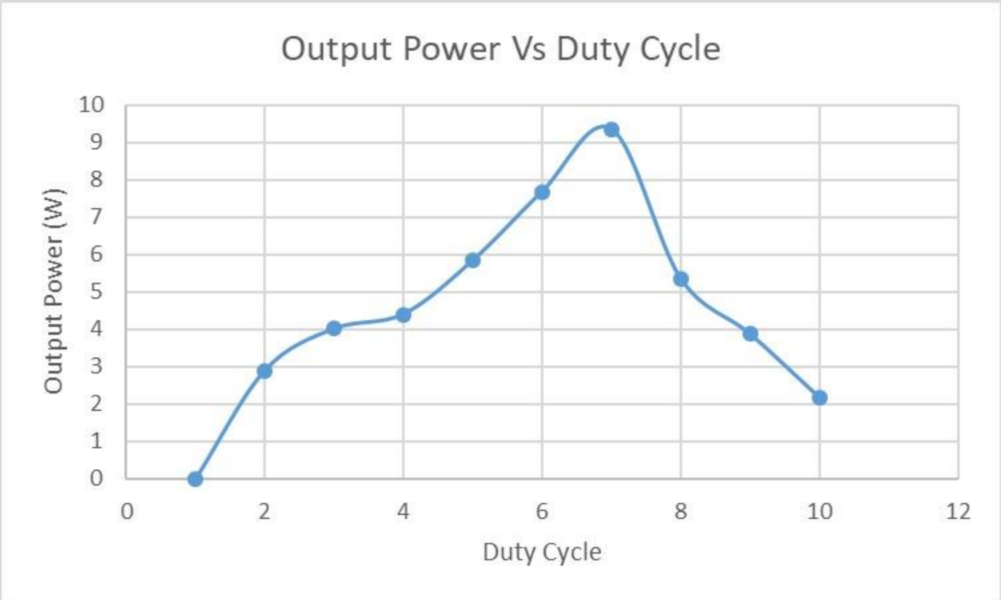

Figure 30 Output power vs Duty cycle graph

Output power vs Duty cycle graph:
From the graph, we can observe that the output power increases with an increase in duty cycle until a certain point. After that point, there is a sudden decrease in the output power. This behavior is due to the same reason as in the output voltage vs duty cycle graph.

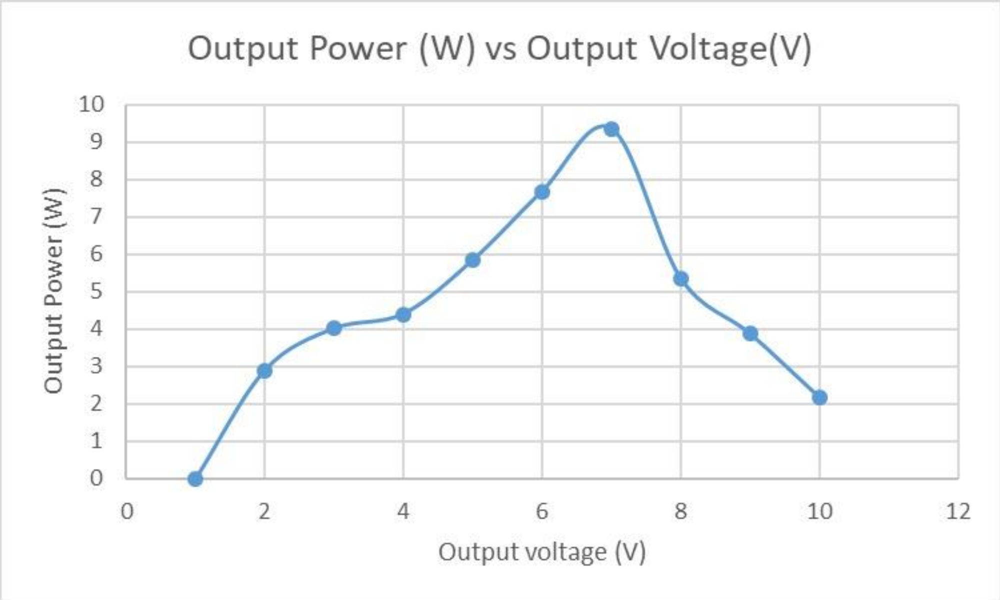

Figure 31 Output power vs Output voltage characteristics:

Output power vs Output voltage characteristics*:*
From the graph, we can observe that the output power reaches a maximum value at a certain output voltage, and beyond that voltage, there is a sudden decrease in output power. This behavior is due to the same reason as in the output voltage vs duty cycle graph.

The sudden decrease in output voltage and v0/vin ratio is due to the inductor's saturation, which leads to a decrease in the output voltage and a sudden change in the voltage gain. This sudden change leads to an increase in the error percentage

WE HAVE OBSERVED....

In this Dual Axis Solar Tracker, when source light falls on the panel, the panel adjusts its position according to maximum intensity of light falling perpendicular to it.

The objective of the project is completed. This was achieved through using light sensors that are able to detect the amount of sunlight that reaches the solar panel. The values obtained by the LDRs are compared and if there is any significant difference, there is actuation of the panelusing a servo motor to the point where it is almost perpendicular to the rays of the sun.

This was achieved using a system with three stages or subsystems. Each stage has its own role.The stages were;

- An input stage that was responsible for converting incident light to a voltage.
- A control stage that was responsible for controlling actuation and decision making.

- A driver stage with the servo motor. It was responsible for actual movement of the panel.

The input stage is designed with a voltage divider circuit so that it gives desired range of illumination for bright illumination conditions or when there is dim lighting. The potentiometerwas adjusted to cater for such changes. The LDRs were found to be most suitable for thisproject because their resistance varies with light. They are readily available and are costeffective. Temperature sensors for instance would be costly.

The control stage has a microcontroller that receives voltages from the LDRs and determines the action to be performed. The microcontroller is programmed to ensure it sends a signal to the servo motor that moves in accordance with the generated error.

The final stage was the driving circuitry that consisted mainly of the servo motor. The servomotor had enough torque to drive the panel. Servo motors are noise free and are affordable, making them the best choice for the project.

The table and graph above provide a comprehensive overview of the performance of a boost converter with varying duty cycles. The boost converter is a widely used power converter in various applications such as battery charging, LED lighting, and DC motor drives. It works by stepping up the input voltage to a higher level to match the desired output voltage.

From the table and graph, it is clear that as the duty cycle increases, the input current also increases, while the input voltage remains constant. This trend is expected since the duty cycle controls the on-time of the switch, and therefore the amount of energy transferred to the output.

The output voltage increases with an increase in duty cycle, which is also expected since the boost converter steps up the input voltage. However, the output current first increases, then reaches a maximum at a certain duty cycle (around 0.6), and then decreases with further increases in duty cycle. This behavior is due to the saturation of the inductor or the switch, and it limits the maximum output current of the converter.

The output power increases with an increase in duty cycle until it reaches a maximum value at a certain duty cycle (around 0.6) and then decreases with further increases in duty cycle. This trend is due to the decrease in output current beyond the maximum value, which offsets the increase in output voltage.

The voltage gain and efficiency of the converter both increase with an increase in duty cycle until they reach maximum values at certain duty cycles (around 0.8 and 0.6, respectively). Beyond these duty cycles, the voltage gain and efficiency decrease, which is attributed to the saturation of the inductor or the switch, and it limits the maximum output power of the converter.

Finally, there is a sudden decrease in the output voltage and V0/Vin ratio at a duty cycle of 0.9, which could be due to the saturation of the inductor or the switch. This trend highlights the importance of selecting appropriate duty cycles for the boost converter to prevent saturation and ensure stable operation.In conclusion, the table and graph provide valuable insights into the behavior of a boost converter with varying duty cycles. The results can be used to optimize the performance of the converter for specific applications, such as maximizing efficiency or output power.

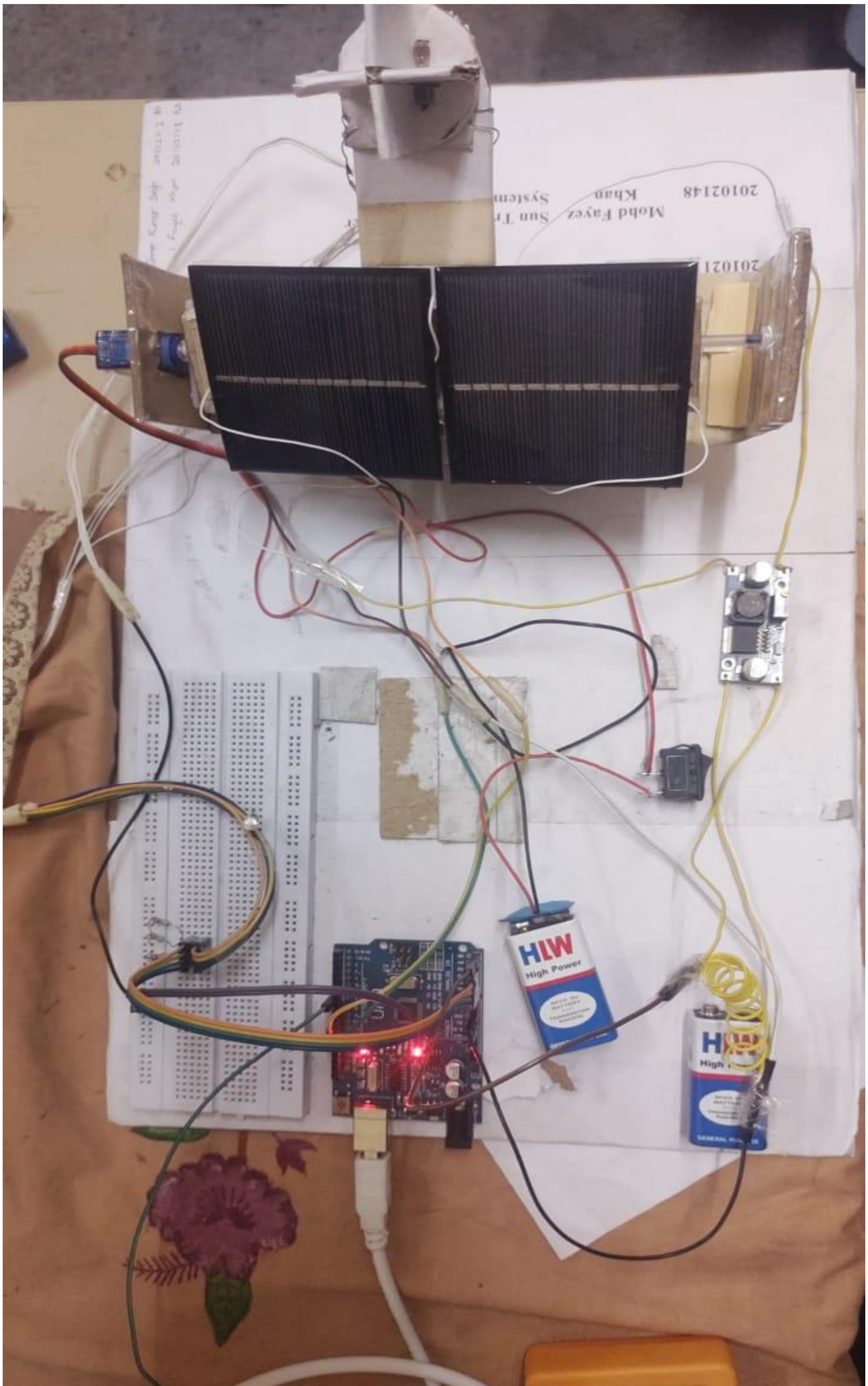

Fig 32

CHAPTER-6

CONCLUSION

In this 21st century, as we build up our technology, population & growth, the energy consumption per capita increases exponentially, as well as our energy resources (e.g. fossils fuels) decrease rapidly. So, for sustainable development, we have to think alternative methods(utilization of renewable energy sources) in order to fulfil our energy demand.

In this project, Dual Axis Solar Tracker, we've developed a demo model of solar tracker to track the maximum intensity point of light source so that the voltage given at that point by the solar panel is maximum. After a lot of trial and errors we've successfully completed our project and we are proud to invest some effort for our society. Now, like every other experiment, this project has couple of imperfections.

(i) Our panel senses the light in a sensing zone, beyond which it fails to respond.

(ii) If multiple sources of light (i.e. diffused light source) appear on panel, it calculates the vector sum of light sources & moves the panel in that point.

(iii) For the fixed input voltage and varying duty cycles gives different values of output voltage.

(iv) At 0.6 duty cycle, peak output voltage and output current can be observed.

This project was implemented with minimal resources. The circuitry was kept simple, understandable and user friendly.

CHAPTER-7

AVENUES FOR FURTHER WORK

With the available time and resources, the objective of the project was met. The project is able to be implemented on a much larger scale. For future projects, one may consider the use of more efficient sensors, which should also be cost effective and consume little power. This would further enhance efficiency while reducing costs. If there is the possibility of further reducing the cost of this project, it would help a great deal. This is because whether or not suchprojects are embraced is dependent on how cheap they can be. Shading has adverse effects onthe operation of solar panels. Shading of a single cell will have an effect on the entire panel because the cells are usually connected in series. With shading therefore, the tracking system will not be able to improve efficiency as is required.

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